Draft

REDWOOD CREEK WATERSHED ANALYSIS

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NEW YEAR'S STORM
DECEMBER 1996 - JANUARY 1997

A major storm struck Northwestern California in late December, 1996 and early January, 1997. Extensive flooding occurred along most major rivers in the region. Rainfall totals for the month of December, 1996, at Orick and at the Minor Creek earthflow were about 27 inches. Peak streamflow on Redwood Creek was about 6,400 cubic feet per second at the O'Kane station and about 43,000 cubic feet per second at Orick. Based on existing flood frequency relations, the peak flow at Orick had a recurrence interval between 15 and 20 years.

Damage assessments are underway at this time (January, 1997). Many road failures have already been documented within the park. Although the full effects of the storm on park resources are not yet known, initial reports indicate that damage was much less than that associated with the storms and floods of 1953-75. The Tall Trees Grove, the focal point of controversy during legislative battles over park expansion, was not damaged in the recent flood. No old-growth redwoods in the Grove were toppled, and flood waters indundated only a low-lying terrace on the north side of the Grove. Several redwoods and other trees fell along the creek in other areas within the park.

The park staff will continue to monitor storm effects, including tree mortality along Redwood Creek, sediment loads at the Orick and O'Kane gaging stations, changes in channel morphology, hillslope erosion, and changes in aquatic habitat. This information will be incorporated into future versions of the Redwood Creek Watershed Analysis.

ADDENDUM

NEW YEARS STORM OF DECEMBER 1996-JANUARY 1997

A storm struck northwestern California in late December of 1996 and continued into early January of 1997. Northern California received a large amount of rain; extensive flooding occurred along most major rivers in the region. Though gages in Redwood Creek basin recorded only 10-16 inches of rain for the storm, the storm followed one of the wettest Decembers on record. Rainfall totals of 27 inches were recorded for the month of December, 1996, at Orick, where the average December rainfall is less than half of that -- 12 inches. The storm produced a relatively high peak streamflow at Orick of about 43,000 cubic feet per second, which correlates with a recurrence interval of 11 years based on existing flood frequency relations. However, the destructive effects of the ll-year peak flow were increased by the saturation of the soil in the basin.

Because of the unusually high precipitation and saturated soils developed during December, the late December storm initiated numerous landslides. Road-related landslides were the major erosional problems from this storm, in contrast to previous storms. In 1964, 1972, and 1975, 25-year higher intensity storms produced inner gorge (valley-in-valley) landslides low on the hillslopes, gullies eroding roads, and road failures at stream crossings, and fewer road-related landslides.

Though some roads and natural resources were greatly damaged by the road-related landslides in this most recent storm, the park's road culverts were not overwhelmed in this storm because of the mild intensities of the rainfall. For example, at Elk Camp, the maximum 6-hour rainfall intensity was 2.5 inches (only a 2-year rainfall event) and the maximum 24-hour rainfall intensity was 7.6 inches (a 10-year event).

The probability is high that a 25-year flood event will occur sometime soon, because the last such event was 23 years ago, in 1975. It is possible that the worst conditions could occur simultaneously to combine the high peak flows of a 25-year or greater event with the saturation of a long duration storm, so as to produce both road-related landslides and road failures at stream crossings. The larger flood events, such as those that occurred in 1964, 1972, and 1975, are a part of the normal climatic regime of this region. However, their higher intensity rainfalls are more damaging to park roads and resources.

Preliminary assessment of the damage from the '97 storm documented many road failures within the park. Within Redwood Creek basin, an estimated 170,000 cubic yards of material was catastrophically eroded along road benches. An additional estimated 410,000 cubic yards of material moved into unstable positions on hillslopes and is perched to fail. In total, approximately 574,000 cubic yards of material are either in Redwood Creek and its tributaries, or visibly unstable as a result of the storm according to preliminary volume estimates. Large failures, concentrated on the abandoned logging roads along Redwood Creek, formed destructive debris torrents that ripped up and entrained downslope soil and vegetation. When this debris was swept into Redwood Creek and its tributaries; old growth trees were uprooted or damaged and aquatic habitats were destroyed. Along the mainstem of Redwood Creek within the park, there were 9 new slides, and 16 reactivated slides. Another 98 landslides were reactivated upstream from park boundaries, and 19 new slides were initiated along Redwood Creek. The Tall Trees Grove, the focal point of controversy during legislative battles over park expansion, was not damaged in the recent flood; floodwaters inundated only a low-lying terrace on the north side of the Grove. The damage was limited only by the low intensity of the storm.

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NEW SLIDES

Work in Progress:

Park staff will continue to monitor storm effects, including tree mortality along Redwood Creek, sediment loads at the Orick and O'Kane gaging stations, changes in channel morphology, hillslope erosion, and changes in aquatic habitat.

Park staff plan to continue evaluation of the effectiveness of watershed restoration efforts in the parks. Studies are underway to assess the damage from the early 1997 storm.

We plan to add a more detailed description of the 1997 storm that generated the flood (above is the initial write-up), a discussion comparing the antecedent precipitation index and recurrence intervals for that storm with other large storms in the past, and graphs of monthly rainfall (December and January) for rain gages in the basin to show how 1997 compares with other years.

Currently a geologist (student) is mapping the new landslides in the Redwood Creek basin that were initiated or reactivated by the 1997 flood. She has completed the mainstem mapping, and is just beginning mapping in tributary basins. Tributary data won't be done for several months, possibly in July/August 1998. Her work to date shows that along the mainstem of Redwood Creek, 98 landslides were reactivated upstream from park boundaries, and there were 19 new slides initiated. Within the park, there were 9 new slides, and 16 reactivated slides along Redwood Creek.

Though we have only the numbers and locations of slides at present, we will convert the total number of slides into a volume of sediment that entered Redwood Creek and analyze the causal mechanisms of the landsliding. The landslide issue is one of two major focuses of the current flood project.

The second focus of the flood project is to evaluate the effectiveness of road rehabilitation techniques on reducing sediment input to streams during this flood. We plan on conducting the field work for this phase during the summer, starting around mid-June. Field mapping will continue through September, and we do not expect results to be analyzed until December 1998. The studies will further assess the damage from the early 1997 storm, compare the amount of material eroded from treated and untreated roads on four different rock-type terrains, and compare the effectiveness of the different techniques of road removal. This information will be incorporated into future versions of the Redwood Creek Watershed Analysis.

Executive Summary

and

Introduction

EXECUTIVE SUMMARY

The Redwood Creek watershed includes national and state park lands in the lower watershed and commercial timber lands in the upper watershed. Timber harvesting and road building have potential to affect park resources by contributing water, sediment, and organic debris to Redwood Creek. This analysis of the Redwood Creek watershed was prepared by Redwood National and State Parks to provide a scientific framework for planning cooperative erosion control efforts with other landowners in the watershed.

We have identified five natural resource issues in the Redwood Creek watershed:

1. **protection of streamside redwoods,**
2. **protection and restoration of aquatic habitat,**
3. **protection of threatened and endangered wildlife,**
4. **maintenance of long-term, sustainable timber production, and**
5. **enhancement of tourism.**

We formulated key questions that guided our analysis of issues 1-3. A similar analysis of issues 4 and 5 requires information and expertise unavailable to the park, and we have provided only general background information.

The protection of streamside redwoods was the primary objective of the establishment and expansion of Redwood National Park. Timber harvesting and road building, as practiced from the 1950's to the mid-1970's, increased streamflow and sediment loads and thereby aggravated threats to alluvial redwood groves. Trends in streamflow, sediment transport, and channel morphology over the past two decades indicate that current land uses are not presently damaging streamside redwoods in the park under the prevailing conditions of moderate annual rainfall. These trends could be reversed by renewed delivery of sediment from hillslopes to the channel system during large storms. Roads remaining from past harvests continue to pose a major threat to alluvial groves.

Aquatic habitat has also been affected by past land-use practices. Fish populations in Redwood Creek are much reduced in comparison to historic accounts. Habitat conditions are probably still quite degraded relative to pristine conditions, but are showing signs of improvement following a period of low to moderate rainfall. The current lack of suitable rearing habitat in the mainstem and tributaries, however, has forced juvenile fish to the estuary, where they are subject to the impacts of uncontrolled breaching at the mouth of the creek.

The protection of wildlife species has become a major regional concern related to all land-use activities, including park management and timber production. The most important habitat type available for the long-term protection of threatened and endangered species is old-growth or late-successional forest. Much of the remaining old-growth redwood forest of Northwestern California is within Redwood National and State Parks. Old-growth habitat within the park is very important for local sub-populations of marbled murrelet, northern spotted owl, pacific fisher and Northern red-legged frog. The park lands of the lower Redwood Creek watershed act as a refuge for some wildlife species displaced from less optimal habitat outside the national and state parks.

Timber production was affected by creation and expansion of the national park, but remains the primary land use upstream of park lands. Production is unlikely to return to the peak levels of the 1950's and 1960's, but will probably increase as second-growth stands reach merchantable size.

Park visitation has increased in recent years, adding to tourism-related income in Humboldt County. The recently implemented cooperative management agreement between the state and national parks and the upcoming General Management Plan/General Plan for the parks should serve to accelerate the increase in park visitation.

The Redwood Creek watershed is recovering from the combined effects of past land-use practices and large storms. Park resources, however, remain vulnerable to the effects of upstream erosion. The next large storm will inevitably cause renewed sediment delivery from hillslopes to stream channels. Although a significant amount of erosion may result from unpreventable natural processes, poorly designed and unmaintained log-haul roads have potential to greatly increase the erosional effects of a large storm. The National Park Service and the California Department of Parks and Recreation remain concerned over the adequacy of some provisions of the forest practice rules to protect park resources from these effects. Potential damage to park resources can be reduced through voluntary and cooperative erosion-control efforts. The treatment of diversion potentials at road-stream crossings is probably the most effective approach to reducing potential threats to park resources.

INTRODUCTION

The Redwood Creek watershed was the focus of a nationwide controversy over the protection of old-growth redwoods. As a result of private donations and legislative action, the lower 40% of the basin was transferred from private ownership to Redwood National and State Parks. The upper 60% remains mostly private timber and ranch lands, with small inholdings by the U.S. Forest Service and Bureau of Land Management. Timber harvesting and roads on upstream lands have potential to affect park resources by contributing water, sediment, and organic debris to Redwood Creek. This analysis of the Redwood Creek watershed was prepared by Redwood National and State Parks to provide a scientific framework for planning cooperative erosion control efforts with private landowners and other government agencies that manage land in the watershed.

The watershed analysis process for federal land management agencies is a part of the Northwest Forest Plan developed in 1994 (Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents Within the Range of the Northern Spotted Owl and Standards and Guidelines for Late-Successional and Old-Growth Forest Related Species Within the Range of the Northern Spotted Owl, USDA-Forest Service and USDI-Bureau of Land Management, April, 1994). Watershed analyses identify important resource management issues, describe existing and past conditions related to those issues, and examine relations between land-use activities and existing conditions (Ecosystem Analysis at the Watershed Scale: Federal Guide for Watershed Analysis, Version 2.2, August, 1995, Regional Ecosystem Office, Portland, Oregon). The analyses can also identify gaps in knowledge of watershed processes. Watershed analyses are not planning or policy documents. Rather, they summarize information to allow informed management decisions to be made. The analyses themselves do not require documentation of National Environmental Protection Act compliance.

This watershed analysis was written by the staff of Redwood National and State Parks, with assistance from the Biological Resources Division of the U.S. Geological Survey and the U.S. Fish and Wildlife Service. An earlier draft of this analysis was distributed to timber companies, ranchers, tribal governments, environmental groups, and government agencies. The present version reflects the comments, suggestions, and additional information received from these outside reviewers.

Authority for Redwood National Park to engage in cooperative resource protection efforts is contained in legislation establishing (PL 90-545, Subsection 3 (e)) and expanding (PL 95-250, Subsection 101 (a6)) the park. PL 95-250 also specified that watershed studies of erosion and sediment transport would be undertaken, with the intent of identifying sources of sediment and causes of erosion. These laws have been cited in Redwood National Park planning documents, including the General Management Plan (1980), the Watershed Rehabilitation Plan (1981), the Resources Management Plan and Environmental Assessment (1988, revised 1994) and the Statement for Management (1992). These plans document the long-term commitment of the park to cooperative watershed planning, research, and management in order to protect park resources.

Watershed Description

WATERSHED DESCRIPTION

The Redwood Creek watershed consists mostly of mountainous, forested terrain. Primary land uses are tourism and fishing on park lands and timber and livestock production on lands upstream of the park.

Location and Physiography

The Redwood Creek watershed is located in the Northern Coast Ranges of California. The watershed is entirely within Humboldt County, and lies to the north and east of the city of Eureka (fig. 1). The town of Orick and the community of Redwood Valley are located within the watershed (fig.1).

Redwood Creek flows into the Pacific Ocean near Orick. The drainage area upstream of the U.S. Geological Survey stream gaging station at Orick (fig. 1) is 278 square miles, and the drainage area 178,000
at the stream mouth is about 285 square miles. The basin is narrow and elongated, with its long 182,000
axis oriented northwest-southeast. The total length of the basin is about 65 miles, and its width varies from 4 to 7 miles (Janda and others, 1975). Total basin relief is about 5,300 feet (Janda and others, 1975).

For the purposes of this watershed analysis, we have divided the Redwood Creek watershed into three sub-basins designated the upper, middle, and lower basins. These sub-basins define areas of differing climate, vegetation, and land use. The upper basin extends from the headwaters downstream to the O'Kane stream gaging station near the State Highway 299 bridge (fig. 1). The area of the upper basin is 67 square miles (Best, 1984). The middle basin extends from the O'Kane gaging station to the south boundary of Redwood National Park, and has an area of 95 square miles (Best, 1984). About 52 square miles of the middle basin comprise the Park Protection Zone, which was created by P.L. 95-250 in 1978 to increase protection of park resources from adverse effects of timber harvesting. The lower basin includes all lands within the Redwood National and State Parks and privately-held lands in and around Orick. The area of the lower basin, including the Prairie Creek watershed, is 116 square miles (Best, 1984).

Climate and Hydrology

The climate of the Redwood Creek watershed is Mediterranean, with mild, wet winters, and warm, dry summers (Janda and others, 1975). The climate is moderated by the proximity of the Pacific Ocean, which maintains a fairly constant temperature year-round. Prevailing winds are northwesterly, bringing cool, moist air and frequent fog to the lower basin. The middle and upper basins are less affected than the lower basin by marine influences.

Mean annual basin-wide precipitation is roughly 80 inches (Janda and others, 1975). Most precipitation falls as rain. Snow falls fairly frequently at altitudes greater than 1,600 feet and rarely at lower altitudes (Janda and others, 1975). Snowmelt can increase streamflow peaks during rain-on-snow events, as occurred in 1964. Rainfall is strongly seasonal, with most rain falling between November and March. The long summer drought is eased by persistent fog in the lower and middle

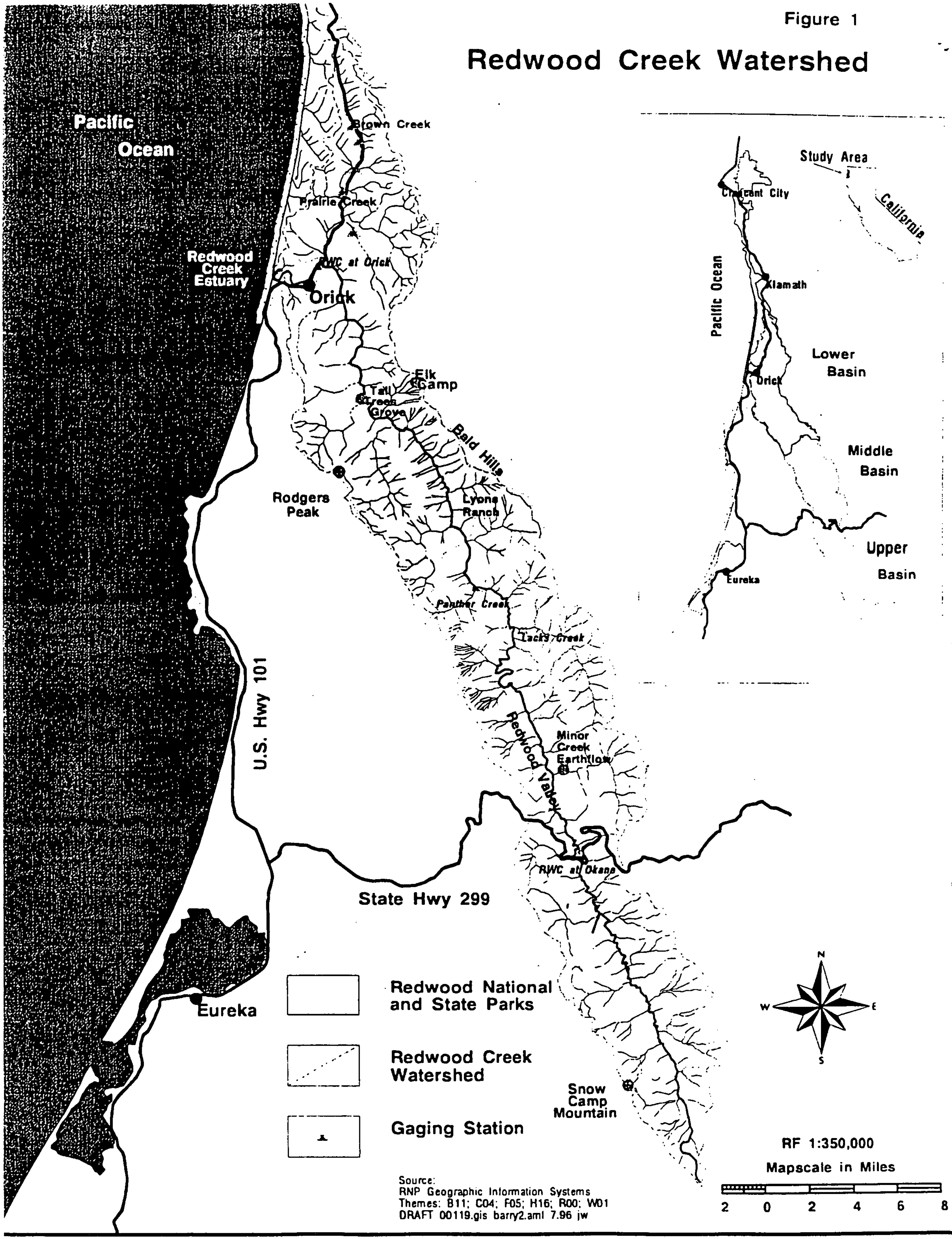


Figure 1

Redwood Creek Watershed

basins Fog condensation adds measureably to soil moisture during the dry summer months (Janda and others, 1975).

Long-term rainfall data were analyzed by Janda and others (1975). They found that the periods 1865-68, 1900-04, and 1951-58 were particularly wet and that the periods 1869-75, 1882-89, and 1917-37 were relatively dry. Rainfall amounts during the period including recent large floods in 1955, 1964, 1972, and 1975 were not unusually large in comparison to long-term records (Janda and others, 1975). The flood-frequency study of Coghlan (1984) supported this conclusion, and indicated that storms such as those that produced the recent large floods are a normal climatic feature. Rainfall was high in 1975 and relatively low between 1975 and 1993. Within this period, the highest rainfall amounts were recorded in 1982, 1983, and 1986 (fig. 2).

Streamflow in Redwood Creek is highly variable from year to year as a result of annual rainfall variations. Streamflow also varies seasonally, owing to the highly seasonal distribution of rainfall. Winter flood flows can be as much as four orders of magnitude higher than summer low flows. On average, stream runoff comprises roughly two-thirds of basinwide precipitation (Janda and others, 1975).

Air quality in the redwood region is generally considered good to excellent. Air quality monitoring over the past years indicates that air pollution levels do not exceed federal standards for sulfur dioxide and total suspended particulates.

Geology

Geologic structure in the Redwood Creek watershed is governed by several parallel north-northwest trending faults (Janda and others, 1975; Harden and others, 1982). These faults range from low-angle thrust faults to vertical faults and form the boundaries between the major lithologic units in the watershed. For much of its length, the channel of Redwood Creek closely follows the Grogan Fault. Rocks located along faults tend to be particularly weak.

Most of the Redwood Creek watershed has experienced late-Cenozoic uplift (Janda and others, 1975). This uplift has been manifested in steep "inner gorge" topography along major streams. Inner gorge slopes are unstable as a result of their steep slopes and their proximity to stream channels.

The bedrock of the Redwood Creek basin was described by Janda and others (1975) and Cashman and others (1996) and mapped by Harden and others (1982). The two major types of rocks are sedimentary rocks, primarily sandstones, to the east of the Grogan Fault and metamorphic rocks, primarily schist, to the west of the fault.

Flora and Fauna

The natural vegetation of the Redwood Creek watershed consists mostly of coniferous forest, but also includes areas of oak woodland and grassland prairie. The distribution of plant communities depends primarily on water availability and fire regime.

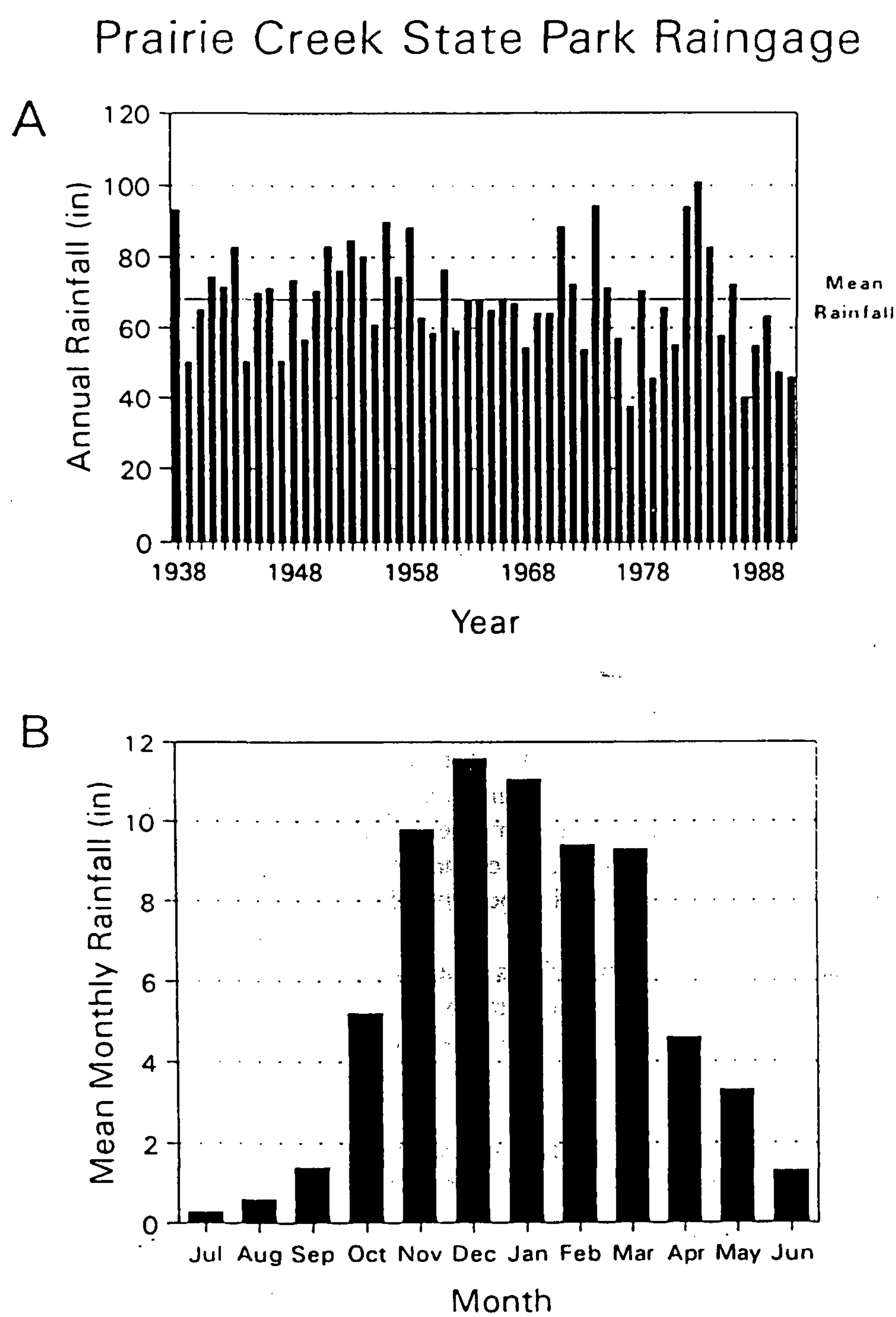


Figure 2. Graph showing annual(A) and mean monthly (B) rainfall at Prairie Creek State Park

Old-growth forest currently covers 24,315 acres in the watershed, equivalent to 14% of its total area. Near the coast, the most common forest tree is the Sitka spruce (Picea sitchensis). Most of the lower-basin forest, however, is dominated by coast redwoods (Sequoia sempervirens). Farther inland, where summer temperatures are higher and fog is less frequent, douglas-fir (Pseudotsuga menziesii) is more common the redwood. Several hardwood species grow in association with both redwood and douglas-fir, including big-leaf maple (Acer macrophyllum), red alder (Alnus rubra), tanbark oak (Lithocarpus densiflora), madrone (Arbutus menziesii), and bay (Umbellularia californica).

Prairies and oak woodlands occur on south- and west-facing ridgetops and hillslopes on the east side of Redwood Creek. The factors controlling prairie and oak woodland distribution are not well understood, but probably include bedrock type, altitude, aspect, distance from the coast, grazing by wildlife and livestock, and fire regime (Janda and others, 1975; Hektner and others, 1983; Walter, 1985; Redwood National Park, 1992). Prairie vegetation within the parks is 37% native grasses and forbs, and 63% non-natives, and this relative abundance of native and exotic plants probably also is representative of prairies outside of the parks. The most common native plants are California oatgrass (Danthonia californica) and foothill sedge (Carex tumulicola). The most common oak in the oak woodlands is the Oregon white oak (Quercus garryana). Prairies and oak woodlands are both subject to invasion by douglas-fir, and the park is actively working to preserve and restore these communities within park boundaries.

Approximately 250 species of wildlife (amphibians, reptiles, mammals, and birds) are known to occupy habitats found in the Redwood Creek watershed (Appendix B). Wildlife habitat can be categorized as riparian, forested (old-growth or second-growth), oak woodland, prairie, or estuarine.

Thirty three species of wildlife are identified as species of special concern (threatened, endangered or sensitive to human activities; Appendix C). Of these species, six species of amphibians, one mammal species and four species of birds occupy habitats along riparian corridors. These species are dependent on streamside vegetation for maintaining population abundance at current levels. Bald eagles (Haliaeetus leucocephalus) forage along the riparian corridor and may nest in the old-growth forested habitat. The marbled murrelet (Brachyramphus marmoratus) and northern spotted owl (Strix occidentalis), require maintaining the current abundance of old-growth habitats for assuring long-term survival of local populations (U.S. Fish and Wildlife Service, 1992; 1996). Recently conducted field surveys showed that these two species occurred in all old-growth habitats sampled on park lands within the watershed. The peregrine falcon (Falco peregrinus),

California brown pelican (Pelecanus occidentalis) and the western snowy plover (Charadrius alexandrinus) utilize habitats found in and around the Redwood Creek estuary for foraging.

Other species of interest that are found within the watershed include amphibians, song birds, large ungulates, and carnivores. Many neotropical migratory songbirds (ie. those species with significant subpopulations that migrate across international boundaries to the south) occupy habitats in Redwood Creek watersheds. Many of these populations of songbirds are threatened by habitat losses outside the United States.

The Redwood Creek watershed provides aquatic habitat for a variety of fish species. Anadromous and resident salmonids identified in Redwood Creek include steelhead and rainbow trout (Oncorhynchus mykiss), coastal cutthroat trout (O.clarki), coho salmon (O.kisutch), and chinook salmon (O.tshawytscha) (Anderson, 1983). Other fish identified or reported include the tidewater goby (Eucyclogobius newberryi), Humboldt sucker (Catostomus humboldtianus), threespine stickleback (Casterosteus aculeatus), coastrange sculpin (Cottus aleuticus), Pacific lamprey (Lampetra tridentata), and eulachon (Thaleichthys pacificus) (Iwatsubo and Averett, 1981). Five species of fish have been listed as species of special concern, endangered species, or sensitive species by federal and state agencies (Appendix C).

Cultural History

Numerous cultural history projects have been completed for park lands in the Redwood Creek watershed. These include cultural resources inventories (Baker, 1981; Baker and Salzman, 1982; Bickel, 1979; Fitzgerald and Smith, 1992; King, 1980; Moratto, 1973; Salzman, 1979), archaeological excavations (Benson, 1981; 1983; King and Bickel, 1980), historic studies (Bearrs, 1969; Greene, 1980; Shoup, 1983; Stanton and Van Kirk, 1992), a research design (Bickel and King, 1980), artifact analyses (Hayes, 1980; 1985), and a summary report (Eidsness, 1988). The information presented below is based on these studies.

Lands within the Redwood Creek basin have been inhabited for at least 4,500 years. Between 1,500 B.P. and the contact period (the early 1800's), the people known as the Chilula lived in the Redwood Creek basin. Based in villages on the ridgecrests in the Bald Hills, and in villages on river benches south of the park, the Chilula based their lives on a seasonal round. Resources were collected seasonally, with fish, game and acorns the primary items. Traditional Chilula territory extended along the basin from near the inland edge of the heavy redwood belt on the north to a few miles above Minor Creek on the south. Chilula neighbors were the Yurok to the north, west and south, the Hupa to the east and the Whilkut to the west and south.

Most reports state that the Chilula were closely tied to the Hupa, both culturally and linguistically, their languages being mutually understandable. Chilula economy was based primarily on the resources of Redwood Creek but because this stream was less rich with fish than the Klamath or the Trinity, greater emphasis was placed on exploitation of other products. Estimates of the Chilula population in the early nineteenth century range from 500 to 600 individuals.

The majority of the Chilula were decimated within the first five years of California statehood. Soon after mining began in the interior, gold seekers began to pass through the Bald Hills and conflicts arose. Early settlers organized a campaign of Indian extermination and deportation, with some Chilula transported to the Mendocino Coast. For a period, the Bald Hillswere avoided by pack trains traveling between the coast and the interior. Eventually, through the efforts of the Indian agents, the remaining Chilula families were moved to the Hoopa Valley and their separate culture, as a result, no longer exists.

Some Chilula, however, retained their ties to their homeland, through intermarriage with the Lyons families who ranched the Bald Hills for over a century, by working as sheep shearers for both the Lyons and other the Redwood Creek ranchers, and by working in the Redwood Creek logging industry. Other Chilula attempted to return to live in Redwood Creek at the end of the nineteenth century and others undoubtedly, continued to hunt and gather in the area. Today, members of the Hoopa Tribe who trace their ancestry to Redwood Creek and the Bald Hills retain strong ties to the basin.

The first contact between the Chilula and outsiders may have come with the early explorers, men such as Jedediah Smith and Josiah Gregg who passed through in 1828 and 1849. By the 1850s, with the discovery of gold in the interior, there were historic developments in the Bald Hills. The Trinidad Trail, which served as a travel route for supply pack trains from the coast to the interior, was constructed. In addition, the first ranches were established during this time period. The 1860 Agricultural Census for Klamath County lists ten small ranches being served by a post office located at Elk Camp in the Bald Hills.

In the 1860's, the Lyons ranches, which would function for over a century in the Bald Hills, were established. Started by Jonathan Lyons and Amelia, his Native American wife, and continued by his sons and grandsons, the Lyons Ranches had thousands of acres, on which they ran tens of thousands of sheep.

The town of Orick originated as a Yurok village near the mouth of Redwood Creek. Miners arrived in the area in the 1850's to search for gold along the Gold Bluffs north of Redwood Creek. The Trinidad Trail used to supply the rich Klamath River gold diggings bypassed Orick, but the need for food generated by the gold rushes on the Klamath and Trinity Rivers created an incentive for the establishment of the first farms and ranches in the Orick Valley.

Orick remained a pastoral community until the advent of large-scale timber harvesting after the Second World War. At that time, the town grew in population, and several sawmills were constructed in and near the town. The timber industry dominated the local economy from the 1940's to the 1970's. Only one mill is still in operation in the Orick Valley. Dairy ranching remains a major part of the local economy, and tourism has become increasingly important.

Public protection of redwoods in the watershed dates to 1923, when Prairie Creek State Park was established with support from the Save-the-Redwoods League. Redwood National Park was created in 1968 and expanded in 1978. Smaller tracts have been added through donations and purchases since then. Redwood National Park was designated a World Heritage Site in 1980 and an International Biosphere Reserve in 1983. Beginning in 1994, the state and national redwoods parks have been
managed cooperatively as Redwood National and State Parks. Park lands in the Redwood Creek watershed now total about 70,000 acres. Of this total, about 30,000 acres are old rowth forest. With the exception of 2,000 acres of grassland prairie and small areas of stream channel and beach, the remainder of park lands are harvested forest.

Floods, Sediment and Land Use

FLOODS, SEDIMENT, AND LAND USE

Relations between floods, sediment, and land use have been central to the debate over resource protection in the Redwood Creek watershed. Damage to redwoods, fish, and other resources coincided with both intensive land use and a series of large storms that were accompanied by widespread flooding and erosion. Erosion rates in northwestern California are naturally high, and a long-standing question is whether land use has significantly increased erosion above natural levels associated with storms. The question has obvious practical importance because erosion related to land use can potentially be prevented, whereas natural erosion caused by intense storms probably cannot.

Recent Large Floods

Floods are critical events for the resources of Redwood Creek because they erode hillslopes, reshape channels, and transport large proportions of fluvial sediment loads. Several major floods have occurred on Redwood Creek during the past 150 years. Recent floods occurred in 1953, 1955, 1964, 1972 (two floods), and 1975. The peak discharges of these floods were remarkably similar, ranging from 45,300 to 50,200 cubic feet per second (cfs). The small range of these flood peaks indicates that watershed physiography (Ricks, 1995) limits the peak discharges, though not the volumes, of floods near the mouth of Redwood Creek.

Recurrence intervals of the recent flood peaks on Redwood Creek have been controversial. Coghlan (1984) estimated recurrence intervals of 25-30 years for the 1955 flood and 45-50 years for the 1964 flood. Waananen and Crippen (1977), however, estimated the 25-year flood at Orick to be 53,600 cfs, and the 50-year flood to be 60,400 cfs. In any case, the 1964 storm was a regionally significant event that caused major damage to towns, highways, and other structures, as well as significant hillslope erosion and channel changes.

Floods in 1861-62 and 1867 were as large or larger than the 1964 flood (Coghlan, 1984). Little is known about the effects of these earlier floods on watershed conditions. A number of redwoods were toppled and carried downstream during the 1861-62 floods, according to one report (Barlow, 1984), but few landslide scars date from this flood.

No large floods have occurred since 1975. Recurrence intervals of annual peak flows since 1976 have all been 5 years or less. The highest peak flow between 1975 and 1996 occurred in 1986 (estimated recurrence interval 4-5 years). Although the probability of a flood of any recurrence interval remains the same for each year, the probability of a flood occurring within a given time period increases as the time period becomes longer. Hence, the probability of a damaging (25-year recurrence interval) flood occurring on Redwood Creek has increased each year since the last flood in 1975, and is presently (1996) equal to 0.60. The odds in favor of a flood will increase each year until a flood does occur.

Timber harvesting and roads can increase storm runoff by reducing canopy interception, decreasing evapotranspiration, compacting soil, intercepting subsurface flow at road cutbanks, and channeling overland flow along roads and skid trails. Land use probably increased streamflow in Redwood Creek during and shortly after the period of intensive harvesting in the 1970's (Lee and others, cited in Nolan and Janda, 1981). Effects of land use are discussed in more detail in the Natural Resources Issues section.

Erosion and Sediment Yield

Two general types of information are available from geomorphic research and monitoring programs of the National Park Service and the U.S. Geological Survey. These are: 1) measurements of erosional processes within the watershed, and 2) records of sediment transport in Redwood Creek.

Erosional Processes

Erosional processes in the watershed range from the removal of individual soil particles by raindrops to extensive landslides that cover entire hillslopes. In general, erosion caused by obvious large-scale earth movement has been better documented than erosion caused by dispersed small-scale processes. The smaller-scale processes, however, may also be of great importance in generating sediment because they are more widespread. Past studies indicate that streamside landsliding and fluvial hillslope erosion may be the most important processes delivering sediment to Redwood Creek (Harden and others, 1978; 1995; Kelsey and others, 1981a; 1981b).

Landslides

Streamside landslides are clearly an important source of sediment in the Redwood Creek watershed, because of their number and volume, and because they deliver sediment directly to channels. Streamside landslides include debris slides, debris avalanches, and earthflows; however, debris slides account for most of the streamside landslide volume (Kelsey and others, 1995). The erosional landform map of Nolan and others (1976) shows streamside landslides along most of the mainstem and major tributary channels in the upper and middle basins. Streamside landslides may be caused in part by channel aggradation (Janda and others, 1975). Sediment deposited in the channel raises water levels during storms, resulting in undercutting of steep hillslopes that subsequently fail as debris slides.

The temporal distribution of streamside landslides was studied by Harden and others (1978; 1995). Using aerial photographs, they determined that the numbers of streamside landslides increased from 100 in 1947 to 415 in 1976. The increase was due mostly to debris slides. Many streamside landslides occurred between 1962 and 1966, probably during the 1964 flood. Between 1970 and 1976, the number of new streamside landslides decreased in the upper basin, but increased in the middle and lower basins. Few streamside landslides have been initiated during the relatively dry period since 1975.

The most areally extensive mass movement features in the watershed are earthflows (Nolan and others, 1976; Harden and others, 1978). The total area covered by active earthflows represents about 9% of the Redwood Creek watershed, and very active earthflows comprise 2% of the watershed area (Harden and others, 1978). The earthflows classified as "very active" can be considered streamside landslides because they deliver sediment directly to major channels.

Previous studies have found that earthflows, despite their large areas, contribute relatively little sediment to Redwood Creek (Harden and other, 1978; Nolan and others, 1979; Kelsey and others, 1995). They are generally grass-covered rather than forested, and are often gullied. Studies in and near the Redwood Creek watershed by Kelsey (1978; 1980), Harden and others (1978), Nolan and others (1979a), Iverson (1984), and Iverson and Major (1987) have shown that earthflows deliver sediment to stream channels through both mass movement and fluvial processes and that earthflow movement is related to annual rainfall and patterns of groundwater flow.

Earthflows may be largely natural erosional features. Kelsey (1978), however, suggested that livestock grazing and subsequent conversion of prairie vegetation from perennial long-rooted native bunch grasses to annual short-rooted exotic grasses may have accelerated or triggered earthflow instability within the past century. In addition, road construction has accelerated gully erosion on earthflows (Walter, 1986), and, through interception of subsurface flow, may have altered streamflow peaks, patterns of groundwater flow, and hence earthflow movement. Earthflow activity may also have been initiated or accelerated by fluvial erosion where earthflow "toes" protrude into stream channels.

Landslides other than streamside landslides include debris avalanches and debris flows (Harden and others, 1978; LaHusen, 1985), slumps (Nolan and others, 1976; Harden and others, 1978), forested block slides (Sonnevil and others, 1985), and some large and relatively inactive earthflows. These landslides are much less significant as sediment sources than are streamside landslides.

Fluvial Hillslope Erosion

Fluvial hillslope erosion in the Redwood Creek watershed is apparent in both natural and disturbed settings (Janda and others, 1975). On unlogged forested hillslopes, fluvial erosion is related to interactions between subsurface piping through root channels and gully and rill development (Janda and others, 1975; Ziemer, 1992). On logged hillslopes, extensive networks of rills and gullies have developed from streamflow diversions and washouts at road and skid trail stream crossings, from ditches and cutbanks, and from interception of subsurface flow along roads and trails (Janda and others, 1975). Surface erosion of logged areas may also have increased as a result of decreased interception of rainfall by the forest canopy following harvest. Prairies are particularly susceptible to gully erosion, and road runoff has carved numerous large gullies in the Bald Hills area.

Fluvial hillslope erosion is much more difficult to quantify at the watershed scale than mass movement processes because fluvial features are smaller, more widely dispersed, and difficult or impossible to measure on aerial photographs. As a result, basinwide estimates of fluvial erosion based on field data are lacking.

Previous studies have documented large increases in fluvial erosion on lands where timber has been harvested or where roads have been constructed (Janda and others, 1975; Nolan and others, 1976; Walter, 1985; Hagans and Weaver, 1987). Kelsey and others (1981a) estimated from sediment-budget calculations that fluvial erosion from hillslopes contributed 68 percent of total sediment mobilization in the upper basin. Hagans and Weaver (1987) found that fluvial hillslope erosion in the lower basin between 1954 and 1980 produced about as much sediment as mass movement processes, including streamside landslides. Although considerable uncertainty is associated with these estimates, they indicate that fluvial hillslope erosion represents a significant sediment source in the watershed.

Channel storage

Massive amounts of coarse sediment were deposited in tributaries and the upper and middle reaches of the mainstem during the flood of 1964 (Janda and others, 1975; Iwatsubo and others, 1976; Nolan and Janda, 1979; Kelsey and others, 1981a, 1981b; Pitlick, 1982; Madej, 1984, 1995; Varnum, 1984; Varnum and Ozaki, 1986; Nolan and Marron, 1995; Madej and Ozaki, 1996). During subsequent floods, particularly in 1972 and 1975, coarse sediment was scoured from tributaries and the upper mainstem and re-deposited in lower reaches (Varnum, 1984; Madej, 1995; Varnum and Ozaki, 1986).

Sediment stored within the channel system continues to move in wave-like fashion downstream (Madej and Ozaki, 1996). As of 1990, peak aggradation was about 5 miles downstream from the Tall Trees Grove and about 4 miles upstream of Orick (fig. 3-5). Channel cross section surveys in 1995 indicated that, for the first time since measurements began in 1973, the channel bed between the Tall Trees Grove and Orick was scouring. The sediment wave, therefore, may have become completely attenuated in the lower reach as a result of particle attrition and selective transport.

Sediment storage in the numerous small tributaries is controlled in part by woody debris. The effects of timber harvest on the recruitment of woody debris, and hence on sediment storage, are discussed below.

Sediment Budget

A sediment budget is a useful tool for assessing the relative importance of erosional processes. Conceptually, a sediment budget balances inputs (sediment mobilization or erosion) against outputs (fluvial sediment discharge from the watershed), after accounting for changes in sediment storage. In the case of Redwood Creek, we are interested in comparing large landslides that may occur naturally and are difficult to prevent to widespread, small-scale processes that are often related to land use and are more easily addressed with erosion-control efforts. Previous studies in and near the Redwood Creek watershed have provided a basis for estimates of fluvial sediment discharge, changes in channel sediment storage, and sediment production by mass-movement and fluvial processes between 1954 and 1980 (table 1; sediment-budget calculations and supporting information are provided in Appendix B).

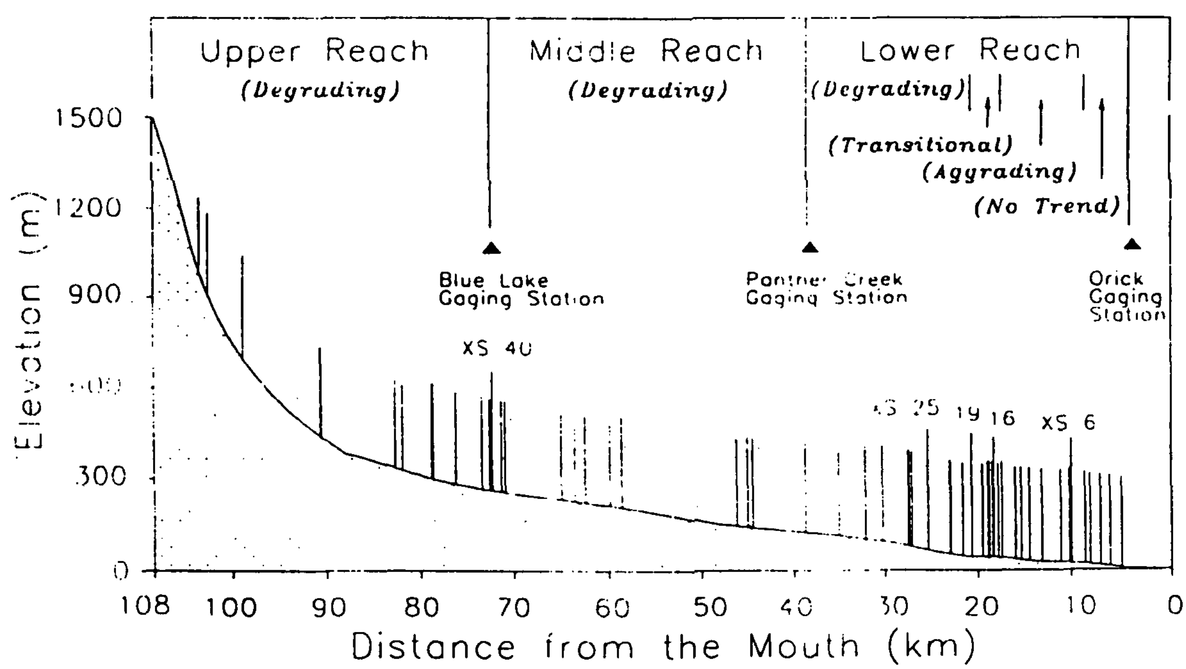


Figure 3. Graph showing longitudinal profile of Redwood Creek.

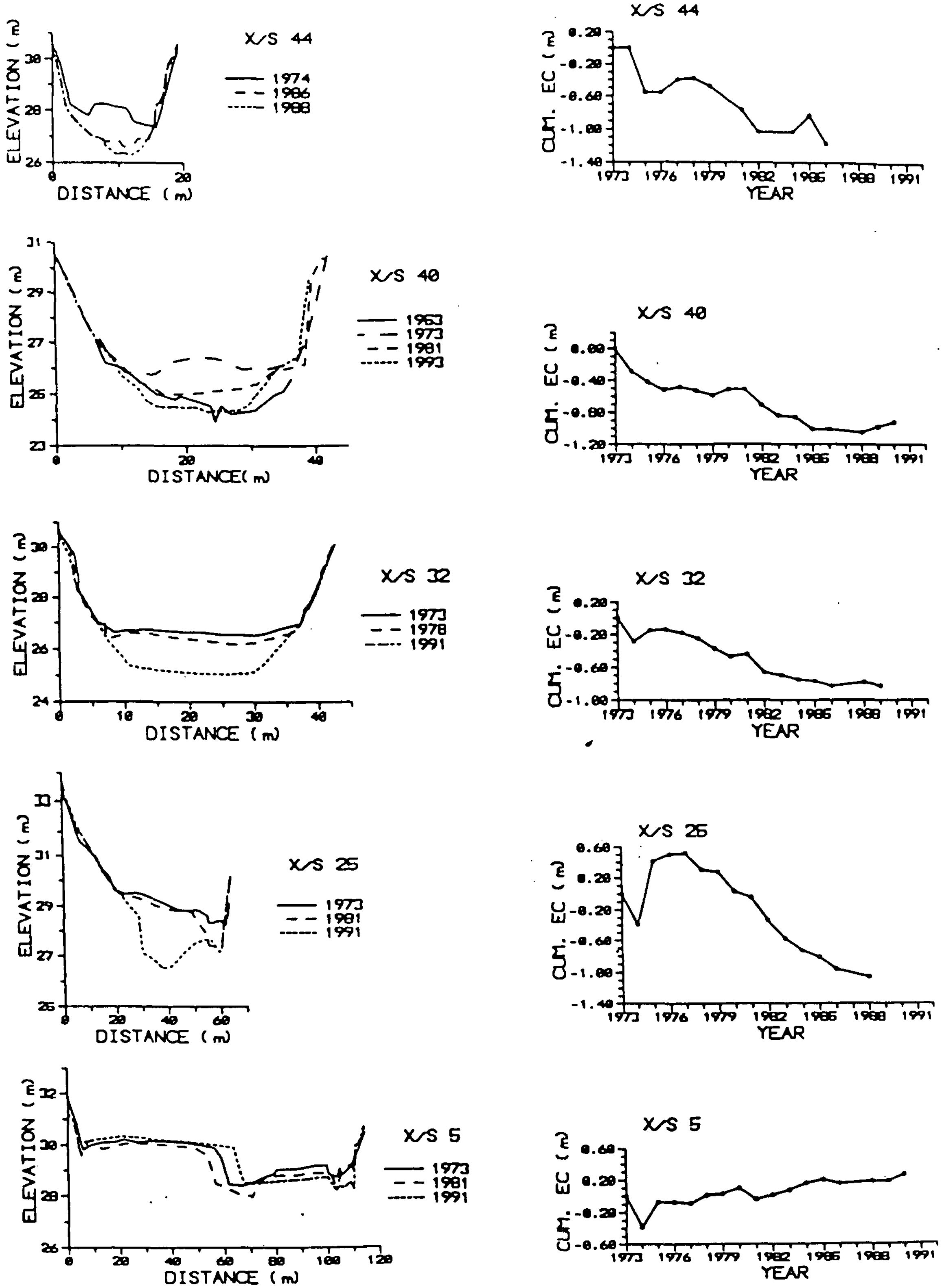


Figure 4 Graph showing selected channel cross-section surveys, Redwood Creek

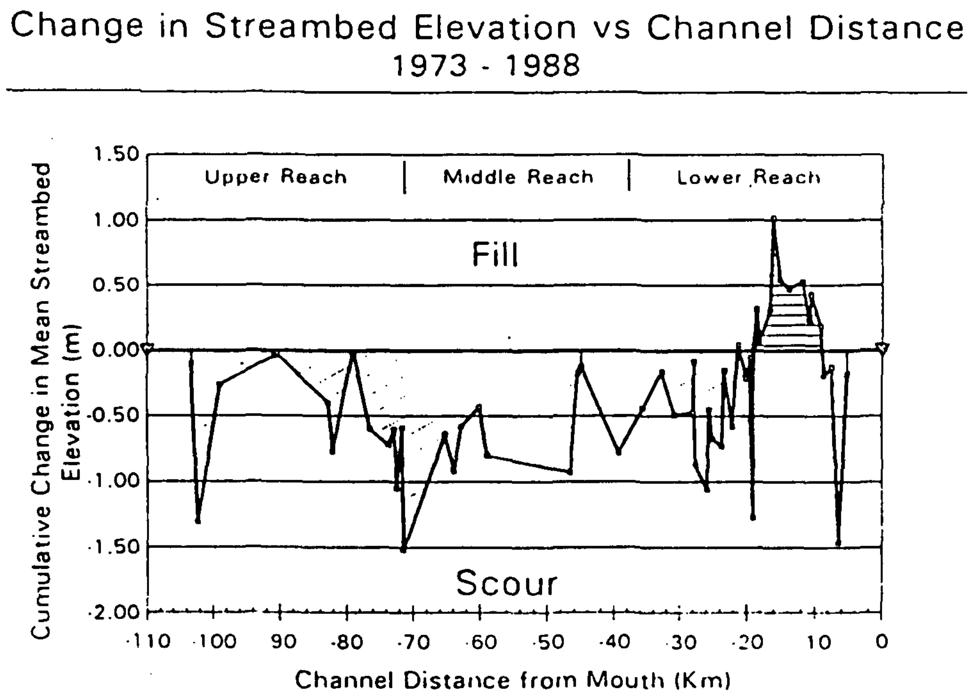


Figure 5. Graphs showing cumulative change in mean streambed elevation along Redwood Creek, 1973-88

Table 1: Sediment budget, Redwood Creek watershed, 1954-80

Sediment Source	*Mass (tons)*	*% Total Contribution*
Roads:		
Haul road cutbanks	430,000	1.0
Surface erosion -Haul roads	1,377,000	3.8
-Skid trails	122,000	<1
Inboard ditches	363,000	1.0
Haul road crossings	2,000,000	5.5
Skid trail crossings	335,000	1.0
Surface erosion on bare ground	3,500,000	9.6
Gullies	8,500,000	23.4
Streambank erosion		
Tributaries	1,650,000	4.5
Mainstem	164,000	<1
Mass movement:		
Mainstem Streamside Landslides	7,100,000	19.6
Tributary Streamside Landslides (sampled, n = 16)	3,900,000	10.7
Tributary Streamside Landslides (unsampled, extrapolated data)	4,400,000	12.1
Earthflows	1,300,000	3.6
Forested Blockslides	263,000	<1
Debris Torrents	900,000	2.5
Total Sediment Input	**36,304,000**	**100**
Additions to Sediment Storage		
Main channel storage	10,400,000	
Tributary channel storage	440,000	
Sediment Output (Orick)	45,000,000	

The Redwood Creek sediment budget (table 1) is not a "balanced" budget because sediment discharge and additions to channel sediment storage exceed erosional inputs. The imbalance of 19,536,000 tons (35% of sediment discharge plus net storage) indicates that we cannot account for the sources of all of the sediment delivered to the channel system, and it provides a rough measure of the overall accuracy of the sediment budget.

TABLE 1: SEDIMENT BUDGET FOR THE REDWOOD CREEK WATERSHED 1954-1980

Sediment Inputs	Mass (tons)	% Total Contribution
Roads: Haul road cutbanks	336,000	<1
Surface erosion-haul roads	1,265,000	3.1
-Skid trails-rills and diversions	2,400,000	5.8
Inboard ditches	410,000	1.0
Haul road crossings	1,166,000	2.8
Skid trail crossings	511,200	1.2
Surface erosion on bare ground	1,757,000	4.3
Gullies (primarily stream diversions)	8,507,000	20.6
Streambank erosion - tributaries	3,849,400	9.3
-mainstem	2,070,000	5.0
Mass movement:		
Mainstem Streamside Landslides	7,100,000	17.2
Tributary Streamside Landslides (sampled basins, n = 16)	3,900,000	9.4
Tributary Streamside Landslides (unsampled basins, extrapolated data)	4,600,000	11.1
Earthflows	1,350,000	3.3
Forested Blockslides	260,000	<1
Debris Torrents on Sandstone Terrain	900,000	2.2
Debris Torrents on Schist Terrain	460,000	1.1
Other road fill failures	453,000	1.1
Landing failures (excluding torrents)	44,000	<1
Total Sediment Input	41,338,600	100
Additions to Sediment Storage		
Main channel storage	10,400,000	
Tributary channel storage	440,000	
Sediment Output (Orick)	45,000,000	

Sediment production by fluvial erosion of roads and hillslopes (roads, surface erosion of bare ground, and gullies on table 1) accounted for 46% of sediment production (table 1). Most of this erosion was related to land use, and could have been prevented with erosion control and road maintenance measures. Of these sources, gullies produced by far the greatest amount of sediment (table 1). Most gullies resulted from streamflow diversions at road-stream crossings (Best and others, 1995; Weaver and others, 1995). The large amount of sediment eroded from gullies could have been greatly reduced if stream crossings had been built without potential to divert streamflow (Best and others, 1995; Weaver and others, 1995).

Sediment production by mass-movement processes and streambank erosion are less clearly related to land use, and also more difficult to control, than fluvial processes on roads and hillslopes. Landslides and streambank erosion contributed a total of 19,677,000 tons, equivalent to 54% of sediment production.

In summary, two significant conclusions can be made on the basis of the sediment budget analysis. First, a large amount of erosion and channel deposition is likely in the next large storm, since we know that about half of total sediment production in past storms was not clearly related to land use, and the sources of a significant amount of sediment cannot be determined with confidence. Second, treatments to remove diversion potentials from road-stream crossings are likely to be effective in reducing sediment delivery to channels from roads built before current (since 1983) forest practice rules required that crossings be built without diversion potential. Given the increasing probability of a major storm in the next few years, treatments of diversion potentials may be the only practicable means of reducing erosion related to land use in the next major storm, because such treatments can be completed quickly and inexpensively and leave roads passable to vehicles.

Recent Trends in Sediment Loads

Fluvial sediment loads are affected by land-use practices and, in turn, affect channel stability, alluvial redwood groves, and aquatic habitat. Because of the importance of sediment to resources in the Redwood Creek basin, the following sections include detailed analyses of trends in recent sediment transport rates in Redwood Creek. These analyses rely on data collected by the U.S. Geological Survey and Redwood National Park between 1971 and 1992.

Annual sediment loads are highly dependent on annual streamflow. Trends in sediment loads resulting from changes in land use are difficult to detect unless variations in sediment loads that result from streamflow fluctuations are removed from the analysis. We mathematically removed the effects of streamflow variations by computing logarithmic least-squares linear regression equations using 1) annual suspended-sediment loads and streamflow and 2) annual bedload and streamflow at both Orick and O'Kane. The regression equations minimize the variation in sediment loads resulting from streamflow variations, and the regression residuals (the differences between the observed and predicted values of suspended-sediment loads or bedloads, in logarithmic units) are therefore a measure of the variations in sediment loads due to other factors (Helsel and Hirsch, 1992). In the case of Redwood Creek, land use is the only likely factor, other than streamflow, to have substantially affected sediment loads. The regression residuals were plotted against time (figs. 6 and 7) to provide an overall picture of trends. The presence or absence of significant trends was determined using the Mann-Kendall test (Helsel and Hirsch, 1992).

Suspended-sediment and bedload data were analyzed seperately to more accurately assess cause-and-effect relations for any trends detected.

If streamflow was affected by land use during the study, regression residuals will not accurately represent sediment-transport trends attributable to land use. Streamflow in Redwood Creek was probably increased as a result of logging and roadbuilding by about 20% during the 1970's (Nolan and Janda, 1981). A comparison of streamflow at the Orick and O'Kane stations with streamflow in an unlogged tributary indicates that effects of land use on streamflow were minimal after 1980. In order to determine if land-use effects on streamflow could have prevented the detection of significant trends, or could have caused false detections of artificial trends, we reduced the values of measured annual streamflow by 20% for the years 1971-80 and repeated the regression residuals analysis. The reduced streamflow data are estimates of streamflow under natural conditions unaffected by land use.

Suspended Sediment

Suspended sediment consists of sand, silt, and clay particles distributed throughout the water column. Fine sediment carried in suspension is of concern primarily because of its effects on aquatic habitat. Large proportions of suspended-sediment loads remain in suspension and are transported to the ocean once they enter the channel system. Fluctuations in suspended-sediment loads are therefore more closely related to short-term changes in watershed conditions than to long-lasting effects of major storms.

Suspended-sediment loads have been computed for about 20 years at the Orick and O'Kane stations. At Orick, annual suspended-sediment loads have ranged from 18,184 to 3,799,775 tons (table 2a), with a mean annual load of 914,821 tons. Annual suspended-sediment yields (loads per unit of contributing watershed area) at Orick have ranged from 65 to 9,888 tons per square mile. At O'Kane, annual suspended-sediment loads have ranged from 1,217 to 695,296 tons (table 2b), with a mean annual load of 165,059 tons. Annual suspended-sediment yields have ranged from 18 to 10,378 tons per square mile.

Residuals for suspended-sediment loads at Orick show a significant ($p<0.001$) downward trend (fig. 6a). This trend indicates that rates of suspended-sediment transport have declined relative to streamflow over the past two decades. When the analysis was repeated using annual streamflow for water years 1971-80 reduced by 20%, the same result was obtained.

Residuals for suspended-sediment loads at O'Kane show no significant ($p=0.250$) trend (fig. 6b). For similar streamflow conditions, suspended-sediment loads have neither increased nor decreased significantly. The second analysis, using estimated natural streamflow for water years 1971-80, resulted in the detection of a significant downward trend. This result indicates that the combined effects of land use on streamflow and erosion caused a larger increase in sediment transport during the 1970's than indicated by the regression residuals computed from measured streamflow and sediment data. The downward trend in suspended-sediment transport in relation to estimated natural streamflow is more significant than the original analysis using measured streamflow volumes indicates.

Table 2: Annual streamflow, suspended-sediment loads, and bedloads at daily sediment stations, 1971-92 [data from annual reports of the U.S. Geological Survey]

a. Orick				b. O'Kane			
Water Year	Streamflow (cfs-days)	Suspended Sediment (tons)	Bedload (tons)	Water Year	Streamflow (cfs-days) (tons)	Suspended Sediment (tons)	Bedload
1971	514,592	2,177,712	--				
1972	536,198	3,799,775	--				
1973	281,843	757,634	--	1973	70,264	184,689	--
1974	629,915	2,228,626	371,804	1974	149,725	657,618	301,502
1975	476,089	2,768,664	251,070	1975	124,160	695,296	243,860
1976	308,627	745,314	100,551	1976	67,873	81,189	21,295
1977	70,117	22,567	2,277	1977	16,117	1,217	724
1978	425,877	948,518	330,195	1978	95,406	122,233	65,950
1979	231,035	292,989	52,100	1979	51,081	54,296	28,436
1980	404,268	704,585	190,778	1980	98,573	162,674	36,152
1981	235,647	187,877	174,021	1981	50,793	46,873	7,143
1982	584,833	1,276,880	377,890	1982	132,041	255,056	74,039
1983	600,462	1,329,818	370,806	1983	131,297	373,940	85,292
1984	458,970	625,810	279,372	1984	120,542	173,401	56,666
1985	265,181	280,541	139,376	1985	63,422	81,351	8,956
1986	362,162	1,010,226	148,237	1986	83,886	239,826	24,563
1987	201,675	103,782	61,790	1987	44,747	12,310	3,654
1988	176,750	156,514	62,255	1988	37,076	28,769	5,623
1989	353,450	463,771	60,950	1989	82,174	89,666	6,385
1990	184,274	191,317	62,215	1990	41,912	32,804	1,618
1991	127,467	34,965	22,967	1991	25,986	5,108	420
1992	102,919	18,184	10,884	1992	22,294	2,870	176

Bedload

Bedload consists of sand, gravel, and cobbles that roll and slide over the streambed. Bedload is of concern because almost all of the coarse sediment that threatens alluvial redwood groves is transported in this manner. Large amounts of coarse sediment, delivered from hillslopes during the flood of 1964, remain stored in the channel system (Madej, 1995). Landslides and other processes have continued to provide coarse sediment to the channel, but at lower rates over the past 25 years than during the 1953-75 period that included large floods. Hence, bedload movement in Redwood Creek in the past three decades has been largely a re-distribution of coarse sediment deposited in 1964.

Bedload accounts for roughly 20 to 25 percent of the total sediment load (commonly computed as the sum of suspended-sediment load and bedload) of Redwood Creek, based on data presented in table 2. The percentage of the total sediment load transported as bedload is slightly higher at Orick than at O'Kane. Annual bedload has ranged from 2,277 to 377,890 tons at Orick (Table 2a). Bedload per unit watershed area at Orick has ranged from 8 to 1,350 tons per square mile. Annual bedload at O'Kane has ranged from 176 to 301,502 tons (Table 2b), and bedload per unit area at O'Kane has ranged from 3 to 4,500 tons per square mile.

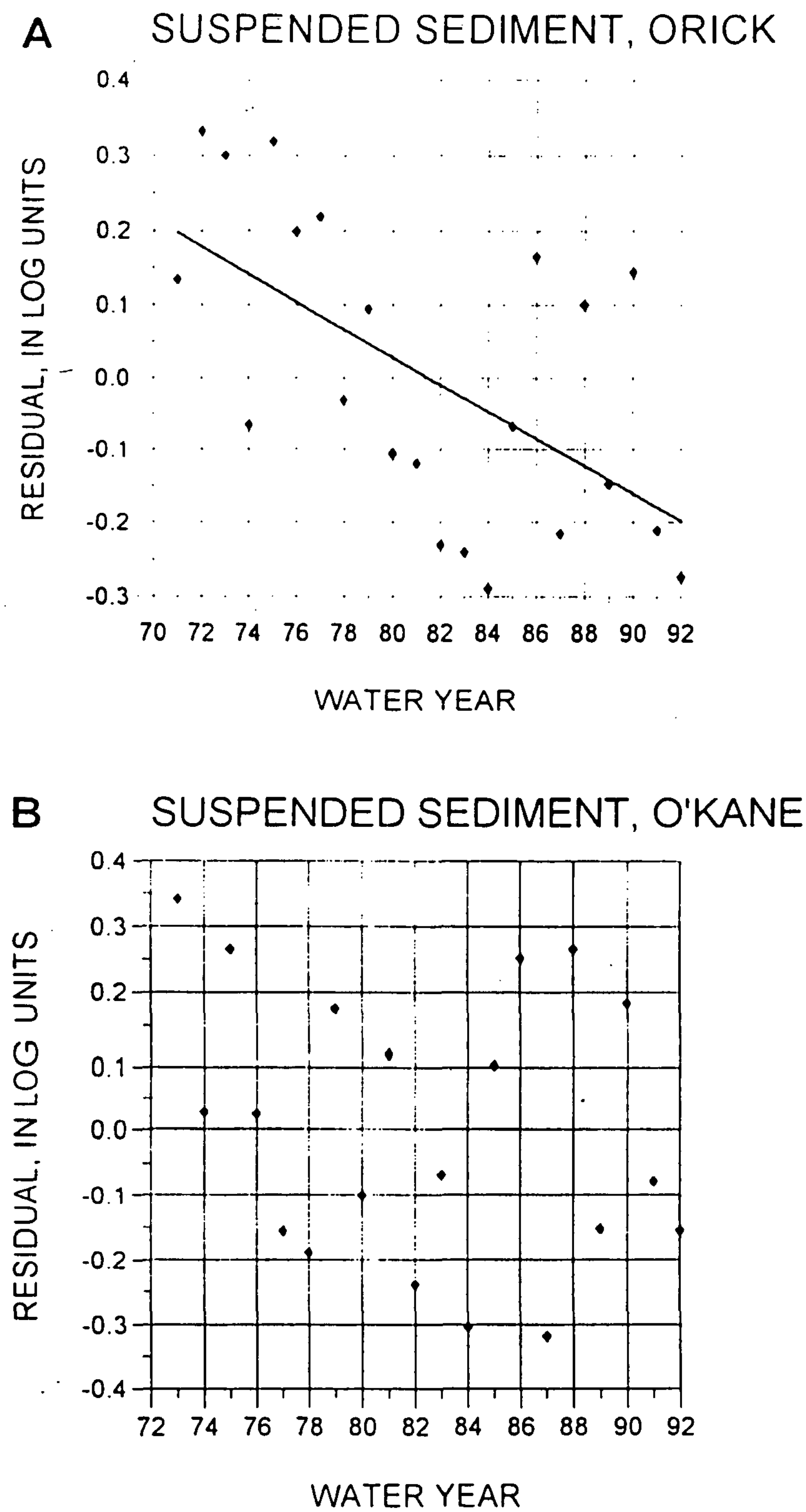


Figure 6 Graph showing suspended-sediment residuals for Redwood Creek at Orick, 1971-92 (A) and Redwood Creek at O'Kane, 1973-92.

Redwood Creek Watershed Analysis Update

Table 2: Annual streamflow, suspended-sediment loads and bedloads at daily sediment stations, 1993-1997.

O'Kane

Water Year	Streamflow (cfs-days)	Suspended Sediment (tons)	Bedload (tons)
1993	94,204	125,684	---
1994	37,713	14,377	---
1995	129,757	268,096	---
1996	118,505	607,792	---
1997	102,062	388,040	---

Orick

Water Year	Streamflow (cfs-days)	Suspended Sediment (tons)	Bedload (tons)
1993	433,132	388,111	---
1994	167,403	73,070	---
1995	461,206	751,906	---
1996	490,647	2,739,995	---
1997		1,845,251	

APPROX
8,000,000 TONS
SEDIMENT
1981 – 1994/YR = 14 T/AC/YR
= 3.2

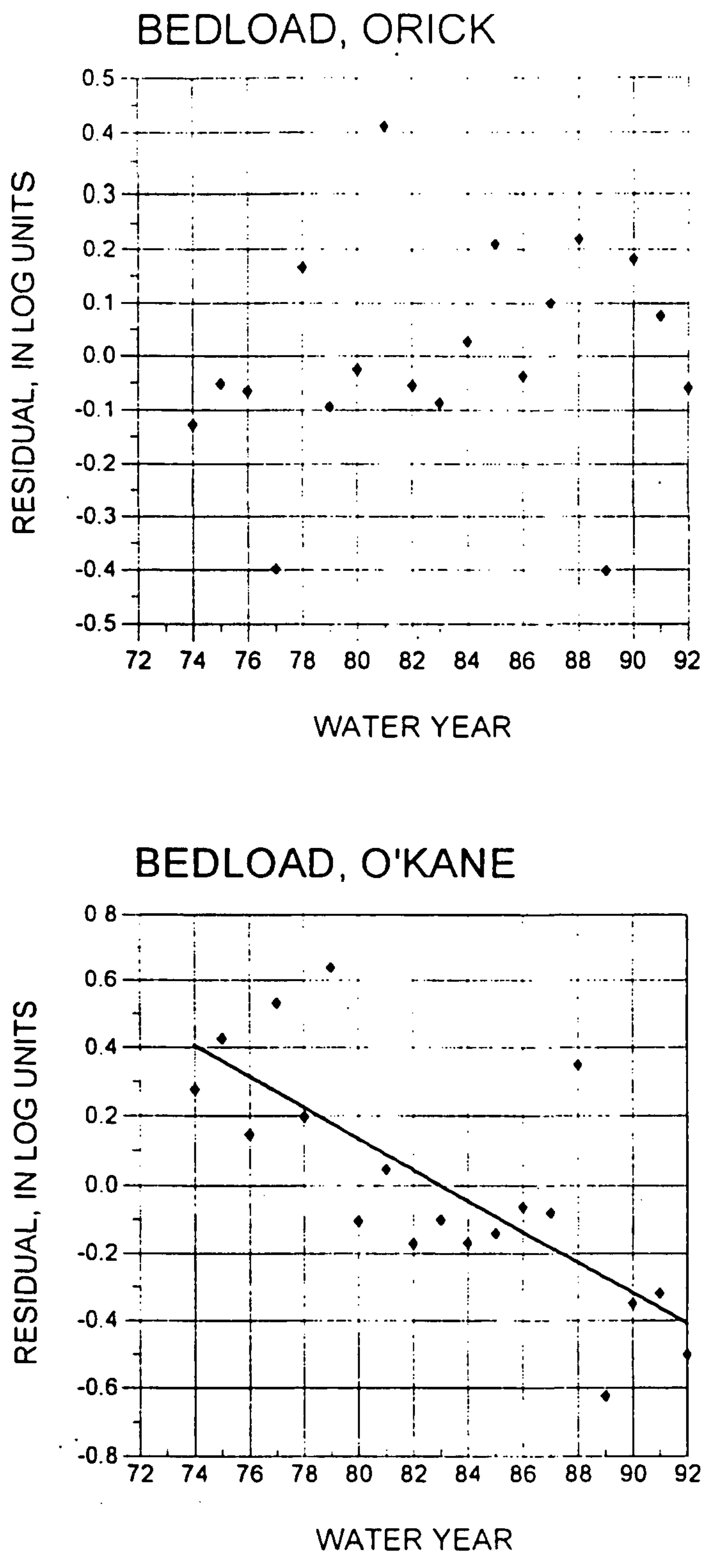


Figure 7: Graph showing bedload of residuals for Redwood Creek at Orick, 1971-92 (A) and Redwood Creek at O"Kane, 1974-92 (B)

Residuals for bedload at Orick show no significant (p=0.108) trend (fig. 7a). This result indicates that bedload transport rates at Orick have not changed much since the mid 1970's. No trend was detected when annual streamflow data reduced by 20% were substituted for measured streamflow in the analysis.

In constrast, residuals for bedload at O'Kane show a highly significant ($p<0.001$) downward trend (fig. 7b). This trend indicates a shift to reduced rates of bedload transport relative to streamflow. Field observations indicate that much of the upper mainstem channel has scoured to bedrock or boulders. This trend was also detected when the reduced values of streamflow for water years 1971-80 were used.

Land Use

The major land use in the watershed during the past 50 years has been timber production with associated roadbuilding. Logging and roads have the potential to increase peak streamflows through disruption and compaction of the natural forest ground cover, reduced canopy interception of rainfall, and concentration of surface runoff along roads and skid trails. Logging and roadbuilding can also accelerate erosion by reducing root strength on steep hillslopes, placing fill across streams and on unstable hillslopes, and concentrating runoff on erodible soils.

Timber Harvest

Logging for ship's masts began as early as the 1850's, but commericial harvesting to supply markets outside the local area started in the 1930's. Early logging operations were clearcuts. Yarding was done with steam donkeys, and logs were transported by rail.

Large-scale logging began after the Second World War, when both tractors and gasoline-powered chain saws became widely available, and when the expanding post-war economy created a high demand for lumber (Janda and others, 1975). Logging during the 1950's was generally done by selective cutting, but clearcutting became the dominant silviculture in the 1960's as timber companies experienced poor success with thinning and natural reseeding (Janda and others, 1975). Tractor yarding has been used much more commonly than cable yarding. Intensive logging was concentrated in the upper-basin stands of Douglas-fir in the 1940's and 1950's but shifted to redwood groves of the middle and lower basins in the 1960's as redwood became more popular for home construction.

Only about 5 percent of the watershed area upstream of the confluence of Prairie and Redwood Creeks had been logged as of 1948 (Best, 1984; 1995), whereas approximately 62 percent of this area had been logged as of 1978 (Best, 1984; 1995). Logging was most intensive between 1949 and 1962, when about 31 percent of this area was logged (Best, 1984; 1995).

Timber harvesting continues to be the primary land use on private lands upstream of the park. Most timber harvests in recent years have been in second-growth stands. No timber is harvested on park lands, but pilot projects to thin second-growth redwoods and douglas-fir were initiated in 1979 and again in 1995. This program may eventually be expanded to large areas of second-growth forest in the park.

Forest practices on private lands are regulated by the California Department of Forestry and Fire Protection. Timber harvest regulation by the state began in 1945, but became more effective following passage of the Z'berg-Nejedly Forest Practice Act of 1973. This act provided the Board of Forestry with authority to develop rules and guidelines for management of non-federal forest lands in the state. On August 25, 1975, following hearings and modifications of initial rules, Forest Practice Rules (FPR's) that would guide timber harvest practices for nearly a decade became effective.

Currently, the FPR's (California Department of Forestry and Fire Protection, 1994) provide stream and riparian protection through Watercourse and Lake Protection Zones (WLPZ's), which are areas immediately along the sides of streams, lakes, or springs. The WLPZ rules are important for protection of park resources because streamside areas provide both sediment and woody debris to the channel system. The roots of streamside trees increase streambank stability, and removal of trees along streams can therefore increase bank erosion. Woody debris naturally contributed by riparian trees acts to store sediment within the channel, thereby reducing downstream sediment loads. Falling and yarding along streams can disrupt ground cover and increase sediment delivery to streams. Removal of streamside trees also reduces riparian shading and can elevate stream temperatures.

The width of a WLPZ and the level of protection that it offers depend primarily on the steepness of streamside areas, the proposed yarding method and the type or "class" of stream that will be affected by timber harvest operations. Class I streams support fish, Class II streams contain aquatic habitat for non-fish species, and Class III streams contain no aquatic life but are capable of sediment transport to Class I and II streams.

The WLPZ provisions of the FPR's were not implemented until 1983, when the vast majority of private timberlands in the Redwood Creek basin, including riparian areas, had already been harvested and after the recent large floods had disrupted riparian zones. As a result, alder and other hardwood species now dominate most streamside areas, which contain far fewer large conifers than existed under natural conditions.

Management of riparian areas under current WLPZ provisions is based on existing conditions rather than natural conditions, and the existing riparian conditions can be further compromised if previously logged areas are re-entered. Although the FPR's are intended to protect the beneficial and restorable uses of water, they allow the continued reduction of critical riparian elements - large and old coniferous trees. For example, WLPZ protection is rarely extended to Class III streams. Class III streams are the biological and physical extensions of Class I and II streams and, in some cases, are still recovering from impacts of early forest practices and large storms. For Class I and Class II streams, requirements for the composition of overstory species within streamside areas are satisfied when only 25 percent of the <u>existing</u> overstory conifers are retained during timber harvest. The requirements for future recruitment of large woody debris are also met by retaining only 2 conifers per acre that are at least 16 inches in diameter and 50 feet tall. Clearly, this approach to management of streamside areas may have the net effect of eliminating nearly all large or senescent conifers from riparian areas.

Under the current FPR's, riparian areas managed for timber production in the Redwood Creek watershed are unlikely to ever provide the function they provided before the advent of logging. Although the current rules provide protection for some streamside areas, vertical stand diversity, species composition, recruitment of large woody debris and shading for stream temperature control are greatly compromised. The biological importance of large trees for shade and large woody debris recruitment beyond the riparian zone is also largely ignored.

Roads

Roads are a major cause of accelerated erosion (Kelsey and others, 1981b; Hagans and Weaver, 1987; Best and others, 1995). The erosion potential of roads is related to maintenance, location, and design (Janda and others, 1975; Best, 1984; Klein, 1987). Common erosion problems associated with roads include washouts and stream diversions at stream crossings, mass wasting of unstable fills and oversteepened cutbanks, and interception of surface and subsurface water by cutbanks and inboard ditches.

About 1,200 miles of forest roads and 5,400 miles of skid trails were built within the Redwood Creek watershed as of 1978 (Best, 1984). About 445 miles of roads and 3,000 miles of skid trails (Steensen and Spreiter, 1992) were included within present park boundaries as a result of park expansion in 1978. In addition, about 20 miles of state highway and county roads cross the watershed, including several miles of abandoned state highway.

The logged areas included within the park in 1978 and private timberlands upstream of the park had similar road densities in 1978. Since that time, watershed restoration efforts have reduced road miles within the park while timber harvesting and residential construction have increased road miles upstream (fig. 8).

Roads upstream of the park boundary as of 1992 totalled about 1,110 miles, based on analysis of aerial photographs. About 66% of these road miles were constructed before 1964, 14% were constructed between 1964 and 1978, and 20% were constructed between 1978 and 1992 (fig. 9). Most of the upper- and middle-basin road network, therefore, was built before enactment of current forest practice rules as amended in 1983 that required new roads to be built without potential to divert streamflow..

Of the total 1,110 miles of roads upstream of the park, about 340 miles were determined to be unmaintained and abandoned as of 1992. Another 180 miles were classified as unmaintained but still driveable. Almost half of the road network is therefore unmaintained in the upper basin. These unmaintained roads are more likely than the maintained roads to fail during a large storm as a result of plugging and rusting of culverts, rotting of organic debris, and diversion of groundwater and streamflow.

Road locations particularly susceptible to failure include steep (>65%) hillslopes on erosion-prone bedrock and soil. About 75 miles of road in the upper basin were constructed on slopes greater than 65%. Of these, about 50 miles are in inner gorge areas adjacent to stream channels, where the impacts of failures are most serious. Roughly 335 miles of the road network upstream of the park

Figure 8

EXISTING ROADS IN THE REDWOOD CREEK BASIN (1992)

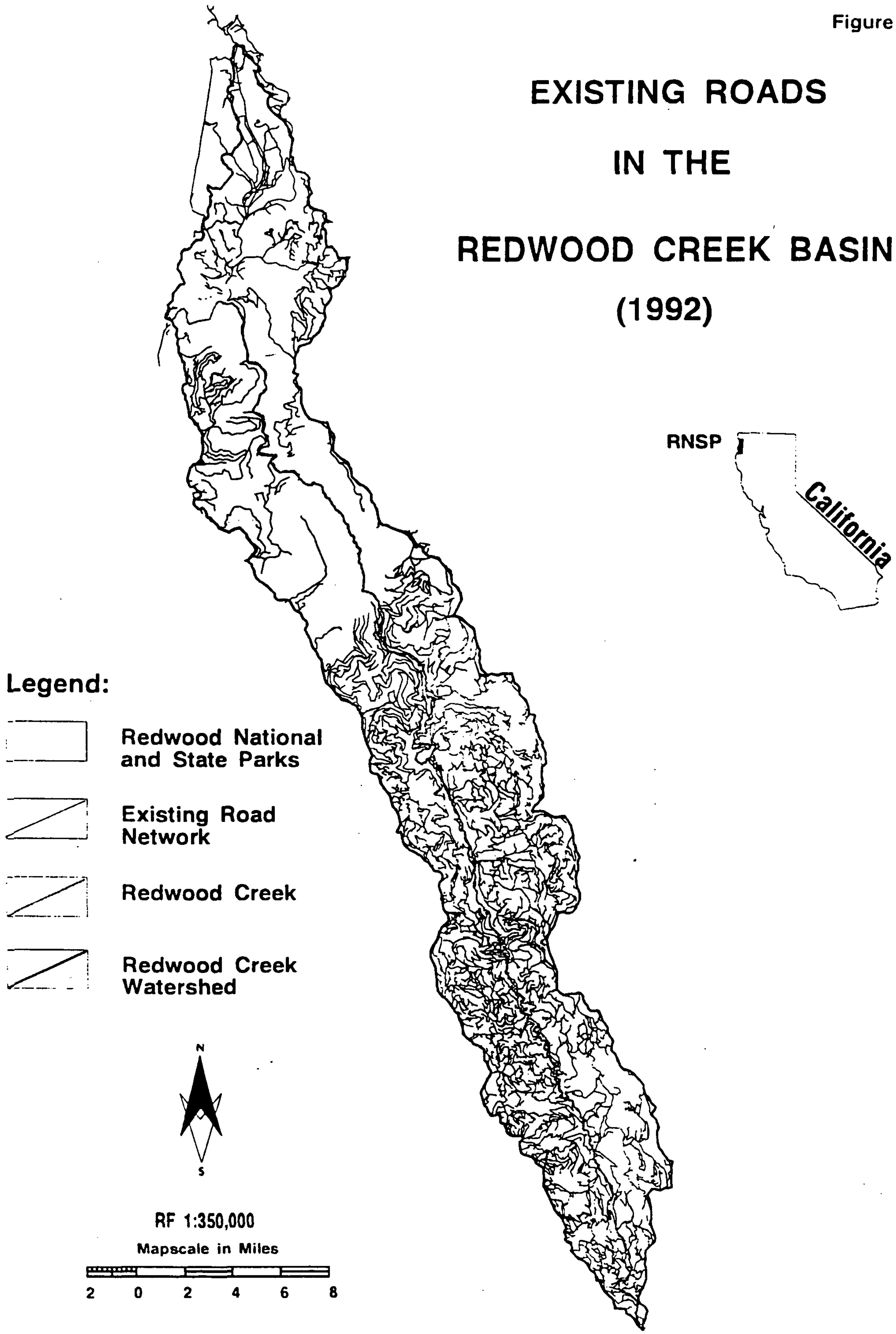
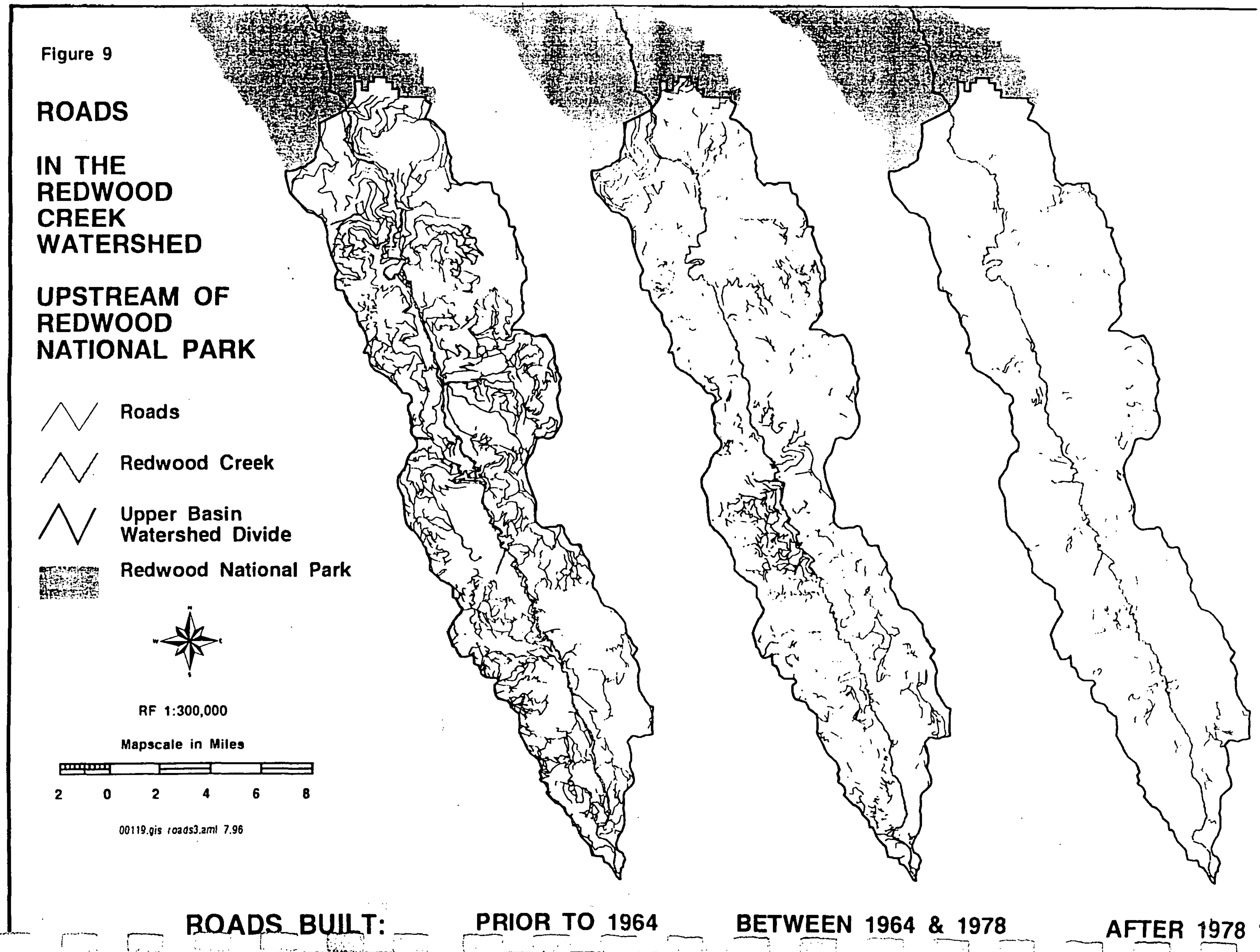


Figure 9


ROADS
IN THE REDWOOD CREEK WATERSHED
UPSTREAM OF REDWOOD NATIONAL PARK
Roads
Redwood Creek
Upper Basin Watershed Divide
Redwood National Park
RF 1:300,000
Mapscale in Miles
2 0 2 4 6 8
00119.gis roads3.aml 7.96
ROADS BUILT:
PRIOR TO 1964
BETWEEN 1964 & 1978
AFTER 1978

were constructed on unstable bedrock units such as the incoherent unit of Coyote Creek and the sandstone and melange unit of Snow Camp Mountain. About 180 miles were constructed on soils units particularly susceptible to landslides and fluvial erosion.

Based on records of Timber Harvest Plans (THPs) filed for commercial timber lands in the the Redwood Creek watershed, 127 miles of new and 111 miles of rebuilt roads were used for logging within THP units between 1978 and 1992 (table 3). In addition, 236 miles of existing roads were used for access and hauling. Rebuilt roads therefore represent almost one-quarter of total logging road mileage used during this period. Although some roads may have been classified as "rebuilt" owing to vegetation encroachment, this classification was commonly used to denote roads that required earthmoving to be made driveable. The high proportion of roads that required rebuilding suggests that road failures have been frequent. Roads and skid trails used for timber harvest during this period included over 1,400 stream crossings (table 4). Most of these were on small headwaters (Class III) streams, and many required rebuilding.

Under the current FPR's, logging haul roads are likely to remain a significant source of sediment during future large storms because the FPR's cease to apply once logging has been completed and the logged area has met conifer stocking requirements. The current maintenance period for roads and erosion-control structures is based primarily on the time required to complete the harvest operation. Typically, road maintenance is required for a period of two to four years: one to three years during the harvest operation plus one year following harvest for stocking. As a result, long-term maintenance of roads,culverts and erosion-control structures has been rare. Unless planned road abandonment and construction of temporary roads (that is, the intentional construction of roads that will be treated to reduce erosion after timber harvests are completed) are encouraged or required by the FPR's, perhaps through a more rigorous assessment of cumulative watershed impacts, roads will remain a significant source of sediment during future large storms.

A new section of U.S. Highway 101 was constructed partially within the Prairie Creek watershed between 1985 and 1992 (fig. 1). This highway section, known as the Redwood Park bypass, has caused substantial sediment delivery to tributaries of Prairie Creek (Meyer, 1994). The most notable impacts occurred during a heavy rainstorm in October, 1989. Suspended-sediment loads of Prairie Creek and its tributaries increased as a result (Meyer and others, 1994). Park staff are currently monitoring streamflow, sediment transport, and aquatic habitat conditions at several locations downstream of the bypass.

During bypass construction, about 350,000 tons of gravel were removed from the channel of Redwood Creek near Orick for highway construction. Bed elevations between the flood-control levees lowered by roughly 1.5 feet as a result.

Mining

Mining within the Redwood Creek watershed has been limited to gravel mining within the channel of Redwood Creek and rock quarries and borrow pits used for road construction. Gravel has been mined between the flood-control levees, near the mouth of Prairie Creek, at the mouth of Tom McDonald Creek, and near Highway 299 (Janda and others, 1975). Gravel extraction by the

Georgia-Pacific Lumber Company between 1951 and 1958 near the Tall Trees Grove totaled between 200,000 and 800,000 tons (Kelsey and others, 1979). This gravel removal at the Tall Trees Grove was not significant relative to total sediment discharge in Redwood Creek, but may have served to decrease the threat of bank erosion by lowering the channel bed locally (Milestone, J.F., Redwood National Park, written commun., 1979).

Livestock Grazing

The prairies of the Bald Hills and nearby grasslands were heavily grazed by sheep and cattle between 1860 and 1980. Grazing was eliminated on park lands in the early 1980's. Cattle grazing continues on grasslands in the middle and upper basins and in the Orick Valley, where several dairies are located.

In other areas of the western United States, livestock grazing has been associated with increased runoff and erosion. Although similar effects may have occurred in Redwood Creek, we consider them to be insignificant in comparison to high natural rates of runoff and erosion and the effects of logging and roadbuilding. Cattle affect water quality in Redwood Creek and its estuary, however, both through the introduction of nutrient-rich waste and reduction of riparian shading. An accurate determination of the effects of past and present grazing would require additional research.

Table 3: Roads utilized for timber harvest in the Redwood Creek watershed, 1978-92

Year	New (mi)	Rebuilt (mi)	Existing (mi)
1978	13	2	32
1979	7	4	16
1980	7	5	22
1981	1	0	5
1982	5	4	8
1983	6	0	26
1984	15	9	16
1985	5	9	6
1986	6	15	20
1987	7	11	8
1988	21	13	24
1989	14	14	24
1990	6	9	13
1991	4	4	4
1992	10	12	12
TOTAL	127	111	236

Table 4: **Streams and stream crossings within timber harvest boundaries in the Redwood Creek watershed, 1978-92**

Year	Streams (mi)	Number of Stream Crossings
1978	38	108
1979	33	88
1980	33	91
1981	6	17
1982	16	55
1983	32	98
1984	21	107
1985	12	66
1986	39	125
1987	18	72
1988	36	198
1989	30	137
1990	26	108
1991	11	39
1992	30	112
TOTAL	381	1,421

Watershed Restoration

The legislation expanding Redwood National Park in 1978 (PL 95-250) authorized a major watershed restoration effort. Congress directed that this work focus on minimizing erosion from past land uses, re-establishing native vegetation, and protecting aquatic and riparian resources along park streams (Spreiter and others, 1995).

Early experimental projects in the first few years of the watershed restoration program (1977-81) utilized a variety of channel and hillslope measures designed to reduce surface and channel erosion and landsliding. These included contour trenches, wooden terraces, willow wattles, mulching, check dams, and channel armoring. Many of these techniques were found to be either ineffective or prohibitively expensive (Weaver and others, 1987). The most effective treatments were removal of road fill at stream crossings and other locations using heavy equipment (Weaver and others, 1987).

Since 1981, former log-haul roads have been the primary focus of the watershed restoration efforts within Redwood National Park. About 175 miles of logging roads have been treated since 1978. The total volume of sediment excavated from roads is roughly 1,300,000 cubic yards. Projects have involved correction of stream diversions, excavations of stream crossings, road outsloping, removal of perched debris, and road decompaction and waterbar construction (Steensen and Spreiter, 1992).

Roughly 270 miles of logging haul roads remain on park lands. Recent surveys located about 1,200 sites with potential or existing erosional problems along old haul roads in the park (Spreiter, 1996). These sites, and appropriate intervening road segments, will be treated in future watershed restoration projects.

Private landowners are currently cooperating with the parks and other agencies to improve hillslope stability and aquatic habitat in the Redwood Creek watershed. Initial erosion control projects on Bureau of Land Management and Stover Ranch roads were completed between 1991 and 1994. In 1995, the parks and all major landowners in the watershed signed Memorandums of Understanding that formalized the intent of all parties to work cooperatively to reduce erosion in the upper basin. Later that year, the parks received a grant from the U.S. Fish and Wildlife Service for erosion control and habitat improvement projects. This first project, on Simpson Timber Company land, was completed in September, 1995, through an agreement with the Humboldt County Resource Conservation District. A second project is scheduled on Stover Ranch property for the summers of 1996-97. In early 1996, an inventory of erosion problems along roads in the upper basin was completed by park geologists on lands managed by Sierra Pacific Industries, Simpson Timber Company, Natural Resources Management, Inc., Western Timber Services, Louisiana-Pacific Corporation, and the U.S. Forest Service. Information collected during the inventory will be used to plan road maintenance and erosion control projects.

Natural Resource Issues

NATURAL RESOURCES ISSUES

The long conflict over resource management in Redwood Creek provided ample documentation of concerns in reports, news articles, and letters. We selected five natural resources issues based on these sources, on consultations among park staff, on federal watershed analysis guidelines, and on comments and suggestions made in reviews of an earlier draft of this analysis. All five issues represent concerns of Redwood National and State Parks that are related to activities and concerns of other landowners in the watershed. For three of the issues, we identified key questions that must be answered in order to resolve the issue, and organized the analysis to discuss each key question sequentially. Where we felt existing information was inadequate to answer these questions, we identified data needs that can be addressed with future monitoring and research. For two of the issues, we did not define key questions because we felt that an adequate analysis of these issues requires interaction with interests outside the park that has not as yet been forthcoming. Lacking the necessary information and expertise to analyze these two issues, we have provided only general background information.

Issue 1: Preservation of Streamside Redwoods

The protection of streamside redwoods along Redwood Creek was a central issue for the establishment and expansion of Redwood National Park, and remains a primary objective of the park. A number of streamside redwoods died during and after floods in the 1960's and 1970's. The health of streamside redwood groves is clearly linked to the streamflow, sediment transport, and channel morphology of Redwood Creek. These in turn are affected by upstream conditions.

The vulnerability of streamside redwood groves to upstream land use was demonstrated by a flood in 1955 in Humboldt Redwoods State Park. The Rockefeller Forest and Founders Grove are old-growth redwood groves occupying alluvial flats along Bull Creek. The watershed upstream of the park was heavily logged prior to 1955. During the 1955 flood, sediment eroded from logged areas, filled the channel of Bull Creek, and caused the flood waters to erode the banks. Over 500 redwoods along the stream were toppled (Schrepfer, 1983). About 200 more died as a result of high groundwater levels after the flood of 1964 (Becking, 1968).

The 1964 flood closely followed the publication of articles by the National Geographic Society describing the discovery and measurement of the redwoods in the Tall Trees Grove along Redwood Creek (Grosvenor, 1964; Zahl, 1964). With public attention focussed on Redwood Creek and memories of Bull Creek still fresh, protection of the old-growth groves along the creek became a nationwide concern.

Key questions for this issue are listed here and repeated below with accompanying text.

1. **How many streamside redwoods died during and after recent floods?**
2. **Why did these redwoods die?**
3. **How was the damage to redwood groves related to flooding and sediment in Redwood Creek?**
4. **How are floods and sediment related to upstream land use?**

5. **What is the potential for future damage to streamside redwoods?**
   a. **Is the channel recovering from aggradation during the floods of 1964, 1972, and 1975?**
   b. **Are streamflow and sediment loads changing?**
   c. **What effects have changes in land use had on streamflow and sediment loads?**
   d. **How can damage to the park respurces be effectively reduced in the next major storm?**

Issue 1: Key Questions

1. How many streamside redwoods died during and after recent floods?

Despite the intense public and scientific scrutiny of Redwood Creek, the number of streamside redwoods that died in the 1960's and 1970's was never determined. Nolan and Marron (1995) refer to "numerous" trees toppled by bank erosion in the park and "numerous" flood-plain trees in the upper and middle basins killed by coarse-sediment deposition. According to Janda and others (1975, p. 243):

> *"Locally, between the mouth of the gorge and the prominent bend immediately upstream from the Tall Trees Flat recent deposition of coarse-grained deposits has killed groves of alder, maple, tanoak, Douglas-fir, and redwood trees at the streamside edges of upper flood plains. Downstream from the Tall Trees Flat only isolated individual trees appear to have been killed by recent deposition of coarse-grained alluvium."*

Photographs of fallen trees (Nolan and Marron, 1995; Redwood National Park files), as well as tree trunks and stumps now buried in gravel and inundated by the stream, prove that some trees died during the period of the recent large floods. On the basis of this evidence, the number of redwoods killed, of all ages, was perhaps between 20 and 50 within present park boundaries. Of these, at least 10 were old-growth trees.

Few redwoods along the stream currently show signs of reduced vigor resulting from adverse soil or groundwater conditions. Several redwoods in the Tall Trees Grove have roots exposed by bank erosion, and could be toppled in future floods (Milestone, J.F., Redwood National Park, written commun., 1979). About a dozen trees in the Tall Trees Grove, as well as some old-growth redwoods in other areas, have dead tops that may be related to exposure to sun and wind after old-growth forest on the west side of Redwood Creek was logged (Veirs, S., National Biological Service, personal commun., 1996).

2. Why did these redwoods die?

The most obvious and direct cause of death for streamside redwoods is the physical removal of supporting alluvial substrate by bank erosion. Fallen redwoods along the creek were documented during the 1970's with photographs (Redwood National and State Park files) and field mapping (Milestone, J.F., Redwood National Park, written commun., 1979). The location of these trees along eroding banks clearly indicates that they fell as a result of undermining by the stream.

Floods and groundwater affect the survival of streamside redwoods because their rooting zone can become saturated during periods of high streamflow. Redwoods are able to tolerate several months of rooting-zone saturation without apparent injury (Becking, 1967; Stone and others, 1969), but longer-term saturation can be harmful or lethal (Agee, 1980). Redwoods are shallow-rooted trees. A 1,000 year-old stand in Humboldt Redwoods State Park had large support roots to only 8 feet below land surface and small roots to 15 feet (Zinke, 1988). Groundwater within 15 feet of the land surface could therefore affect some redwood roots.

Groundwater levels below alluvial terraces supporting old-growth redwoods closely follow the water level of Redwood Creek (McFadden, 1983). The permeability of terrace alluvium is about 1,800 feet per day (McFadden, 1983), which is very high in comparison to most geologic materials. Water is able to flow rapidly between the stream and the local alluvial aquifer. Long periods of high streamflow therefore result in long periods of high groundwater levels within alluvial terrace deposits.

During a study in 1982, when streamflow in Redwood Creek was moderate to high, the groundwater level was within 5 feet of land surface for 10% of the time (McFadden, 1983). This result indicates that during periods of moderate to high streamflow, part but not all of the rooting zone of old-growth redwoods becomes saturated. Complete saturation of the rooting zone probably occurs infrequently, and is unlikely under existing conditions to persist long enough to cause the deaths of streamside redwoods.

Another suggested cause of death for streamside redwoods is burial of redwood roots with coarse sediments (Janda and others, 1975; Kolipinski and others, 1975). Coarse sediments lack nutrients and water-holding capacity, and may act as a physical barrier to the growth of adventitious roots. Coarse-sediment burial caused the deaths of an undetermined number of trees of several different species upstream of the park boundary following the 1964 and 1972 floods (Janda and others, 1975; Nolan and Marron, 1995). The thickness of coarse-sediment deposits within park boundaries was substantially less than in the upper and middle basins (Madej, 1995), and coarse-sediment burial was not a likely cause of death for many trees within the park (Milestone, J.F., Redwood National Park, written commun., 1979; Veirs, S., National Biological Service, personal commun., 1995).

In summary, the deaths of streamside redwoods within present park boundaries during the past four decades is attributable primarily to physical undermining by bank erosion. High groundwater levels and coarse-sediment burial probably affected streamside trees upstream of the park, but are unlikely to have killed many old-growth redwoods in the park.

3. *How was the damage to redwood groves related to flooding and sediment in Redwood Creek?*

The widespread hillslope erosion and streamside landsliding that accompanied the 1964 flood introduced huge volumes of sediment into the upper and middle reaches of the creek (Janda and others, 1975). The creek was unable to transport all of this sediment to its mouth, and instead stored much of it within and along the channel (Madej, 1995). As the channel filled with sediment, channel bed elevations increased (Madej and Ozaki, 1996), and the capacity of the channel to convey peak flows was reduced. The channel adjusted its width to accommodate flood peaks by eroding its banks (Janda and others, 1975). Along much of the upper and middle reaches, the channel doubled its width between 1947 and 1974 (Nolan and Marron, 1995). As the locus of sediment deposition shifted downstream between 1974 and 1981, streambanks eroded along the lower reach (Nolan and Marron, 1995), including the banks where streamside redwoods were undermined.

This sequence of events has apparently affected the Tall Trees Grove. Aerial and ground photographs, channel cross sections, and interviews with lumber company workers employed during the 1940's through the 1970's (Milestone, J.F., Redwood National Park, written commun., 1979) all indicate that the channel bed near the Grove aggraded by roughly 5 feet sometime after the 1955 flood. The channel has not widened much (Nolan and Marron, 1995), but banks have eroded enough to endanger old-growth trees. A total of 5 redwoods with roots exposed by bank erosion and 4 fallen redwoods were mapped in the Tall Trees Grove in 1979 (Milestone, J.F., Redwood National Park, written commun., 1979).

The channel aggradation also forced the stream to flow at higher elevations, closer to alluvial terrace surfaces and to the rooting zone of streamside redwoods. Streamside redwoods have therefore been placed at an increased risk of not only physical removal of their supporting substrate, but also burial with coarse sediment and saturation of their rooting zone.

4. How are streamflow and sediment transport in Redwood Creek affected by upstream land uses?

Timber harvesting can increase runoff and streamflow through concentration of surface flow along roads and skid trails, decreased infiltration as a result of soil compaction, reduced canopy interception of rain and fog, and reduced transpiration. Lee and others (1975, cited in Nolan and Janda, 1981) found evidence for a 20% increase in annual streamflow on Redwood Creek beginning in the mid-1960's, coincident with large-scale harvesting. Kolipinski and others (1975) concluded that timber harvesting increases storm runoff and peak-flow volumes, especially when soil moisture prior to the storm is moderate. Nolan and Janda (1981) reported that during 1975-76 streamflow from recently harvested basins within the Redwood Creek watershed was about twice the streamflow from an unharvested basin.

Mahacek-King and Shelton (1987) used a hydrologic model to infer that timber harvest had increased peak flows and reduced base flows in Redwood Creek. According to their model, the 1964 flood was increased by roughly 40% as a result of land use. This result may be in error, however, because the model fails to account for the snowmelt that contributed to the flood. Their results are also suspect because the model predicts streamflow substantially in excess of basinwide precipitation in some months.

The weight of the available evidence from previous studies indicates that total streamflow and moderate stormflow peaks have been increased to some degree by timber harvesting and roads. The major floods that damaged streamside redwood groves probably were not affected much by land use. Rainfall and snowmelt amounts were so great during those floods that large areas of the watershed would have been saturated, and would have contributed surface runoff, even under natural conditions (Nolan and Janda, 1981).

Timber harvesting and roadbuilding can also increase erosion and fluvial sediment loads. Harvesting accelerates landsliding, as a result of reduced root strength on unstable hillslopes, and increases surface erosion of bare soil on steep slopes. Roads can cause significant erosion if they are not properly designed, located, and maintained. Stream-crossing fills can be eroded if culverts plug or fail, and water diverted by crossings, cutbanks, and ditches can erode large hillslope gullies. Unstable road fills can fail as landslides.

Sediment-discharge measurements on Redwood Creek tributaries during the 1970's showed that harvested basins had appreciably higher sediment loads than unharvested basins (Kolipinski and others, 1975; Nolan and Janda, 1981). Nolan and Janda (1981) suggested that timber harvest increased sediment loads by roughly a factor of two if differences in streamflow were removed from the analysis, but that the combination of increased runoff and increased erosion in harvested areas had a total effect of increasing sediment loads by a factor of 10.

The results of our sediment-budget analysis (table 1) indicate that erosional processes related to land use accounted for roughly half of total sediment production during the 1954-80 period, if mass movements and streambank erosion are considered to be natural processes. These processes, however, may also have been affected by land use. Many landslides occur during large storms (Harden and others, 1978), and because the storms of 1955 and 1964 were meteorologically similar, differences in landslide volumes for the two storms can be reasonably attributed to changes in land use. Timber harvesting and roadbuilding in the years between the two storms was extensive. Volumes of streamside landslides for selected tributaries of Redwood Creek were published by Pitlick (1982, Table 4, p. 10) for periods between aerial photography dates. We compared landslide volumes for 1954-58 with volumes for 1962-66. Each of these periods included one major storm. Total landslide volume for the 1962-66 period was about 4 times larger than total landslide volume for 1954-58. On the basis of this comparison, land use activities as practiced in the 1950's and 1960's increased landslide volumes by a factor of 4, and therefore added substantially to sediment loads in Redwood Creek.

Although streambank erosion occurs as a natural consequence of alluvial channel behavior, increased streamflow related to land use may have accelerated streambank erosion rates along Redwood Creek and its tributaries (Nolan and Marron, 1995). Unfortunately, we lack the data necessary to differentiate natural from accelerated streambank erosion, and for purposes of the sediment budget, we have included streambank erosion with the natural processes.

In summary, land use activities as practiced in the 1950's-70's increased streamflow and sediment loads in Redwood Creek and its tributaries. The changes attributable to land use are difficult to quantify. Streamflow was probably increased by about a factor of 2 in heavily disturbed tributary watersheds and by roughly 20% in the watershed as a whole. Sediment loads were probably increased by a factor of 2 to 10. These increases almost certainly contributed to flooding, sedimentation, bank erosion, and redwood deaths in the park.

As noted previously, some redwoods were probably killed in floods of the nineteenth century, before widespread timber harvesting in the watershed. With redwood groves situated on fine-grained alluvial terraces along the creek, some old-growth trees would probably have been toppled by the floods of the mid-twentieth century even under natural conditions. The increase in sediment loads attributable to land use, however, indicates that the number of trees killed in the twentieth century floods exceeded the number that would have been killed under natural conditions.

5. *What is the potential for future damage to streamside redwoods?*

a. *Is the channel recovering from aggradation during the floods of 1964, 1972, and 1975?*

As of 1995, the channel of Redwood Creek was recovering along most of its length from the aggradation induced by the floods of the 1960's and 70's (Nolan and Marron, 1995; Madej and Ozaki, 1996; channel cross-section survey files, Redwood National and State Parks). In the upper reach, the channel has scoured to its estimated pre-1964 bed and exhumed bedrock in many locations. In the lower reach, the wave of aggradation that has been moving toward Orick for three decades appears to be attenuating as a result of sediment storage, selective transport, and particle attrition. Without a new introduction of large amounts of sediment, the channel configuration will probably be relatively stable in the near future. Although renewed bank erosion near streamside redwood groves remains possible, it is not likely to cause the loss of many trees if current trends continue.

b. *Are streamflow and sediment loads changing?*

Streamflow records from Little Lost Man Creek (fig. 1) were compared to records at the Orick and O'Kane stations to determine whether trends in streamflow on Redwood Creek could be detected or reasonably attributed to changes in land use. The watershed of Little Lost Man Creek is unaffected by timber harvests or roads upstream of the gaging station, and streamflow on Little Lost Man Creek therefore represents streamflow from old-growth forest under natural conditions.

The ratios of streamflow per unit of contributing drainage area at both the Orick and O'Kane stations to streamflow per unit area at Little Lost Man Creek decreased between 1975 and 1988 (Fig. 10). Between 1984 and 1988, the ratios were slightly above or less than 1.00 (Fig. 10). These trends indicate that hydrologic conditions in the upper basin and the basin as a whole have approached the conditions of the undisturbed Little Lost Man watershed.

Regression residuals indicate changes in both suspended-sediment and bedload transport rates (Figs. 6 and 7). Suspended-sediment loads, relative to natural streamflow, have declined at Orick and O'Kane. Bedload relative to natural streamflow has decreased at O'Kane, but not at Orick.

c. *What effects have changes in land use had on streamflow and sediment loads?*

While the expansion of Redwood National Park reduced the number of board feet harvested in the Redwood Creek watershed, the number of acres harvested before and after the park expansion did not change much. The average annual acreage harvested in the basin in the 14 years after park

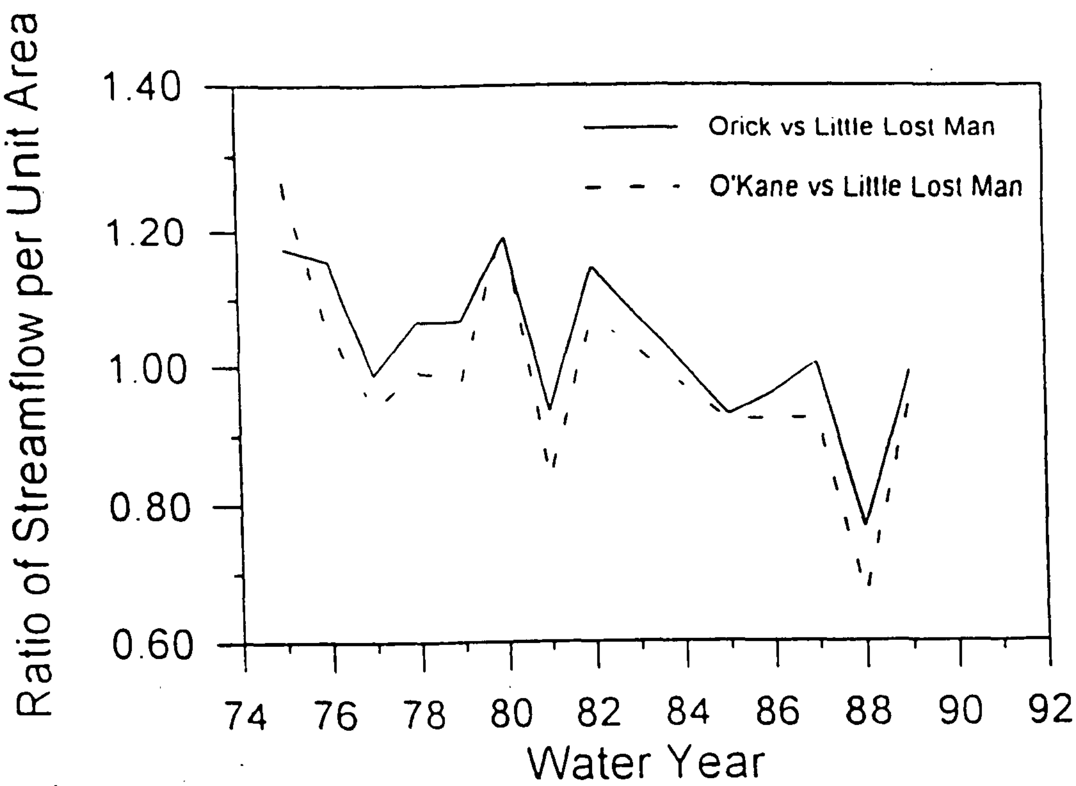


Figure 10. Graph showing ratio of streamflow per unit area on Redwood Creek to streamflow per unit on Little Lost Man Creek, 1975-1988

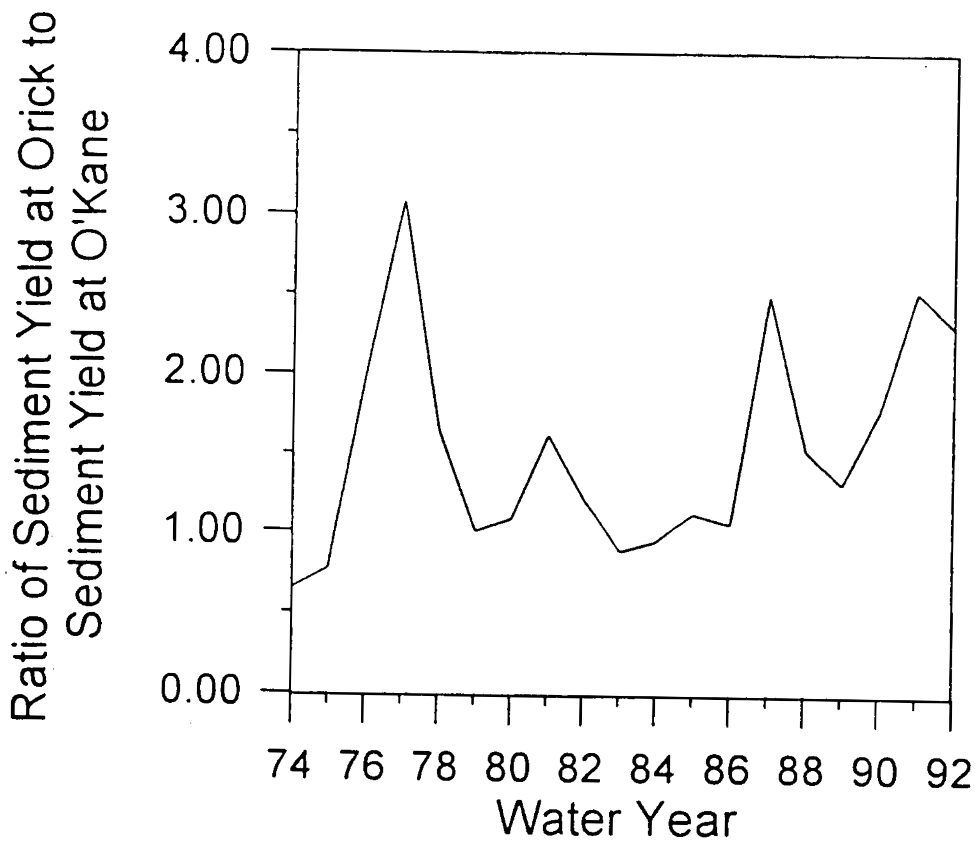


Figure 11. Graph showing ratio of total sediment yield at Orick to total sediment yield at O'Kane

expansion was virtually the same as the average for the 8 years preceding expansion (table 5). After the park lands in the lower basin were removed from the commercial timber land base, harvesting shifted to the upper and middle basins. Harvesting increased by 88% in the upper basin and by 178% in the middle basin after 1978 (table 5).

Table 5: Average annual acres of timber harvest in the Redwood Creek watershed, 1971-78 and 1979-92 |sources: Best, 1984, and Redwood National Park timber harvest plan files|

	Upper Basin	Middle Basin	Lower Basin	Middle + Lower Basin	Entire Basin
1971-78	350	501	1,205	1,706	2,056
1979-92	660	1,393	0	1,393	2,053
Percent change	**+88**	**+178**	**-100**	**-18**	**-0.1**

Forest practice rules that regulate harvest and roadbuilding practices have also changed within the past two decades. New rules adopted in 1973 and 1983 by the California Board of Forestry include additional restrictions on equipment operations and harvesting along major streams and on unstable areas, and require that stream crossings on log-haul roads be capable of passing a 50-year flood without eroding. These rules were intended to reduce off-site impacts on riparian resources.

The streamflow ratios shown in figure 10 demonstrate that the increased streamflow related to land uses in the early 1970's has gradually declined. At present, annual streamflow per unit area for the upper basin and for the entire watershed are not much different than streamflow per unit area in an undisturbed old-growth watershed. The decreases in streamflow per unit area at Orick and O'Kane, relative to Little Lost Man Creek, are probably attributable to decreased land surface disturbance.

The regression residuals analysis indicates decreased suspended-sediment loads at Orick (Fig. 6) during a period when harvest acreage was unchanged for the watershed as a whole. This downward trend therefore provides evidence that land use since 1978 has not substantially increased suspended-sediment loads in Redwood Creek. Alternatively, the trend may indicate that the watershed restoration program within the park has reduced erosion dramatically in the lower basin. Most likely the observed trend is a result of both improved land use in the upper and middle basins and watershed restoration and cessation of logging in the lower basin, as well as the lack of a major storm in the years following 1975.

Suspended-sediment residuals for O'Kane indicate either no change or a downward trend in sediment transport relations during a period when timber harvests increased substantially and rainfall has been moderate. If this intensified land use had caused a major increase in erosion, an upward trend would have been detected. Because no upward trend was apparent, the increase in harvesting in the upper basin probably had only limited effects on sediment transport.

The downward trend in bedload transport at O'Kane could also be related to improved land use. A more likely cause, however, is the decreased sediment supply due to scouring of coarse sediment deposited in 1964. Much of this sediment is still stored within the lower channel, where it continues to supply coarse sediment for transport as bedload (Madej, 1995). Hence, the lack of a downward trend in bedload at Orick is probably attributable to continued flushing of sediment delivered to the channel system in 1964.

Average annual total-sediment yields for O'Kane and Orick, computed for the period 1974-92, are remarkably similar: 3,210 tons per square mile at O'Kane and 3,120 tons per square mile at Orick (fig. 11). The upper basin, which is almost entirely private timber and ranch lands, has therefore contributed over the past 20 years about the same amount of sediment per unit area as the watershed as a whole, which includes Redwood National and State Parks. This similarity holds true when the sediment load is divided into suspended-sediment and bedload components. Taken together with the trends in sediment transport, it indicates that recent land use in the upper basin has not yet caused a major influx of sediment into the channel system of Redwood Creek.

While current land uses therefore do not seem to be presently damaging streamside redwoods in the park, the effects of earlier periods of land use still have potential to cause major resource damage. Road mileage upstream of the park has increased by 50% since the 1964 flood. Most of these road miles were built before the current forest practice rules were in effect, and over one-third are unmaintained and are no longer driveable. Records of timber harvest plans indicate that many stream crossings and road segments have failed since they were originally constructed. Many more failures are likely as the road network ages.

We analyzed existing road crossings and past failure volumes in the watershed to estimate the amount of sediment that could be eroded from upper and middle basin road-stream crossings in a storm similar to the 1964 storm. On the basis of the average number of crossings per square mile and measured erosion from failed crossings, a total of 908,000 tons of sediment could be mobilized in a future major storm.

Although not all crossings would actually fail during the next large storm, most of the old and unmaintained crossings probably would. Streamflow would also be diverted along roads and onto hillslopes at many crossings, resulting in even greater volumes of eroded sediment. Our estimates of past road-related fluvial erosion (table 1) indicate that gullies resulting from stream diversions at road-stream crossings accounted for roughly four times as much sediment as erosion of the stream crossings themselves. In addition, renewed delivery of hillslope sediment to the channel would initiate a new episode of streamside landsliding (Janda and others, 1975). The threat to streamside redwoods posed by unmaintained and abandoned roads, therefore, remains significant.

To summarize, trends in streamflow and sediment transport indicate that current land uses under conditions of moderate rainfall are not presently damaging streamside redwoods in the park. These trends could be reversed by renewed delivery of sediment from hillslopes to the channel system during the next major storm. A substantial amount of erosion is likely from natural processes that cannot be controlled as well as from processes linked to land use.

d. How can damage to park resources be effectively reduced in the next major storm?

Roads remaining from past logging continue to pose a major threat to alluvial groves. Roads built before current forest practice rules were in effect comprise over half of the road mileage in the watershed. These older roads have a high risk of crossing failures and stream diversions at crossings. The sediment budget (table 1) indicates that gullies resulting from such diversions were a major sediment source in past storms. Removal of diversion potential can be done relatively quickly and inexpensively, and treatments leave roads passable to vehicles. Given the high probability of a major storm in the next few years, the erosion potential related to roads can be most effectively reduced by removing diversion potentials at road-stream crossings.

Issue 2: Protection and Restoration of Aquatic Habitat

Aquatic habitat is an important component of the Redwood Creek watershed because of its role in supporting anadromous and resident fisheries. Redwood Creek fisheries support both commercial ocean fishing and sport fishing along the creek and its tributaries. Sport fishing in the watershed attracts both local residents and visitors, and brings substantial income to the county.

Floods, erosion, and land use have potential to adversely affect aquatic habitat. The erosion and sediment deposition that accompanied the recent floods have altered habitat conditions by filling pools, burying riffles, reducing cover and riparian shading, and mixing fine sediments with gravels used for nesting.

Fish populations in Redwood Creek are well below historic levels, and several salmon and trout species are presently under consideration for listing as threatened species (Appendix C). Habitat conditions throughout much of the channel system are poor, especially for fish that use the creek for summer rearing. The Redwood Creek estuary, an important summer rearing habitat, has been adversely affected by construction of flood-control levees. Commercial and sport fishing have been drastically reduced in recent years.

Key Questions:

1. **What conditions limit fish distribution and populations?**
2. **How are these conditions related to land use?**
3. **How have these conditions changed in recent years?**

Issue 2: Key Questions

1. *What conditions limit fish distribution and populations?*

Fish distribution and numbers are determined by habitat availability and quality. Habitat availability is limited by streamflow, stream gradients, and physical barriers such as boulders and log jams. Habitat quality is limited by channel substrate, water temperature, dissolved oxygen, food supply, and predation.About 59 miles of the mainstem of Redwood Creek and 50 miles of tributaries are accessible to anadromous fish (Brown, 1988). No natural or artificial barriers to fish migration, such as waterfalls, dams, or debris jams, are located along the mainstem except in the uppermost 2-3 miles of the headwaters, where steep channel gradients prevent migration. However, with the exception of Prairie Creek, which enters near the mouth of Redwood Creek, tributary streams are generally short and steep and provide relatively little habitat for anadromous salmonids. The lower reaches of most major tributaries are accessible to fish, but many tributaries become impassable a short distance upstream due to steep gradients and debris jams (Brown 1988; fig. 12). Pitlick (1982) concluded that 95 percent of the sediment stored in tributaries was deposited in downstream reaches, and as a result, some tributaries are presently impassable for juvenile salmonids during summer low flows.Streamflow infiltrates into thick gravel deposits at tributary confluences, leaving insufficient surface flow for migration of juvenile salmonids. Excessive sediment deposition in tributaries has also reduced the quality of rearing areas.

The only engineered structure on a tributary to Redwood Creek is a small dam at the former Prairie Creek fish hatchery on Lost Man Creek. The dam creates a partial barrier to upstream migration of fish. Summer dams and road culverts also create partial barriers to migration of fish.

Spawning occurs along the lower reaches of tributaries and along the mainstem of Redwood Creek. Distribution of spawning in Redwood Creek has been determined based on juvenile distribution studies by Anderson (1988) and Brown (1988), and direct observations by fisheries professionals. Presence of juvenile steelhead in Twin Lakes Creek (fig. 1) indicate that steelhead spawn in the uppermost headwaters of Redwood Creek. Based on winter observations, chinook salmon utilize the mainstem at least up to Noisy Creek (fig. 1). Both coho salmon and cutthroat trout are found primarily in Prairie Creek and its tributaries, possibly owing to the lower gradient and more pristine nature of that watershed (Anderson and Brown, 1983). Although few in number, juvenile coho salmon observed upstream of Highway 299 indicate that some spawning occurs in the reach above Highway 299.

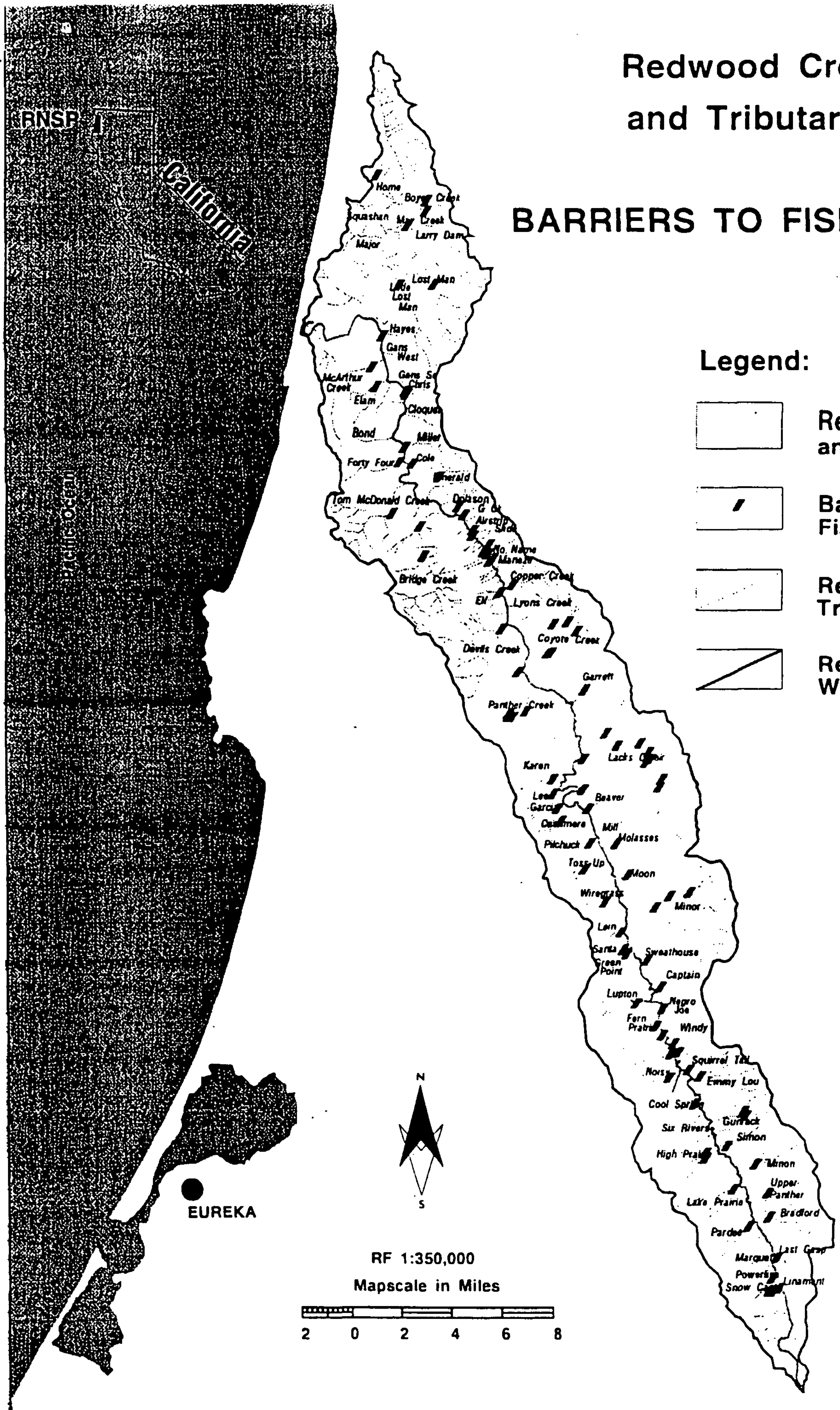
Salmonids utilize most of the mainstem and the lower reaches of major tributaries for rearing. A study of juvenile rearing habitat in the summer and fall of 1980-81 concluded that all identified summer rearing habitat for juvenile steelhead, coho and cutthroat in the watershed occurred in third order or larger tributaries and along the of Redwood Creek (Brown, 1988). Anderson (1988) documented that salmonid fish utilized 58 of 111 tributaries sampled. Juvenile steelhead were the most common and widely distributed. In contrast, cutthroat trout and coho salmon primarily occurred in the Prairie Creek system. No juvenile chinook were observed in the tributaries or mainstem of Redwood Creek during this study, because chinook had migrated to the estuary by the time stream surveys were conducted in the late summer. Anderson (1988) documented that the young-of-the-year were significantly larger in the cooler westside tributaries than the eastside tributaries. Brown (1988) found that of 47 accessible tributaries surveyed, ten (21 percent) contained 79 percent of the juvenile rearing habitat. The ten tributaries with accessible habitat were all low gradient (less than 0.11 ft/ft).

The Redwood Creek estuary provides valuable rearing habitat for salmonids (Hofstra, 1983; Hofstra and Sacklin, 1987). Studies have shown that extended estuarine rearing increases survival of juveniles and number of returning spawners (Reimers, 1973).

Figure 12

Redwood Creek and Tributaries

BARRIERS TO FISH PASSAGE



Legend:

- Redwood National and State Parks
- Barrier to Fish Migration
- Redwood Creek Tributary
- Redwood Creek Watershed Divide

Source:
RNP Geographic Information Systems
Themes: B11; F05; H16; W01
DRAFT 00119.gis fish.aml 7.96 jw

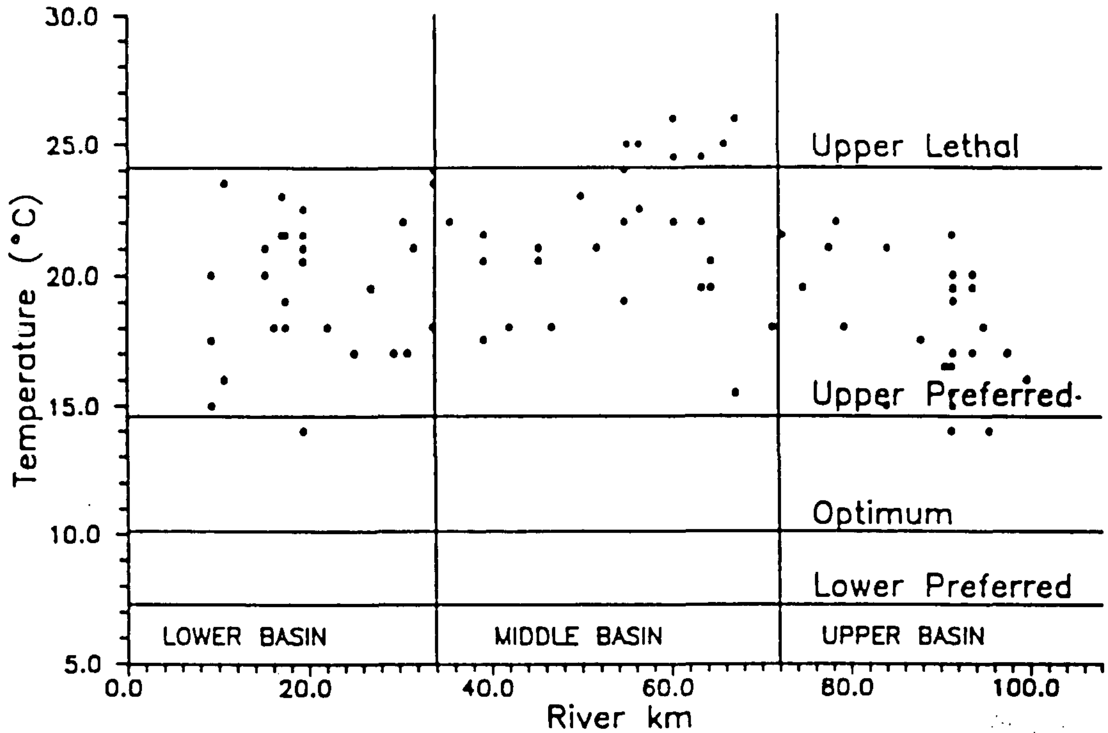


Figure 13. Graph showing water temperatures in relation to salmonid habitat

Channel substrate affects the spawning success of salmon and trout, which lay their eggs in gravel nests, or redds. Particles smaller than 8 millimeters in diameter can fill interstices between gravel particles and reduce the flow of water-borne dissolved oxygen that is necessary for egg survival. Fine sediment can also physically block emerging fry. Large amounts of fine sediment were incorporated into the bed material of Prairie Creek as a result of erosion related to highway construction (Klein, 1987).

Summer water temperatures are a problem for juvenile steelhead and coho salmon, because these species remain in the stream system for at least one year after hatching. Adult summer steelhead are also particularly vulnerable during low-flow conditions to stressful summer water temperatures because they reside in the pools throughout the summer. Reisser and Bjornn (1979) determined the preferred ranges, optimum and upper lethal temperatures for rearing salmonids. Based on laboratory experiments, the upper preferred water temperatures for steelhead and coho salmon was 14.6 °C. The upper lethal temperatures for steelhead and coho were 24.1 and 25.8 °C, respectively.

Anderson (1988) determined that in the mainstem of Redwood Creek during the summers of 1980 and 1981, water temperatures were generally between the upper preferred and upper lethal temperatures for juvenile steelhead (fig. 13). In some reaches, water temperatures exceeded the upper lethal temperature. For example, the U.S. Geological Survey measured a water temperature of 33.5 °C at the O'Kane gaging station in 1977 (Madej, Mary Ann, National Biological Service, written commun., 1996).

Long-time residents of the Redwood Creek watershed recall cooler summertime water temperatures before 1964 (Van Kirk, Susie, written communication, 1994). Trends in water temperature can be inferred by comparing data collected in 1974 and in 1990. During 1974, water temperatures ranged from 19.5 °C at Orick to 28 °C in Redwood Valley (Bradford and Iwatsubo, 1978). Water temperatures above Panther Creek were greater than 24 °C during this time period, with the highest water temperatures measured in the Redwood Valley reach. During 1990, mainstem and tributary water temperatures were measured as part of the summer steelhead survey (Anderson, 1993). The highest water temperatures, ranging from 20.5 to 24.5 °C, were measured in the mainstem. East-side tributaries were cooler, with a mean of 18.0 °C and ranging from 15.5 to 20.0 °C. West-side tributaries were coolest with a mean of 15.2 °C and ranging from 12.0 to 18.0 °C. Summer water temperatures have apparently cooled several degrees since the mid-1970's, although they still remain well above the preferred temperature of juvenile salmonids and at times exceed the upper lethal temperatures of steelhead and cutthroat trout (Reiser and Bjorn, 1979).

Cold pools in the lower reaches of Redwood Creek offer potential high quality rearing habitat and holding areas for juvenile salmonids and migrating adult summer steelhead (Keller and Hofstra, 1982; 1984; Ozaki, 1988). Juvenile salmonids have been observed utilizing cold pools during hot summers on other northcoast rivers (Nielsen and others, 1994). Cold pools form when gravel bars isolate cool tributary or intragravel flow from streamflow in the mainstem. These cold pools represent less than 8% of the total pools on the lower creek and are ephemeral features which form, change locations, or are destroyed during moderate winter flows.

Riparian vegetation plays a crucial role in providing channel stability, shade, woody debris, and nutrients to Redwood Creek and its tributaries. Riparian vegetation therefore exerts a major influence on aquatic habitat in the watershed.

Unfortunately, no information on winter rearing habitat in Redwood Creek is available. While winter rearing is not restricted by water temperature, it may be restricted by runoff regimen and channel morphology. Future monitoring will be required if information on winter rearing is determined to be needed for management activities.

Dissolved oxygen is critical for most forms of aquatic life. Salmonids require dissolved oxygen concentrations of generally 8 mg/L or higher for survival (e.g., Reisser and Bjorn, 1979). Dissolved oxygen concentrations are frequently at saturation during winter months, when high turbulence provides aeration of stream water (Iwatsubo and others, 1976; Bradford and Iwatsubo, 1978). During summer, high temperatures, reduced turbulence, and decaying organic material can reduce dissolved oxygen concentrations to 7 mg/L or less. Summer dissolved oxygen levels are normally higher in tributaries than in the main channel of Redwood Creek (Bradford and Iwatsubo, 978). Weekly mean dissolved oxygen concentrations measured within streambed gravels in three tributaries of Redwood Creek ranged from 3.2 to 11.4 mg/L (Woods, 1980).

Although clear evidence is lacking, food availability in Redwood Creek appears to be adequate to support reasonable populations of fish. Streambed scour may reduce densities of benthic invertebrates (Cordone and Kelly, 1961), and reduction in riparian vegetative cover may have decreased the terrestrial input of food into the stream system.

Benthic invertebrates are an important food source for fish. Numbers of benthic invertebrates do not appear to be clearly related to distance upstream from the ocean or to land use of tributary basins where samples were collected; rather, abundance of benthic invertebrates may be related to bed material size. In their 1974-75 study, Iwatsubo and Averett (1981) found that benthic invertebrates were more abundant at sites with coarse bed material. Insolation and algal productivity may also affect invertebrate distribution. Numbers of benthic invertebrates were generally higher in autumn than in spring; invertebrate densities upstream of the Redwood Creek estuary in springtime samples ranged from 190 to 6,000 invertebrates per square meter, whereas densities measured in the fall ranged from 22 to 51,000 invertebrates per square meter (Iwatsubo and Averett, 1981). Invertebrate densities were higher in the Redwood Creek estuary than in the channels upstream. Benthic invertebrate communities recovered rapidly following a large storm and flood in 1975 (Iwatsubo and Averett, 1981).

Salmonids in Redwood Creek are subject to natural predation by mammals and birds. Although the number of predators in the freshwater environment has probably decreased in historic times, the reduced number of deep pools following the 1964 flood has possibly made fish more vulnerable to predation. Anadromous fish are also subject to predation in the ocean, particularly by marine mammals and humans. Poaching occurs on Redwood Creek and also reduces wild fish stocks, particularly summer steelhead.

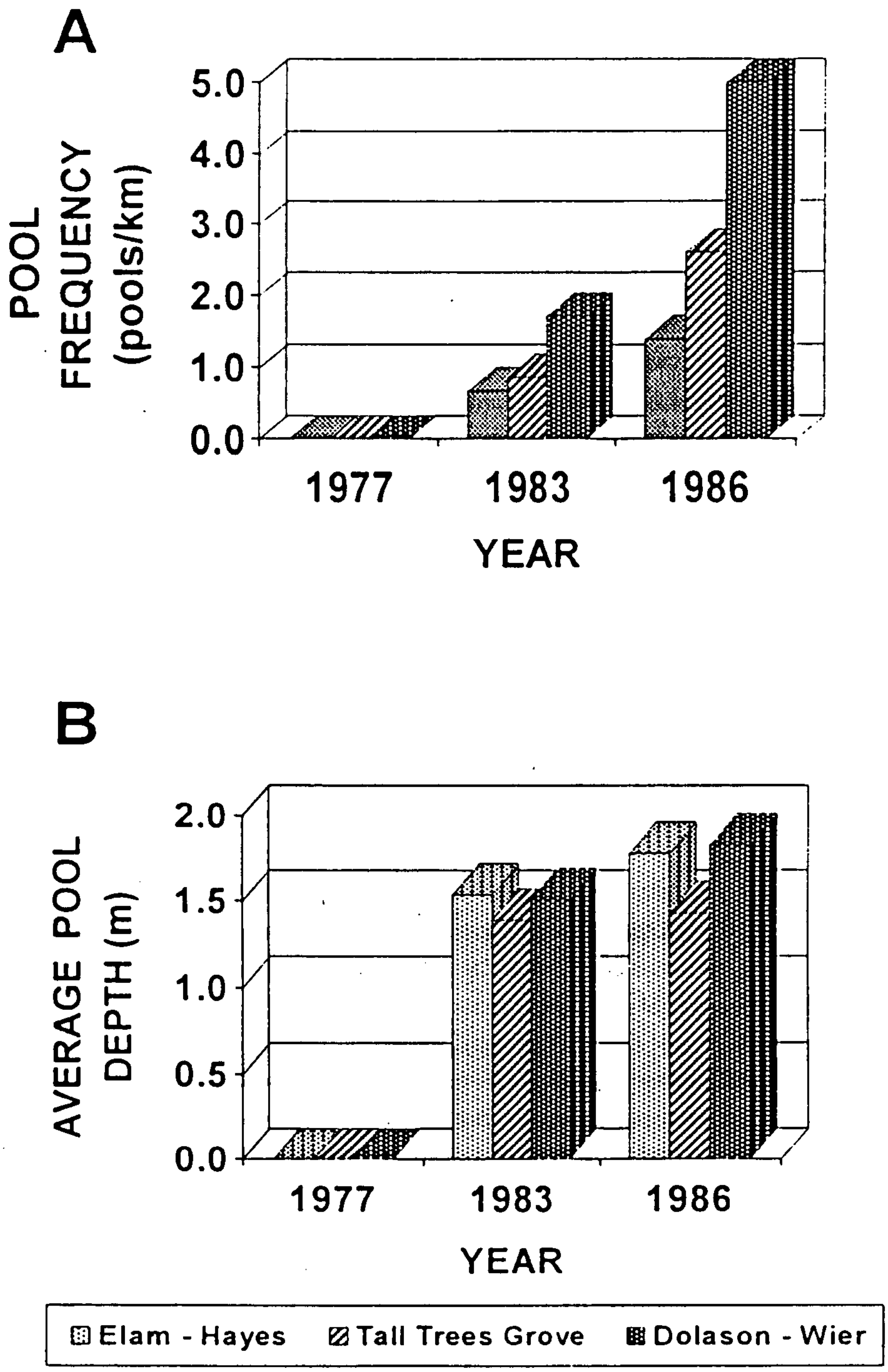


Figure 14. Graph showing frequency of pools and riffles (A) and average pool depth (B) in Redwood Creek, 1977, 1983, 1986.

2. *How are these conditions related to land use?*

As discussed previously, erosion related to logging and roads increased sediment loads, added to channel sediment storage, and resulted in channel widening and loss of riparian vegetation. These changes adversely affected aquatic habitat by reducing channel substrate sizes, filling pools, reducing shade, increasing water temperature, and decreasing dissolved oxygen concentrations.

The California Department of Fish and Game and National Park Service conducted a survey on Redwood Creek in 1972 (on-file, California Department of Fish and Game, Eureka, California). They reached the following conclusions:

> *"Redwood Creek is not suitable as a trout stream. Steelhead production is severely limited and salmon production is reduced. The upper 10 miles is choked with logging debris, collapsed bridges, and sediment... About 60 percent of the adjacent slopes are unstable or sliding. Approximately 80 percent of the immediate watershed has been logged in a manner detrimental to the stream. The production of fish and fish food organisms is extremely limited by the lack of pools and shelter, the great amount of fine sediments in the stream bottom and by the unstable nature of the streambed."*

Although conditions have changed since the time of this report, some of the problems describes still persist.

Rearing habitat in the Redwood Creek estuary has been affected by flood-control levees along the lower 3.2 miles of the creek. The levees, completed in 1968, adversely affected fish populations through loss of available habitat, decreased dissolved oxygen, increased temperatures and salinity in the north and south sloughs (Ricks, 1985; Hofstra and Sacklin, 1987), altered circulation and sedimentation patterns, and changes in channel morphology between the levees. About half of the lower estuary has filled or become isolated from the main channel as a result of the influence of the levees (Ricks, 1985). Sediment accumulating at the creek's mouth forms a berm that results in frequent inundation of adjacent privately-owned pastures during the summer. The berm separating the estuary from the ocean periodically is artificially breached. At other times the berm breaches naturally. This uncontrolled breaching of the berm causes a loss of habitat and juvenile salmonids to be swept to sea where their survival rate is much reduced (Hofstra and Sacklin, 1987). To prevent adverse impacts on fish, the park began a program of controlled breaching in 1982. Controlled breaching lowers the water level in the estuary at a slower rate than unregulated breaching. The park is currently seeking a permit to conduct controlled breaching that would minimize impacts to fish while still reducing flooding of private lands.

3. *How have these conditions changed in recent years?*

Channel deposition has destroyed much of the pool/riffle configuration of the creek, drastically reducing rearing habitat for fish. In 1977, channel aggradation had filled essentially all pools in sampled reaches of the lower mainstem (fig. 14a). By 1986, pools had re-established in all sampled reaches (fig. 14a), and average residual pool depths were about 4 feet (fig. 14b).

Changes in channel bed elevations in Redwood Creek are reflected in changes at the mouths of tributaries. Cross sections have been surveyed on selected tributaries of Redwood Creek for over 20 years. When Redwood Creek aggraded, the tributary beds near their confluences with the mainstem also aggraded. Increased sedimentation at the tributary mouths can cause streamflow to infiltrate into the additional coarse bed material, so that summer low flows are decreased. In some cases, tributary mouths dry completely in summer, and fish are trapped. Sediment accumulation at tributary confluences impedes the movement of fish during low flow periods. As the bed of Redwood Creek has scoured in recent years, tributaries are beginning to scour the deposits at their mouths. Bridge Creek has scoured more than 8 feet, and Tom McDonald and Harry Wier Creeks have scoured more than 2 feet since 1975 (Madej, M.A., National Biological Service, written communication, 1995).

The particle-size distribution of streambed material in Redwood Creek prior to the 1964 flood is unknown, but the stream bed probably consisted of mostly gravel and cobbles throughout much of the channel. Local residents noted a decrease in bed material sizes after 1964 (Nolan and Janda, 1979).

Data on bed material size distribution were collected by Iwatsubo and others (1976) and Kelsey and others (1981). These data cannot be compared quantitatively because of changes in sampling methods and locations. Iwatsubo and others (1976) reported bed material size data for three mainstem stations and four tributary stations. They excluded particles larger than 152 mm. They reported that the percentage of particles larger than 6.72 mm ranged from 21 to 63 percent at the mainstem stations and from 18 to 98 percent at the tributary stations. Kelsey and others (1981a) measured the size distribution of particles larger than 4 mm, and reported that median grain sizes of bed material along the mainstem varied from 16 to 128 mm. They reported a gradual downstream decrease in grain size along the channel.

Site-specific data on surface and subsurface bed material particle size distributions for two reaches of Redwood Creek near the Tall Trees Grove were presented by Lisle and Madej (1992). Median sizes ranged from 6 to 38 mm for surface material and from 6 to 24 mm for subsurface material.

Additional data on bed material particle size distributions were collected as part of the U.S. Geological Survey (USGS) forest geomorphology project and the Redwood National Park (RNP) sediment budget project. Nolan and Marron (1995) reported that mean bed material grain size at 11 of 13 cross sections surveyed by the USGS increased between 1976 and 1982.

Recent data collection by park staff allows comparison of USGS data collected in 1979 with present conditions. Pebble counts were repeated in 1994 at 8 cross sections using methods identical to those used by the USGS in 1979. At two cross sections, the percentage of bed material finer than 8 mm (that is, in the size range that is potentially harmful to fish) increased slightly, while at four cross sections the percentage of fines decreased. The fines percentage was unchanged at one cross section. The median particle size at seven of the cross sections increased between 1979 and 1994, while median particle size was unchanged at one cross section. Although the evidence is not compelling, this comparison indicates a slight trend toward coarsening of bed material in Redwood Creek.

Analysis of aerial photographs and interviews with long-time residents indicate that the riparian zone of Redwood Creek has been substantially altered in the past 40 years. Prior to intensive timber harvesting in the watershed, riparian vegetation was dominated by conifers. Most of this riparian forest has since been harvested, except within the original 1968 national park boundary, which included 26% of the length of the creek. The riparian zone along the entire channel has been affected by flooding and sedimentation. The original riparian vegetation along Redwood Creek has therefore been reduced by a combination of harvesting, bank erosion, and landslides. Riparian vegetation has re-established in recent years, but regrowth is generally broadleaf species such as alder (Alnus) or willow (Salix) rather than conifers. A program of conifer planting on terraces in Redwood Valley was initiated in 1994 by Barnum Timber Company.

Canopy closure, determined as the percentage of channel length covered by vegetative growth, is a useful measure of the effectiveness of riparian vegetation in providing shade and nutrients to the channel. Canopy closure along 7 miles of the mainstem was measured on sequential aerial photographs for three contiguous reaches in the upper basin. In 1954, canopy closure was primarily provided by conifers, and ranged from 34 to 82%. In 1966, after several years of intensive timber harvest and the large floods of 1955 and 1964, channel closure was completely absent in all of the study reaches. By 1978, channel closure was still absent in two of the reaches and was only 1% in the remaining reach. In 1992, canopy closure in the three reaches ranged from 9 to 54%, and was provided primarily by broadleaf species. In the lower basin, the Redwood Creek channel was wide enough even before 1955 to prevent complete canopy closure.

Few data are available to describe past and present salmonid populations in Redwood Creek. Most of the available population data are either from Fish and Game reports from the 1960's and 1970's or from more recent fish surveys conducted since 1983 by Redwood National Park. In 1965, the California Department of Fish and Game (CDFG) estimated spawning escapement of 5,000 chinook, 2,000 coho and 10,000 winter steelhead. However, these estimates were derived using data from the Eel River, and cannot be considered as reliable as field data from Redwood Creek. The 1979 Chinook salmon spawning run was estimated to be 1,850 fish (Ridenhour and Hofstra, 1994) based on that summer's estuarine juvenile population. A total of 9,610 coho juveniles were seined from Prairie Creek and its tributaries in 1951 (Hallock and others, 1952). As many as 2,000 coho salmon may still be returning annually to Redwood Creek, according to Ridenhour and Hofstra, although many of these are probably hatchery fish. Aside from the 1965 CDFG population estimates for winter steelhead, no other data are available. Adult summer steelhead are much less numerous than the winter run steelhead. Over the past 14 years, adult summer steelhead surveys in a 16 mile index reach determined a high of 44 summer steelhead; however, in a some years, no summer steelhead were observed (Anderson, 1993; 1995). Adult summer steelhead have been identified as a species of concern throughout their range (CDFG, 1993).

Recent fish population studies on Redwood Creek include ongoing monitoring of juvenile fish populations in the Redwood Creek estuary, tributary spawning surveys, adult summer steelhead surveys, and hatchery trapping records on Lost Man Creek. Fish surveys have been conducted primarily within the park, with only limited surveys upstream of the park. The most intensive monitoring has been conducted in Prairie and Bridge Creeks, two of the tributaries with higher quality salmonid habitat. Since 1983, annual winter spawning surveys of steelhead, chinook and coho, on Prairie and Bridge Creek, have documented numbers of live fish, carcasses and redds.

Numbers of live fish in Prairie Creek exhibit considerable year-to-year fluctuations. The highest number of live chinook, coho and steelhead observed since 1983 were 101, 99, and 33 respectively. In contrast, numbers of live fish in Bridge Creek peaked in the mid-1980's and have declined since then. On Bridge Creek, the highest number of chinook salmon observed was 272 fish in 1986 and the number of live steelhead and carcasses was 126 in 1985. Fish populations in Bridge Creek have been affected by a large debris jam that partially blocked fish migration until it was modified by Redwood National Park in 1988.

The limited data available indicate that the anadromous fishery of Redwood Creek has experienced a substantial reduction during the last 30 years. In 1975, the U.S. Fish and Wildlife Service, Division of Ecological Services, stated that "inspite of the lack of reliable definitive data, it is safe to assume that current fish runs are far below those which occurred 70-80 years ago" (Chupp, N.R., U.S. Fish and Wildlife Service, written commun., 1976). By 1994, five fish species found in Redwood Creek were classified as a species of concern, threatened, or endangered by the U.S. Fish and Wildlife Service and the California Department of Fish and Game (Appendix C).

To summarize, fish populations in Redwood Creek are much reduced in comparison to historic accounts. Habitat conditions are probably still quite degraded relative to pristine conditions, but are showing signs of improvement. Although channel deepening and pool development have been observed in all but the lower few miles of the creek, the mainstem generally lacks an adequate pool-riffle structure and cover. Coarse sediment deposited in the mainstem allows a large proportion of summer base flows to infiltrate and flow subsurface, thereby limiting the surface water available to fish and increasing surface water temperatures. Large deltas still block some tributary mouths and prevent migration of fish. The lack of suitable rearing habitat in the mainstem and tributaries has forced juvenile fish to the estuary, where they are subject to the impacts of uncontrolled breaching. Spawning habitat is improving slowly as gravels are cleaned of fine sediment. Canopy closure along the upper reaches of Redwood Creek is increasing, but is still far less than it was early this century. Tributary water temperatures are generally suitable for salmonids, but are suboptimal for fish along much of the mainstem. Recruitment of large woody debris and nutrients are probably well below historic levels. This condition is likely to persist into the future as deciduous willows and alders take the place of evergreen conifers along much of the mainstem and tributaries, and as large conifers along watercourses in the upper basin are harvested.

Issue 3: Protection of Threatened and Endangered Wildlife

The protection of threatened and endangered wildlife has had a major effect on resources management, particularly timber production, in the past decade. A court injunction in 1989 stopped all timber harvests on federal lands until adequate protection for the northern spotted owl was provided. The injunction was lifted in 1995, following approval of the Northwest Forest Plan. Regionally, protection of the marbled murrelet has recently affected land-use activities.

Threatened and endangered species generate the most concern for management of wildlife habitat. The primary concern is for protection of remaining suitable habitat. Research and management programs for species of special concern are directed by recovery plans that are approved by the U. S. Fish and Wildlife Service (Endangered Species Act 1973).

In the Redwood Creek watershed, six wildlife species are federally listed as threatened or endangered, and seven species are candidates for federal listing. An additional 20 species are identified as species of concern, because of their population status in California (Appendix C). Within park boundaries, these species of concern are managed under the same guidelines as designated threatened and endangered animals.

Several other categories of wildlife species are in need of some kind of management focus as well. Ungulate and large carnivore populations are reduced by poaching. Protection of breeding habitat has been identified as a priority need for neotropical migrant songbirds because many populations are declining in numbers.

Key questions:

1. **What habitat characteristics are needed to maintain species of special concern and other important wildlife species?**
2. **What management activities affect those habitat characteristics?**

Issue 3: Key Questions:

1. What habitat characteristics are needed to maintain species of special concern and other Important wildlife species?

Bald Eagle

There are no known territories located within the watershed. However, potentially suitable habitat exists along approximately 10 miles of lower redwood creek where it passes through old-growth. These streamside old-growth stands provide potential foraging roosts on the large trees that are adjacent to the creek. Historic reports exist of bald and golden eagle (*Haliaeetus leucocephalus* and *Aquila chrysaetos*) nesting sites in the area. The absence of bald eagles in the area is attributed to the decline of historic salmon and steelhead runs.

In the upper watershed a bald eagle was detected soaring during February 1995 approximately three miles south of Highway 299. Several incidental sightings of a bald eagle were made during the summer in Freshwater Lagoon (< 1 mile from estuary). Multiple incidental detections have also been made in the Tall Trees Grove. These detections suggest that eagles may be using the Redwood Creek watershed, however additional informal surveys have resulted in no detections.

The watershed is located within the California/Oregon Coast Recovery Zone (Zone 23) of the Bald Eagle Recovery Plan. The recovery goal for this large zone is 28 breeding pairs and 52 territories. It is estimated that the watershed could contribute two territories to this goal given the opportunities along old-growth stands in the lower watershed. However an increase in forage, in the form of anadromous fish and carrion, must occur for any increase in bald eagle use to be realized.

Marbled Murrelet

The watershed is located entirely within Marbled Murrelet Zone 1. In this region, Zone 1 is defined as a 35 mile-wide zone in which there is a higher likelihood of marbled murrelet occurrences Zone 2 is located inland where there is a lower likelihood of occurrence.

The California population of murrelets is approximately 6,500 birds and the national park land in the Redwood Creek watershed contains the highest density of murrelets in California (Ralph & Miller 1995). Extensive surveys have been conducted along all trails in the park's land in the watershed, and it is generally accepted that all national park old-growth stands in the watershed are occupied.

The watershed is located within the Siskiyou Coast Range Recovery Zone (Zone 4) of the Marbled Murrelet Recovery Plan. This zone contains large blocks of suitable habitat critical to the three-state recovery over the next 100 years. However, the amount of suitable habitat protected in parks is probably not sufficient by itself to guarantee long-term survival of murrelets in this zone. On the other hand, a considerable amount of habitat is preserved in parks such that survival may be more likely in this zone than in several of the other zones. (USFWS 1995)

The BLM parcels are designated as marbled murrelet critical habitat (CA-11-a). This 4,081 acre critical habitat unit contains 1,395 acres (34%) of suitable murrelet habitat. Surveys have resulted in one occupied stand in this unit. There are no records of murrelet detections on private or Forest Service lands.

Northern Spotted Owl

There are 56 known spotted owl territories in the watershed (28 Redwood National Park, 21 private land, 4 Bureau of Land Management, and 3 Forest Service).

Surveys covering all of Redwood National Park lands in the watershed were conducted in 1993, 1994 and 1995 by Humboldt State University (HSU). In 1994 re-visits were conducted on 23 territories. Seven of the 23 territories visited attempted to nest (30%), and all seven were successful, producing 8 fledglings. Limited re-visits were conducted in 1995 on 16 territories. Three attempts to nest were noted (16%), but only one was successful and produced two fledglings

(Tanner & Gutierrez 1993, 1994 & 1995). Approximately 25% (approx. 900 acres) of Forest Service land was surveyed in 1992. Three territories were located on Forest Service lands and one nest produced one young. The Bureau of Land Management (BLM) has surveyed all of its holding in the watershed. Of the four activity centers on BLM land three support pairs and one supports a single male; one young was fledged in 1992. The large expanses of private land has been surveyed in compliance to timber harvest plans. Summary information is not available for surveyed areas, but 21 territories on private land are documented for the watershed.

Spotted owl habitat in the watershed varies in relation to land owner. Redwood National Park contains large blocks of old-growth redwood habitat. On private industrial timberland most habitat has been removed via timber harvest except within the cores of known owl territories. In the middle watershed small BLM parcels contain important old-growth and other suitable owl habitat. In the upper watershed scattered Forest Service parcels contain suitable habitat, but are very small in size.

The BLM holdings total 4,100 acres, of which 2,165 acres (53%) is suitable as nesting and roosting habitat. All BLM territories are below the 40% 'take' threshold of protected suitable habitat within the home range. All of the BLM holdings are designated Late-Successional Reserve (RC-326), and critical habitat (CA-47). This critical habitat unit, containing Douglas-fir, provides a protected area of habitat connecting the Northern Interior Coast Range with the redwood habitat of the Coastal subprovince. The area is roughly centered between Redwood National Park and critical habitat unit C-29 (each approximately 7 miles away), and borders the Hoopa Indian Reservation. The area is expected to support two pairs over time, currently it supports three pairs and a single male.

The Forest Service parcels total 3,608 acres, of which 936 acres (26%) are suitable as nesting and roosting habitat.

American Peregrine Falcon

There are no know peregrine falcon eyries in the watershed. One cliff in the watershed, located in the national park, exhibits a potential to provide moderate quality nesting opportunities. The cliff was surveyed twice in 1994, but the site was not occupied. No ledges have been enhanced in the watershed. Foraging habitat for peregrines exists in the form of riparian vegetation along tributaries to Redwood Creek where songbirds and other bird prey reside. Foraging opportunities also exist around the estuary and in the foredunes of the beach. Additional surveys (including a ledge assessment) are needed to better determine the suitability of the one potentially suitable cliff.

Amphibians

Information is available from Redwood Sciences Lab and private timber companies on surveys for amphibians. There are presence data for Del Norte and southern torrent salamanders, and tailed frogs. No relative abundance, trend, or comparison data are available. All of these species are of special concern because of their low vagility and vulnerability to disturbance.

Tailed frogs and southern torrent salamanders are dependent on swift clean water flowing down high gradient creeks. Suitable habitat, therefore, is present in many of the tributaries to Redwood Creek however precise information is not available since suitability is largely defined by micro-site characteristics. It has been thought that only competent geology types could provide conditions for these two amphibians. New information in the Prairie Creek sub-watershed suggests that in undisturbed areas, creeks retain conditions favorable for tailed frogs and torrent salamanders even in less competent geologic types. On the private industrial timberland in the middle and upper watershed these species are only found in the very competent geologic types due to the high amounts of logging related ground disturbance.

Del Norte salamanders are associated with talus slopes and down logs. There are eight documented detections of Del Norte salamanders in different areas of the watershed. Additional data are not available and research is still being conducted to assess the salamanders response to disturbance.

Other amphibian species are present in the watershed (see Appendix B&B). The non-native bull frog that is causing a decline in native amphibians has not been detected in the watershed, but is present in the Trinity and Eel basins to the South.

Humboldt Marten & Pacific Fisher

The Humboldt marten is a distinct sub-species of the American marten that occurred in the narrow northwest humid coast strip, chiefly within the redwood belt. Humboldt martens were common in the late nineteenth and early twentieth century, and there are three historic sightings in the watershed. However, the last verifiable record of a Humboldt marten is from the late 1940's near Smith River and an intensive survey effort beginning in 1991 resulted in no detections. Much evidence suggested the Humboldt marten was extinct in California until one was photographed at a camera station in the Blue Creek watershed (approx 20 miles NE of watershed). If the Humboldt marten persists in the watershed its numbers are greatly reduced from overtrapping, habitat disturbance by timber harvesting, and interspecific competition with fisher. American martens are associated with mature, mesic coniferous forests and use a diversity of large live and dead woody structures for refuge and for foraging sites. Suitable habitat exists in the watershed at the old-growth groves in the park and on the BLM parcels. This habitat would be instrumental in recovery if the Humboldt marten is indeed extant. (Golightly & Zielinski 1996)

There are detections of fisher throughout the watershed. In 1990 and again in 1994 Pacific fishers were petitioned for listing under the Endangered Species Act, but it was found that listing was not warranted. Fishers are associated with large accumulations of woody debris and higher elevations. Stands composed of Douglas-fir seem to have more detections relative to redwood stands. Stands with greater hardwood components also produce more detections. Therefore, the old-growth redwoods will contribute somewhat to fisher habitats, but upland stands with Douglas-fir either as the dominant or co-dominant overstory species with a significant hardwood component will be important in providing habitat for the fisher. Analysis of the distribution of fisher detections has shown an increase in detections from the coast inland. However, an important exception to this rule exists in the watershed in the McArthur Creek sub-watershed. This area (near the coast) has the highest number of detections of any survey stations and is considered a "hot spot" of fisher activity.

The same analysis of detections resulted in a north-south trend with areas in the middle (townships 5-12) having the majority of detections, and the north and south areas (townships 0-3 & 13-18) having relatively few (Klug 1996). The watershed is in the middle (higher detection frequency) area.

California Brown Pelican

The California brown pelican is a summer resident of coastal marine and estuary habitats. This species is relatively common along the north coast. Brown pelicans nest on undisturbed islands off the coast and depend on highly productive marine habitats for foraging. Brown pelicans are often observed in the vicinity of the estuary but precise quantitative data are lacking.

Western Snowy Plover

The western snowy plover is a yearlong resident of coastal dunes and estuaries. They have been found infrequently during the winter at Gold Bluff Beach but no evidence of nesting activities have been observed in the area surrounding the Redwood Creek estuary. Individuals would be expected to use the estuary and adjacent dunes for feeding and nesting. However, human disturbance by recreational activities has probably caused local sub-populations to abandon preferred nesting sites on sandy beaches, and invasion of exotic European beach grass has reduced habitat availability in the dunes. This species is subject to heavy predation by gulls and ravens.

Roosevelt Elk

Elk are of concern in the park because they are an important attraction for visitors, and because they play an important role in the ecology of prairies, marshes, and forests. Elk use a combination of open habitats for foraging and forested habitat for hiding cover. As forage species dry and cure late in the year, forested habitats are utilized more for foraging because of increased nutrient value of the vegetation.

Current threats to elk habitat include invasion of exotic grasses (especially Arrhenatherum sp.) in the prairies. Elk diet analyses indicate that elk do not graze on the three most aggressive exotic prairie plants. Encroachment by douglas fir has contributed to a reduction in size of prairie habitats by 10-20% Past vegetation management practices may have negatively impacted elk use of the historic prairies in the Redwood Creek watershed. Clearcut areas attract elk because of the increased foraging opportunities for the first 10 years following treatments. Beyond 10 years post-cutting, the foraging opportunities are reduced due to closure of the overhead canopy. Fire suppression and grazing of domestic livestock in the prairies have changed the natural plant species composition. This change in habitat probably selected against elk use of these areas during some seasons. Elk numbers, however, have increased in recent years in the Redwood Creek watershed, possibly as a result of reduced livestock grazing.

Illegal harvesting of elk can impact population size if incidents are frequent enough. The actual mortality rate due to poaching is currently unknown. However, poaching mortality may be substantial since 4 of 16 radio collared elk were poached during a one and a half year study.

Quantitative data on the abundance or sex and age classification of elk in the Redwood Creek basin does not exist. However, an evaluation of habitat use by elk in the Bald Hills was completed in 1991. Elk in this area do not appear to make seasonal migrations, as they do in areas with more severe climates. Grenier (1991) found that use of habitats by elk did not differ during different times of day but was different depending on the season. Elk use prairies, south aspects, and upper elevations more than would be expected based on abundance of available habitat. They switch from high use of prairies throughout most of the year to greater use of forested habitat during the breeding season.

Large Carnivores

The abundance of large carnivores in the Redwood Creek watershed is poorly understood. Coyote, black bear, mountain lion and bobcat all occupy habitats within the basin. One study has been undertaken to assess the abundance of coyotes in the basin. Steinberg (1991) found greater response to howling surveys on the east side of the basin compared to the west side. She found dusky-footed woodrats (Neotoma fuscipes) to be the most common prey of coyotes and a review of the literature indicates that wood rat abundance is greatest in early and late seral stages of forest succession (Sakai and Noon, 1993). Studies to assess the abundance of other carnivores have not been completed.

Black bears use a variety of habitats and forage on a variety of foods. Home range sizes for black bears are smaller in Northern California than in other areas of western United States. Home range area for sows with cubs in the Redwood Creek watershed is between 0.4 and 0.8 square miles. Bears will forage on the cambium layer beneath the bark of young live trees, especially during the post denning period. This behavior is typically not tolerated well on private timber lands adjacent to the Park. Some individuals become pests when habituated to human food sources. Past experiences have shown that relocation of problem bears is not a viable solution and these individuals are generally euthanized, thus increasing mortality rate on the local population. A study to assess the abundance, distribution, habitat selection, and activity patterns of bears in the Bridge Creek drainage was initiated by Schroeder and Hofstra (1983). Preliminary results showed that sows with cubs frequented old-growth stands while cubless females utilized a variety of habitat types.

Survey and Manage Species

The Northwest Forest Plan (NFP) identifies species for which standards and guidelines for forest management may not be protecting certain species of vascular plants, fungi, mosses, bryophytes, mollusks, arthropods, amphibians, and mammals (USDA et al. 1994). These species require additional mitigation in the form of surveys and protection of known sites. It is not known which of these species may be present on federal lands in the watershed. As surveys are conducted and background information is analyzed, more information on status and trends of these species will be available.

Rare Plants

Pacific yew (*Taxus brevifolia*) is known to be present in the watershed by two occurrence. The Pacific yew is shade tolerant and grows in association with old-growth forests. Surveys for Pacific yew in lower Redwood Creek resulted in no additional detections, however, unsurveyed suitable habitat in the Lost Man Creek sub-watershed exhibits potential for additional occurrence.

The Natural Diversity Database documents nine rare plants occurring within the Redwood Creek watershed, all of which occur in the middle and upper watershed and not in the national park. Six of these occur in lower montane coniferous habitats in either openings or mesic areas. Woodlands, serpentine areas, and bogs also provide habitat for many of the rare plants. None of these species or habitats are protected under the Endangered Species Act.

Bensoniella oregona ("bensoniella") is a perennial herb found in bogs, fens, openings of lower montane coniferous forest, and meadows. Bensoniella is known in California from fewer than 10 occurrences, and is threatened by logging and grazing. Six occurrences are known in the watershed.

Sanicula tracyi (Tracy's sanicle) is a perennial herb found in montane woodlands, and openings of coniferous forest. Tracy's sanicle is threatened by logging, grazing, and development.

Thermopsis robusta (robust false-lupine) is a perennial herb found in coniferous forests. Robust false-lupine is potentially threatened by logging.

Cedum laxum flavidum (pale yellow stone crop) is a perennial herb found in chaparral, woodlands, lower montane coniferous forest, and serpentine areas.

Epilobium oreganum (Oregon fireweed) is a perennial herb found in bogs, fens, and mesic lower montane coniferous forest. Oregon fireweed is threatened by logging and is known from fewer than 1000 plants at about 20 sites in Oregon. There are three records of Oregon fireweed in the watershed.

Microseris borealis (northern microseris) is a perennial herb found in bogs, fens, mesic l lower montane coniferous forest, and meadows. Northern microceris is known is known in California from only two occurrences. There is one record of northern microseris in thewatershed.

Thalaspi californicum (Kneeland Prairie pennygrass) is a perennial herb found in prairies and serpentine areas. Kneeland Prairie pennygrass is known from fewer than five occurrences and is potentially threatened by road maintenance.

Sidalcea oregana eximia (coast checkerbloom) is a perennial herb found in coniferous forest and meadows. Coast intergrades with sspp. *oregana* and *spicata*.

Unique Habitats - The Bald Hills

Information presented here is summarized from the Bald Hills Management Plan (Redwood National Park 1992).

Approximately 1,700 acres of prairie and 660 acres of Oregon white oak woodland occur along the ridge top and southwest facing slopes of the Bald Hills. This area boasts the greatest plant diversity of any area in the park. However, significant ecological problems threaten these communities including:

(1) encroachment of Douglas-fir,
(2) replacement of native herbaceous species with non-native species,
(3) lack of natural fire, and
(4) declining wildlife habitat.

Historically (prior to the introduction of livestock in the 1850's), the prairie vegetation was primarily native bunchgrasses including *Danthonia, Stipa, Melica, Poa,* and *Festuca.* Oak woodlands were dominated by Oregon white oak (*Quercus garryana*) with scattered individuals of black oak (*Quercus kelloggii*). This vegetation was maintained by earthflow movement, soils with impaired drainage, lightning caused fire, and yearly fires set by Native Americans. These prairies were larger in extent than they are today. European explorers in the Jedediah Smith party reported Elk herds of hundreds, perhaps thousands of animals using this area. Historic reports exist of bald and golden eagle nesting sites in the area.

Today, 67% of the plant species are native and 33% are introduced. *Danthonia californica.* (California oatgrass) is the primary native grass in the Bald Hills prairies, but distribution is patchy and comprises no more than 50% of the cover in any area. In the woodlands 75% of the plant species are native and 25% are introduced. Currently, Douglas-fir encroachment has reduced the size of woodlands and prairies to 75% of their size in 1850, and more than half the remaining oak woodlands already have sufficient Douglas-fir in the understory to convert those areas during the next few decades. As of 1992, 15 prescribed burns totaling 356 acres and experimental tree girdling have been conducted to address Douglas-fir encroachment and restore native species.

The Bald Hills prairies provide one of the few examples of a healthy, endemic Roosevelt elk population in California. Since cattle were removed from the park in 1982, the herd has dramatically expanded its use of the prairies. About 100 elk presently live in the Bald Hills extensively using that habitat. It is anticipated that as second-growth forests mature and the ground forage decreases, elk will use these forests less, increasing the already high use of the prairies.

2. *What management activities affect those habitat characteristics?*

Past land management practices have changed the natural abundance of coniferous forest and prairie/oak woodland habitats. The decrease in quantity of old growth forest stands has reduced the amount of available habitat for all species that are dependent on these vegetation types for food, cover and security. The impacts of logging large tracts of forested lands has created both positive and negative impacts to wildlife habitat. Human activities in the prairie/oak woodlands (ranching and fire suppression) have reduced the amount of habitat available for wildlife.

Canopy nesting/foraging bird species (including marbled murrelet and northern spotted owl) and many species of amphibians have lost significant amounts of habitat which cause direct population declines. The mosaics of second growth forests have created additional edge habitats which are detrimental to the remaining individuals. Avian nest predators are more common near the edge of a habitat type (Paton, 1994). Hence large forest stands reduce that exposure to avian nest predation and protects reproductive success.

Ranching and fire suppression strategies have changed the character of prairies and oak woodlands. The primary impacts to wildlife habitat are replacement of native grasses by exotic species and encroachment by douglas fir. This reduction in the amount of prairie/oak woodland habitat has most likely created population declines in small mammals, amphibian and bird species associated with these habitat types. The negative impacts of displacement of large mammals by ranching activities has been partly offset by logging forests and creating suitable temporary alternative habitat for these species.

Second growth forests have evolved as a result of these human manipulations to the habitat. While some species do benefit from this new habitat type, the effects are short lived relative to the life cycle of redwood forest ecosystems.

Human activities in and around the estuary have created changes in habitat structure and quality that affect wetland related species. Recreational and domestic activities (fishing, firewood gathering, vehicle travel across beaches and dunes, dairy farming and hay production) have displaced nesting activities of many bird species and have probably contributed to an increase in populations of ravens, crows and gulls.

With only a finite amount of land available as wildlife habitat, the abundance of each habitat type (old-growth conifer forest, prairie, oak woodland) changes with each new human activity. In most cases these changes in habitat abundance produce non-natural population fluctuations for many species of wildlife.

To summarize, the most important habitat type available for the long term protection of threatened and endangered species is old-growth or late-successional forest. Most of the original old-growth forests of Northwestern California have been harvested, but within the park, significant areas of this habitat type still exist. As second-growth stands mature, the area of late-successional forest will increase to approximately twice the present area of old-growth forest. This habitat within the Redwood Creek watershed is very important for local sub-populations of marbled murrelet, northern spotted owl, pacific fisher and Northern red-legged frog. The lower Redwood Creek watershed may act as a refuge for less optimal habitat outside the national and state parks.

Issue 4: Timber Production

Timber production is clearly an important natural resource issue in the Redwood Creek watershed. We have not formulated key questions for this issue as we did for issues 1-3, however, because the information and expertise needed to develop and answer key questions for this issue are in the hands of industry, rather than the park. Given the proprietary nature of industrial data, such information is unlikely to be forthcoming. We have therefore restricted our analysis to a discussion of the effects of the park and environmental regulations on the timber industry. Our purpose in presenting this information is to provide perspective on the balance between resource protection and economically sustainable industrial production.

The two major commercial forest species in Humboldt County are redwood and douglas fir. Detailed countywide statistics for these two species are not available, but statewide statistics provide some insight into past growth and harvest trends. For both redwood and Douglas fir, the

the California North Coast, "There are not sufficient sawtimber stocks with associated growth to maintain output until new stands, regenerated since the 1950's, can reach merchantable sawtimber size (Oswald, 1978, p. 19)."

The amount of live sawtimber, the percent of sawtimber greater than 21 inches in diameter, and the area of commercial timber land for each species declined between 1952 and 1976 (table 6; U.S. Forest Service, 1958; 1973; 1982). These trends are consistent with a decrease in available merchantable timber. Timber production may increase over the next few decades as second-growth stands mature, but the peak production levels of the 1950's will probably never be achieved again.

Countywide, timber production peaked in the 1950's as housing construction increased during the economic boom that followed the end of the Second World War (fig. 15). Timber production fluctuated after the mid-1950's, but generally declined throughout the 1960's and early 1970's. Production dropped dramatically in the mid-1970's, around the time of National Park expansion, increased during the 1980's, and decreased again following the injunction against timber harvesting on federal lands in 1989.

The creation and expansion of Redwood National Park removed forest lands from production. About2,200 million board feet (MBF) were included within 1968 park boundaries in Redwood Creek, which at that time represented about 10% of the Humboldt County timber volume (Vale, 1966). The 1978 expansion included about 1,310 MBF of standing timber (U.S. Department of Justice, 1983). The total amount of timber removed from production was therefore about 3,510 MBF, roughly nine times greater than current annual countywide timber production (fig. 15).

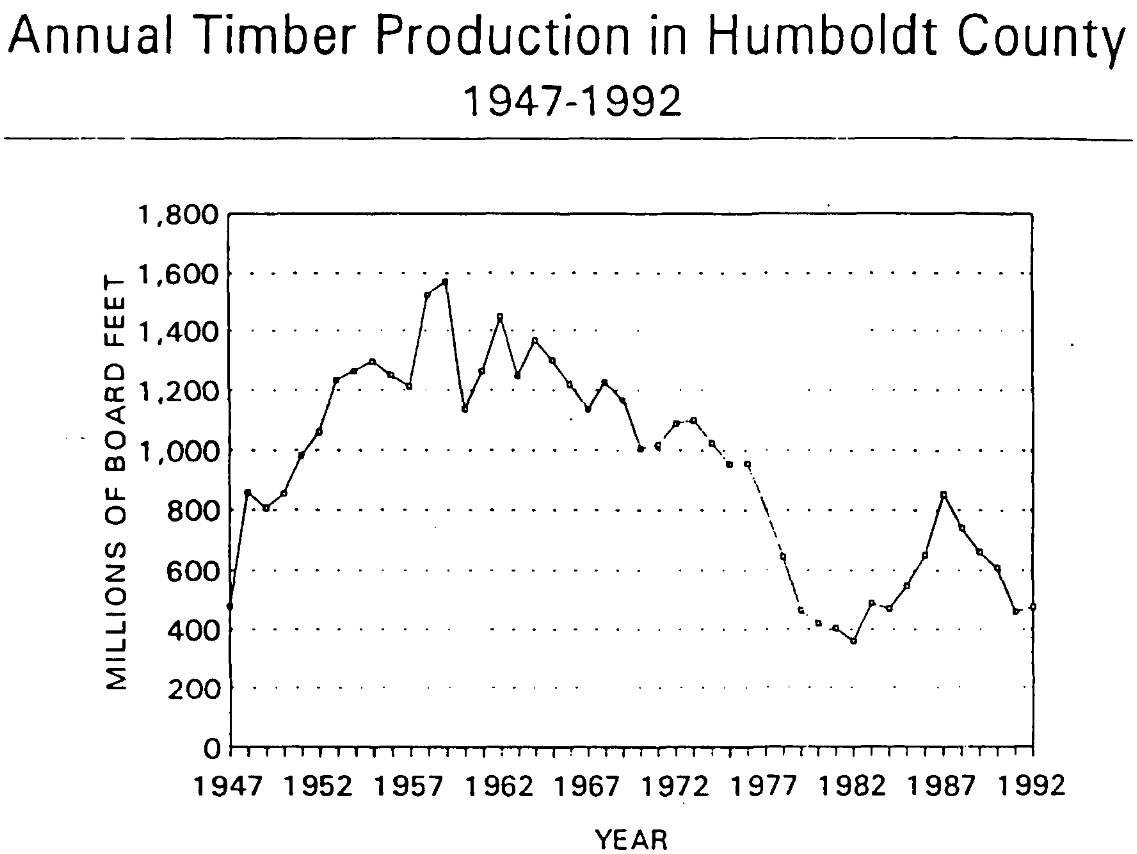


Figure 15. Graph showing annual timber production in Humboldt County, 1947-92

Table 6: Annual growth and cut of redwood and Douglas-fir, California, 1952 and 1976 [from U.S. Forest Service Forest Resources Reports No. 14, 20, and 23; MBF, million board feet; CTL, commercial timber land]

a.) Redwood

Year	Annual Growth (MBF)	Annual Cut (MBF)	Live Sawtimber (MBF)	Percent Sawtimber >21" dbh	CTL (acres x 1,000)
1952	396	987	36,124	91	1,588
1970	--	--	23,129	81	--
1976	479	820	21,434	77	650

b.) Douglas Fir

Year	Annual Growth (MBF)	Annual Cut (MBF)	Live Sawtimber (MBF)	Percent Sawtimber >21" dbh	CTL (acres x 1,000)
1952	787	2,333	116,912	92	4,378
1970	--	--	79,818	85	--
1976	844	1,326	72,938	82	2,709

Employment in timber-related occupations was predicted to decline by 300 jobs as a result of the creation of the Redwood Creek unit of Redwood National Park in 1968 (Arthur D. Little, Inc., 1967). This estimate was supported by Vale's (1966) estimate that about 10 MBF were required to sustain each timber-related job. However, by 1986, 2,850 workers had been approved for weekly benefits and 2,142 workers had qualified for severence pay under the Redwood Employees Protection Program that was included in park expansion legislation (Redwood National Park, 1987).

Issue 5: Tourism

Like timber production, tourism is an important economic concern to local communities. Tourism is also of concern to the park, because tourism is closely related to park visitation. As we did with Issue 4, we felt that we lacked adequate information and expertise to analyze this issue in detail. We have, however, provided some background material to illustrate the relations between tourism, park visitation, and the local economy.

Tourism has become an increasingly important part of the Humboldt County economy. Countywide travel expenditures rose from $222,000,000 in 1991 to $232,000,000 in 1993, and the number of local jobs related to tourism has risen from 3,394 to 3,918 during the same period (Dean Runyon Associates, 1993-95). Local tax receipts related to the visitor industry were about $3,500,000 in 1993 (Dean Runyon Associates, 1995). Countywide that year, 125 jobs were related to public campgrounds and 833 jobs were related to day travel (Dean Runyon Associates, 1995)

The local economy was expected to benefit from increased tourism related to park establishment. Visitation was predicted to increase to 1,600,000 visitors-days per year by 1983 (Arthur D. Little, Inc., 1967). Actual park visitation was less than 400,000 visitor-days in 1992, but increased steadily to more than 550,000 visitor-days by 1995. Although predicted levels of visitation have not been reached, the park has brought substantial income into the area through increased tourism. Tourism attributed to the park resulted in an estimated income of almost $6,000,000 to the economy of Humboldt County in 1992, an amount equivalent to 3% of the countywide annual travel expenditures.

The completion of a cooperative management agreement between the state and national parks in 1993 removed a major obstacle to increased visitation. All park lands within the authorized boundary of the national park are now jointly managed. The cooperative agreement has increased the level of visitor services and provided visitors with better information on park features and facilities. The revised Redwood National and State Parks General Management Plan/General Plan, currently in progress, will identify additional visitor service needs.

National and state parks will probably continue to attract increasing numbers of visitors. In a survey of tourists in 1990, 32% of respondents listed "scenery, coasts, and redwood forest" as the attractions that they liked the most (Crowe, 1990). In neighboring Del Norte County, Redwood National Park was the most popular tourist destination in 1989 as determined by a visitor survey (University of Oregon, written communication, 1989).

Conclusions

CONCLUSIONS

The Redwood Creek watershed is recovering from the combined effects of past land-use practices and large storms. During the past two decades, no large storms have affected the watershed, and regulation of land-use activities has provided increased protection of natural resources. Upstream land uses during this period have not had demonstrably adverse effects on streamside redwoods, aquatic habitat, and wildlife within the park.

The next large storm, however, will inevitably cause renewed sediment delivery from hillslopes to stream channels, through both natural and unpreventable processes as well as processes related to land use. The park remains concerned over the adequacy of some provisions of the forest practice rules to protect park resources in a major storm.

Potential damage to park resources can be reduced through voluntary and cooperative erosion-control efforts. The most significant source of preventable erosion in the watershed is the network of abandoned and unmaintained roads in and upstream of the park. Treatment of diversion potentials at road-stream crossings is probably the single most effective approach for reducing damage to park resources.

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Appendices

APPENDIX A:

WILDLIFE SPECIES IN THE VICINITY OF THE REDWOOD CREEK WATERSHED

The following list is based on recorded observations by visitors and park staff that are in the Redwood National and State Parks wildlife database and on species which could be expected in habitats present in the watershed. Habitat associations include only those that are found within the Redwood Creek watershed.

Habitat Association

g	=	grasslands and agricultural lands
r	=	riparian and deciduous forest
c	=	conifer forest
2	=	young second-growth and brush
l	=	lake/stream/lagoon/marsh/pond
b	=	beaches/dunes/ocean waters near shore
o	=	outcrop, rock rubble
w	=	wide habitat ranges

Presence

y	=	year-round
s	=	seasonal
B	=	Breeding

Common Name	Scientific Name	Habitat/Presence
Amphibians		
Pacific giant salamander	*Dicamptodon tenebrosus*	crl/yB
Del Norte salamander	*Plethodon elongatus*	o/yB?
Southern torrent salamander	*Rhyacotriton variegatus*	lr/yB?
Northwestern salamander	*Ambystoma gracile*	lgcr/yB
Rough-skinned newt	*Taricha granulosa*	crlg/yB
Painted salamander	*Ensatina eschscholtzii*	rc/yB
Clouded salamander	*Aneides ferreus*	c/yB
Black salamander	*Aneides flavipunctatus*	rcg/yB
California slender salamander	*Batrachoseps attenuatus*	w/yB
Western toad	*Bufo boreas*	
Red-legged frog	*Rana aurora*	rlc/yB?
Foothill yellow-legged frog	*Rana boylei*	rl/yB
Tailed frog	*Ascaphus truei*	lr/yB?
Pacific tree frog	*Pseudacris regilla*	rlcg/yB
Reptiles		
Rubber boa	*Charina bottae*	w/yB
Valley garter snake	*Thamnophis sirtalis fitchi*	w/yB
Calif. red-sided garter snake	*T. sirtalis infernalis*	w/yB
Coast garter snake	*T. elegans terrestris*	w/yB
Oregon garter snake	*T. couchi hydrophilus*	l/yB
W. yellowbelly Racer	*Coluber constrictor mormon*	g/yB
California kingsnake	*Lampropeltis getulus californiae*	r/yB

Common Name	Scientific Name	Habitat/Presence
Northwestern ringneck snake	*Diadophis punctatus occidentalis*	gro2/yB
Pacific gopher snake	*Pituophis melanoleucus catenifer*	w/yB
Sharptail snake	*Contia tenuis*	rc/yB
Pacific rattlesnake	*Crotalis viridis*	w/yB
Northwestern pond turtle	*Clemmy marmorata marmorata*	lr/yB
Western skink	*Eumeces skiltonianus*	w/yB
Southern alligator lizard	*Elgaria multicarinata*	gc2o/yB
Northern alligator lizard	*Elgaria coerulea*	co/yB
Western sagebrush lizard	*Sceloporus graciosus graciosus*	c/yB
Western fence lizard	*Sceloporus occidentalis*	w/yB
Mammals		
Opossum	*Didelphis marsupialis*	gr/yB
Vagrant shrew	*Sorex vagran*	rc/yB
Pacific shrew	*Sorex pacificu*	cr/yB
Marsh shrew	*Sorex bendirei*	r/yB
Trowbridge shrew	*Sorex trowbridgei*	c/yB
Shrew-mole	*Neurotrichus gibbsi*	r/yB
Townsend mole	*Scapanus townsendii*	rgc/yB
Coast mole	*Scapanus orarius*	rg/yB
Little brown bat	*Myotis lucifugus*	grc2/sB?
Yuma myotis	*Myotis yumanensis*	grc2/sB?
Long-eared myotis	*Myotis evotis*	grc2/sB?
Fringed myotis	*Myotis thysanodes*	grc2/sB?
Long-legged myotis	*Myotis volans*	grc2/sB?
California myotis	*Myotis californicus*	grc2/sB?
Silverhaired bat	*Lasionycteris noctivagans*	grc2/sB?
Big brown bat	*Eptesicus fuscus*	grc2/sB?
Hoary bat	*Lasiurus cinereus*	grc2/sB?
Spotted bat	*Euderma malulatum*	rc/sb?
Townsend's big-eared bat	*Plecotus townsendii*	grc2/sB?
Pallid bat	*Antrozous pallidus*	gr2/sB?
Mexican free-tailed bat	*Tadarida brasiliensis*	gr/sB?
Brush rabbit	*Sylvilagus bachmani*	2r/yB
Mountain beaver	*Aplodontia rufa*	rc/yB
Allen's chipmunk	*Tamias senex*	c/yB
Siskiyou chipmunk	*Tamias siskiyou*	c2/yB
California ground squirrel	*Spermophilus beecheyii*	g/yB
Western gray squirrel	*Sciurus griseus*	rc2/yB
Chickaree	*Tamiasciurus douglasi*	c/yB
Northern flying squirrel	*Glaucomys sabrinus*	c/yB
Valley pocket gopher	*Thomomys bottae*	g/yB
Beaver	*Castor canadensis*	l/yB
Western harvest mouse	*Reithrodontomys megalotis*	gr/yB
Deer mouse	*Peromyscus maniculatu*	2g/yB

Common Name	Scientific Name	Habitat/Presence
Dusky footed woodrat	*Neotoma fuscipes*	2cr/yB
Bushy-tailed	*Neotoma cinerea*	o/yB?
California redback vole	*Clethrionomys occidentalis*	c/yB
White-footed vole[b]	*Arborimus albipes*	r/yB
Red tree vole	*Arborimus pomo*	c/yB
California vole	*Microtus californicus*	g/yB
Townsend vole	*Microtus townsendi*	rg/yB
Longtail vole	*Microtus longicaudus*	gr/yB
Muskrat[c]	*Ondatra zibethica*	l/yB
Pacific jumping mouse	*Zapus trinotatus*	rg/yB
Porcupine	*Erethizon dorsatum*	c/yB
Coyote	*Canis latrans*	w/yB
Gray fox	*Urocyon cinereoargenteus*	r2g/yB
Black bear	*Ursus americanus*	r2c/yB
Raccoon	*Procyon lotor*	r/yB
Martin[a]	*Martes americana*	c/yB?
Fisher[b]	*Martes pennanti*	c/yB?
Shorttail weasel	*Mustela erminea*	r2c/yB
Longtail weasel	*Mustela vison*	rl/yB
Spotted skunk	*Spilogale putorius*	rg2/yB
Striped skunk	*Mephitis mephitis*	g2/yB
River otter	*Lutra canadensis*	l/yB
Mountain lion	*Felis concolor*	w/yB
Bobcat	*Felis rufus*	g2/yB
California sea lion	*Zalophus californianus*	bl/yB
Harbor seal	*Phoca vitulina*	bl/yB
Roosevelt elk	*Cervus elaphus Roosevelti*	w/yB
Black-tailed deer	*Odocoileus hemionus*	w/yB
Birds		
Red-throated loon	*Gavia stellata*	bl/s
Common loon	*Gavia immer*	bl/y
Pied-bill grebe	*Podilymbus podiceps*	bl/y
Western grebe	*Aechmophorus occidentalis*	bl/y
Brown pelican	*Pelecanus occidentalis*	bl/y
Double-crested cormorant	*Phalacroxorax auritus*	bl/y
Great blue heron	*Ardea herodias*	lrcg/yB?
Great egret	*Casmerodius albus*	lrg/yB?
Cattle egret	*Bubulcus ibis*	g/s
Green-backed heron	*Butorides striatus*	lr/yB
Black-crowned night-heron	*Nycticorax nycticorax*	lrc/yB
Brant	*Branta bernicla*	lb/s
Canada goose	*Branta canadensis*	lb/s
Wood duck	*Aix sponsa*	rl/yB
Mallard	*Anas platyrhynchos*	rl/yB

Common Name	Scientific Name	Habitat/Presence
Cinnamon teal	*Anas cyanoptera*	rl/yB
American wigeon	*Anas americana*	lr/y
Hooded merganser	*Lophodytes cucullatus*	l/s
Common merganser	*Mergus merganser*	l/yB
Red-breasted merganser	*Mergus serrator*	l/s
Turkey vulture	*Cathartes aura*	w/sB
Osprey	*Pandion haliaetus*	c/sB
White-tailed kite	*Elanus caeruleus*	g/yB
Bald eagle	*Haliaeetus leaucocephalus*	l/y?B?
Northern harrier	*Circus cyaneus*	g/yB
Sharp-shinned hawk	*Accipiter striatus*	rc/yB
Cooper's hawk	*Accipiter cooperii*	rc/yB
Northern goshawk[a]	*Accipiter gentilis*	c/?
Red-shouldered hawk	*Buteo lineatus*	r/yB
Red-tailed hawk	*Buteo jamaicensis*	2g/yB
Rough-legged hawk	*Buteo lagopus*	g/s
Golden eagle	*Aquila chrysaetos*	g/y?B?
American kestrel	*Falco sparvarius*	g2/yB
Merlin	*Falco columbarius*	rg2/s
Peregrine falcon	*Falco peregrinus*	lbr/y?B?
Blue grouse	*Dendragapus obscurus*	c/yB
Ruffed grouse	*Bonasa umbellus*	rc/yB
California quail	*Callipepla californica*	r2c/yB
Mountain quail	*Oreortyx pictus*	2/y?
American coot	*Fulica americana*	lg/yB
Western snowy plover	*Charadrius alexandrinus*	b/yB
Semipalmated plover	*Charadrius semipalmatus*	b/y
Killdeer	*Charadrius vociferus*	blg/yB
Black oystercatcher	*Haematopus bachmani*	b/yB
Willet	*Catoptrophorus semipalmatus*	l/s
Spotted sandpiper	*Actitis macularia*	l/yB
Marbeled godwit	*Limosa fedoa*	bl/s
Sanderling	*Calidris alba*	bl/s
Western sandpiper	*Calidris mauri*	gl/s
Least sandpiper	*Calidris minutilla*	gl/s
Pectoral sandpiper	*Calidris melanotos*	gl/s
Dunlin	*Calidris alpina*	bl/s
Common snipe	*Gallinago gallinago*	gl/s
California gull	*Larus californicus*	blg/y
Western gull	*Larus occidentalis*	blo/yB
Glaucous-winged gull	*Larus glaucescens*	bl/y
Caspian tern	*Sterna caspia*	bl/s
Forester's tern	*Sterna foresteri*	bl/s
Marbled murrelet	*Brachyramphus marmoratus*	c/yB

Common Name	Scientific Name	Habitat/Presence
Band-tailed pigeon	*Columba fasciata*	rc/sB
Mourning dove	*Zenaida asiatica*	g2/yB?
Common barn-owl	*Tyto alba*	g/yB
Western screech owl	*Otus kennicottii*	rc/yB
Great horned owl	*Bubo virginianus*	w/yB
Northern pygmy-owl	*Glaucidium gnoma*	?c/yB
Burrowing owl	*Athene cunicularia*	bg/yB?
Spotted owl[b]	*Strix occidentalis*	c/yB
Barred owl[b]	*Strix varia*	c/?
Short-eared owl	*Asio flammeus*	g/s
Northern saw-whet	*Aegolius acadicus*	?c/yB
Common nighthawk	*Chordeiles minor*	g/sB
Vaux's swift	*Chaetura vauxi*	lc/sB?
Anna's hummingbird	*Calypte anna*	gr/yB
Rufus hummingbird	*Selasphorus rufus*	2/s
Allen's hummingbird	*Selasphorus sasin*	2r/sB
Belted kingfisher	*Ceryle alcyon*	lr/yB
Lewis woodpecker	*Melanerpes lewis*	gcr/s
Red-breasted sapsucker	*Sphyrapicus ruber*	rc2/yB
Downy woodpecker	*Picoides pubescens*	rc/yB
Hairy woodpecker	*Picoides villosus*	rc/yB
Northern flicker	*Colaptes auratus*	w/yB
Pileated woodpecker	*Dryocopus pileatus*	c/yB
Olive-sided flycatcher	*Contopus borealis*	c/sB
Western wood-pewee	*Contopus sordidulus*	rc/sB
Pacific slope flycatcher	*Empidonax difficilis*	rc/sB
Black phoebe	*Sayornis nigricans*	glr/yB
Tree swallow	*Tachycineta bicolor*	glr/sB
Violet-green swallow	*Tachycineta thalassina*	grc/sB
Northern rough-winged swallow	*Stelgidopteryx serripennis*	lg/sB
Barn swallow	*Hirundo rustica*	gl/sB
Steller's jay	*Cyanocitta stelleri*	c/yB
Scrub Jay	*Aphelocoma coerulescens*	gr/yB
American crow	*Corvus brachyrhnchos*	rg/yB
Common raven	*Corvus corax*	w/yB
Black-capped chickadee	*Parus attricapillus*	r/yB
Chestnut-backed chickadee	*Parus rufescens*	rc/yB
Red-breasted nuthatch	*Sitta canadensis*	c/s
Brown creeper	*Certhia americana*	rc/yB
Bewick's wren	*Thryomanes bewickii*	2r/yB
House wren	*Troglodytes aedon*	2r/sB
Winter wren	*Troglodytes troglodytes*	cr/yB
American dipper	*Cinclus mexicanus*	l/yB
Golden-crowned kinglet	*Regulus satrapa*	c/yB

Common Name	Scientific Name	Habitat/Presence
Ruby-crowned kinglet	*Regulus calendula*	rc/sN
Western bluebird	*Sialia mexicana*	rg2/s
Mountain bluebird	*Sialia currucoides*	g/y?
Townsend's solitaire	*Myadestes townsendi*	rc/sN
Swainson's thrush	*Catharus ustulatus*	rc/B
Hermit thrush	*Catharus guttatus*	rc2/y
American robin	*Turdus migratorius*	w/yB
Varied thrush	*Ixoreus naevius*	crg/yB
Wrentit	*Chamaea fasciata*	rc/yB
American pipit	*Anthus rubescens*	g/s
Cedar waxwing	*Bombycilla cedrorum*	cr/sB
Northern shrike	*Lanius excubitor*	g/s
Solitary vireo	*Vireo solitarius*	c/s
Hutton's vireo	*Vireo huttoni*	rc2/sB
Warbling vireo	*Vireo gilvus*	rc/sB
Orange-crowned warbler	*Vermivora celata*	rc2/yB
Nashville warbler	*Vermivora ruficapilla*	rc2/y
Yellow warbler	*Dendroica petechia*	r/sB
Macgillivray's warbler	*Oporornis tolmiei*	r2/s
Yellow-rumped warbler	*Dendroica coronata*	rc/y
Black-throated gray warbler	*Dendroica nigrescens*	g2/sB
Townsend's warbler	*Dendroica townsendi*	rc/sN
Hermit warbler	*Dendroica occidentalis*	c/sB
Common yellowthroat	*Geothlypis trichas*	r/sB
Wilson's warbler	*Wilsonia pusilla*	rc/sB
Yellow-breasted chat	*Icteria virens*	r/sB
Western tanager	*Piranga ludoviciana*	c2/sB
Black-headed grosbeak	*Pheucticus melanocephalus*	rc/s
Lazuli bunting	*Passerina amoena*	2/sB
Rufous-sided towhee	*Pipilo erythrophthalmus*	r2/s
Chipping sparrow[b]	*Spizella passerina*	2c/sB?
Savannah sparrow	*Passerculus sandwichensis*	g/yB
Fox sparrow	*Passerella iliaca*	r2/s
Lincoln's sparrow	*Melospiza lincolnii*	r2/s
Song sparrow	*Melospiza melodia*	wide/yB
White-throated sparrow	*Zonotrichia albicollis*	r2/s
Golden-crowned sparrow	*Zonotrichia atricapilla*	r2/s
White-crowned sparrow	*Zonotrichia leucophrys*	gr2/yB
Dark-eyed junco	*Junco hyemalis*	rgc2/yB
Red-winged blackbird	*Agelaius phoeniceus*	bgr/yB
Western meadowlark	*Sturnella neglecta*	g/yB
Brewer's blackbird	*Euphagus cyanocephalus*	g/yB
Brown-headed cowbird	*Molothrus ater*	rg2/yB
Northern oriole	*Icterus galbula*	r/sB

Common Name	Scientific Name	Habitat/Presence
Purple finch	*Carpodacus purpureus*	rc/yB
House finch	*Carpodacus mexicanus*	g2/yB
Red crossbill	*Loxia curvirostra*	c/yB?
Pine siskin	*Carduelis pinus*	crg/yB
Lesser goldfinch	*Carduelis psaltria*	g2r/yB
American goldfinch	*Carduelis tristis*	g2r/yB
Evening grosbeak	*Coccothraustes verspertinus*	rc/s
European starling[c]	*Sturnus vulgaris*	wide/yB
House sparrow[c]	*Passer domesticus*	g/yB

[a] Unlikely
[b] not reported, but likely
[c] nonnative

APPENDIX B:
STATE AND FEDERALLY LISTED THREATENED, ENDANGERED AND SENSITIVE FISH AND WILDLIFE SPECIES IN THE VICINITY OF THE REDWOOD CREEK WATERSHED (Species known or expected to occur ,based on habitat, in or near the Redwood Creek watershed)

TAXA	USFWS*	CALIF**	HABITAT
<u>BIRDS</u>			
California Brown Pelican *Pelecanus occidentalis californicus*	FE	SE	Coast and ocean.
Double-crested Cormorant (rookery site) *Phalacrocorax auritus*		CSC	Coast, bays, lakes, rivers.
Osprey *Pandion haliaetus*		CSC	Rivers, lakes, coasts. Known to breed i park.
White-tailed Kite *Elanus caeruleus*		SFP	Open foothills, grasslands, river valleys, marshes. Known to breed in park.
Bald Eagle *Haliaeetus leucocephalus*	FT	SE,SFP	Coast, lagoons, rivers and associated mature/old-growth forests.
Northern Harrier *Circus cyaneus*		CSC	Marshes, fields and prairies.
Sharp-shinned Hawk *Accipiter striatus*		CSC	Forest and thickets.
Cooper's Hawk *Accipiter cooperii*		CSC	Broken woodlands, canyons, river groves.
Ferruginous Hawk *Buteo regalis*	C2	CSC	Arid plains, open rangelands.
Golden Eagle *Aquila chrysaetos*		CSC,SFP	Open mountains, canyons, foothills, plains.
Merlin *Falco columbarius*		CSC	Open areas, coniferous forests.
Peregrine Falcon *Falco peregrinus*	FT	SE,SFP	Coastline.
Ruffed Grouse *Bonasa umbellus*		CSC	Mixed or deciduous woodlands.
Western Snowy Plover (breeding) *Charadrius alexandrinus nivosus*	FT	CSC	Beaches, coastal dunes. Several records from Lake Talawa, Stone Lagoon.
California Gull *Larus californicus*		CSC	Coast, beaches, lakes, rivers.
Marbled Murrelet *Brachyramphus marmoratus*	FT	SE	Feeds offshore, nests in old-growth forests.
Northern Spotted Owl *Strix occidentalis caurina*	FT	CSC	Old-growth and mature 2nd growth forests.
Great Gray Owl *Strix nebulosa*	FSS	SE	Dense forests and adjacent meadows. Three records in park. Transient.

TAXA	USFWS*	CALIF**	HABITAT
Short-eared Owl (breeding) *Asio flammeus*		CSC	Prairies, marshes, dunes, irrigated lands.
Burrowing Owl (burrowing sites) *Athene cunicularia*		CSC	Prairies, seashore dunes.
Purple Martin *Progne subis*		CSC	Open or logged forests, towns farms.
Black-capped Chickadee *Parus atricapillus*		CSC	Mixed and deciduous woodlands, willo thickets.
Yellow-breasted Chat (breeding) *Icteria virens*		CSC	Stream tangles, briars, willow thickets moist canyons.
MAMMALS			
Pallid Bat *Antrozus pallidus*		CSC	Caves, mine tunnels, crevices in rocks buildings, trees.
Townsend's Western Big-eared Bat *Plecotus townsendii townsendii*	C2	CSC	Caves, mine tunnels, old buildings and hollow trees.
Red Tree Vole *Arborimus longicaudus*		CSC	Spruce, hemlock, fir forests.
White-footed Vole *Arborimus albipes*	C2	CSC	Dense forest near small streams.
Pacific Fisher *Martes pennanti pacifica*	C2	CSC	Mature conifer forests, riparian areas.
???Wolverine *Gulo gulo*	C2	ST	High mountains. Several unverified sightings in the area.
HERPETOFAUNA			
Western Pond Turtle *Clemmys marmorata*	C2	CSC	Aquatic habitats and nearby forests, grasslands. Dead juvenile found in Redwood Creek estuary.
Southern Torrent Salamander *Rhyacotriton variegatus*		CSC	Well-shaded springs, streams and seeps in coastal forests.
Del Norte Salamander *Plethodon elongatus*	C2	CSC	Rock rubble or riverbeds, roadfills, moss-covered talus.
Tailed Frog *Ascaphus truei*		CSC	Cold, clear, rocky streams in humid forests
Northern Red-legged Frog *Rana aurora aurora*	C2	CSC	Humid forests, woodlands, grasslands, streamsides.
Foothill Yellow-legged Frog *Rana boylei*		CSC	Woodland, chapparal, or forest stream

<u>FISH</u>			
Tidewater Goby *Eucyclogobius newberryi*	FE	CSC	Estuarine. Recorded in Redwood Creek estuary in 1981.
Coast Cutthroat Trout *Onchyrhynchus clarki clarki*		CSC	Streams, rivers, and ocean.
Coho Salmon *Onchyrhynchus kisutch*	FP?	CSC	Streams, rivers, and ocean.
Chinook Salmon (spring run) *Onchyrhynchus tshawytscha*		CSC	Streams, rivers, and ocean.
Summer Steelhead Trout *Onchyrhynchus mykiss gairdneri*	FSS,C2	CSC	Streams, rivers. Known in Redwood Creek

*Federal status of species in 50 CFR 17.11 & 17.12, August 29, 1992, USFWS. Endangered and Threatened Wildlife & Plants.

FE	Endangered
FT	Threatened
FSS	Sensitive species
C2	Category 2 candidate for federal listing
FPL	Proposed for federal listing as threatened

**California Department of Fish and Game Natural Diversity Database, Special Animals, August 1991, and CDFG State & Federal Endangered & Threatened Animals of California, revised January, 1994.

SE	Endangered
ST	Threatened
CSC	Species of special concern
SFP	Fully protected species

Appendix C - 1998

SEDIMENT BUDGET FOR THE REDWOOD CREEK WATERSHED, 1954 - 1980

A sediment budget was constructed for the Redwood Creek watershed for the purpose of documenting the location, timing, mechanisms and volumes of major sources of sediment (both natural and management-related), the volume of sediment storage and the sites where that sediment is stored in stream channels, and the net sediment output from the Redwood Creek basin at Orick, California. The budget was based on a combination of field work, monitoring and stream gaging, interpretation of aerial photographs and extrapolation of results from other studies. The time period chosen (1954-1980) encompasses four large floods in the basin (in 1964, January and March, 1972, and 1975), and was bracketed by the availability of air photos in 1954 and 1978. Field mapping in 1980 filled in many gaps in the air photo interpretation. The following sections describe how each item in Table 1 was estimated. Many different measurement units were used by various investigators in studies spanning many years. We tried to list the original measurements along with the appropriate conversions. All estimates for this sediment budget were converted to English tons, based on measurements of bulk densities of soil, colluvium and alluvium (listed below). This sediment budget does not differentiate sediment according to particle size, and both bedload and suspended sediment-sized particles are considered. We recognize that many of the items listed are rough estimates, and are based on extrapolations of data from small study sites to large areas. Nevertheless, we feel this method is adequate to show the relative importance of various erosional processes even if the exact volumes of sediment cannot be measured.

SEDIMENT PRODUCTION ASSOCIATED WITH ROAD NETWORKS:

Unpaved logging roads are commonly a source of sediment to streams channels. Roads contribute sediment through several processes: Cutbank erosion and failures, surface erosion from unpaved roads, erosion of inboard ditches, road fill failures, landing failures, and erosion of road fill at stream crossings. Although not as large as haul roads, skid roads and skid trails are more numerous and also contribute sediment to stream channels. In addition to those sources of sediment listed below, there are several unmeasured sediment sources: Cutbank and road fill failures that were not included under other mass movement categories, landing failures that feed into a stream, and sheetwash and Cutbank erosion from skid trails. As more data are collected from field studies, these categories may be added to the budget.

Cut bank erosion:

Ten grids of nine erosion pins each were installed on the east side C-line in Redwood National Park in 1979 (Madej, unpublished data). Pins were 9-inch steel nails that were painted orange, and they were driven into the Cutbank perpendicular to the ground surface until they were flush with the ground. Pins were spaced 18 inches horizontally from each other, above the talus pile at the toe of the Cutbank. Data covers period from Nov. 1979 to June 1986 (seven winters, with moderate intensity rains) at 10 sites, on both schist and sandstone terrain. Only 48 pins remained undisturbed for the seven-year period. For the 48 erosion pins that remained intact for seven years, mean depth of erosion was 1.12 inches. (1.12 in/7 years = 0.16 inch/year, or 1.6 inches (0.13 ft) in 10 years.) There was no significant difference between sandstone and schist terrain.

Many assumptions and simplifications were used to estimate a sediment yield from cutbanks:

1) Based on erosion pin data, a rate of 0.13 ft. of Cutbank retreat in ten years was applied to all haul roads in the basin. On abandoned roads, it was assumed that 10 years after road construction, a combination of revegetation and the cessation of road grading and ditch cleaning would protect cutbanks from further significant erosion and contribution of material into inboard ditches. Without road grading and ditch cleaning, a debris apron forms at the base of cutbanks and stores material eroded from upslope cutbanks. Cutbank slides would contribute sediment over and above that recorded by erosion pins, but this factor was not measured in the field.

2) Haul roads were assumed to have only one cut bank (no throughcuts were considered), with an average height of 10 ft. Skid trails were assumed to have negligible Cutbank erosion.

3) All material eroded from the Cutbank was assumed to reach the inboard ditch. Based on a road inventory in Redwood National Park (Spreiter, 1995) of more than 700 culverts, 70% of culverts draining inboard ditches feed into stream channels (the remainder were ditch relief culverts or drained springs). This value is considerably higher than Raines and Kelsey's value for Grouse Creek, an adjacent watershed. However, most of the 1250 miles of roads in the Redwood Creek basin are abandoned or unmaintained, with few functioning waterbars or ditch relief culverts. Therefore, we assumed that about 70% of sediment reaching the inboard ditch was delivered to a stream during the first ten years after road construction, with no contribution to streams after 10 years.

4) About 1400 miles of road were constructed in the Redwood Creek basin by 1978.

5) A bulk density of 100 lbs/ft3 (1.6 g/cm3) based on soil surveys (Popenoe, 1987) was used to convert volumes of eroded Cutbank material to mass. (This bulk density was used for all hillslope erosion calculations, unless noted otherwise).

The calculation used was:

10 ft. high cutbanks x 0.13 ft. retreat in 10 years x 5280 ft/mile = 6864 ft3 for each mile of haul road over 10 years x 70% delivery = 4805 ft3/mile

4805 ft3/mile = 240 tons/mile of haul road over a 10-year period.

240 tons/miles of road x 1400 miles = 336,000 tons from Cutbank erosion

This estimated yield of 240 tons/mile of road is similar to that of Reid and Dunne's measurement of Cutbank erosion of 15 metric tons/km of road per yr (=26.6 tons/mile of road per yr or 266 tons/mile of road in 10 years) for logging roads on the Olympic Peninsula, but greater than Raines and Kelsey's 1991 estimate of 13.5 tons/mile/yr or 135 tons/mile per 10 year periods for Grouse Creek, a 170 km2 basin adjacent to Redwood Creek.

Surface Erosion From Unpaved Roads:

Estimates of surface erosion were based on Reid and Dunne's work (1984) on logging roads in the Clearwater River, Olympic Mountains, Washington. There, under 3900 mm/yr of rainfall on sandstone and graywacke bedrock, the sediment yields from unpaved roads varied by use level:

Heavy use	500 tonnes/km/yr
Moderate use	42 tonnes/km/yr
Abandoned	0.51 tonnes/km/yr

These values need to be adjusted for conditions in the Redwood Creek basin. For Redwood Creek, the amount of surface erosion is probably less than in the Olympics because rainfall totals and rainfall intensities are less. Raines and Kelsey accounted for the difference in precipitation between Grouse Creek and the Clearwater basin by multiplying sediment yield rates by 0.76 (the ratio of the Grouse Creek R factor (a rainfall and runoff factor) to the Clearwater R factor). Redwood Creek has about the same R value as Grouse Creek, so the same method was used. Also, the average width of haul roads in the Redwood Creek basin is six meters (20 ft.) (based on road inventories of more than 150 miles of roads), which is 1.5 times the average width of roads in the Clearwater basin. Finally, only the sediment washed off from roads that drains into stream channels (via inboard ditches and culverts) should be counted in this sediment budget. From road inventories in the Redwood Creek basin (Spreiter, 1995), 70% of road drainage structures feed into stream channels. Thus, the adjustment factor for Redwood Creek is

0.76 x 1.5 x 0.70 = 0.80.

Erosion from road surfaces is very sensitive to traffic levels (Reid and Dunne, 1984), which in turn is dependent on the type of timber harvest, length of the harvest plan, and post-harvest activities. It was assumed that during the time period 1954-1980, all roads in the Redwood Creek watershed had heavy use for one year during timber harvest, moderate use for three years, and were abandoned the remainder of the time.

1400 miles of road constructed by 1978 = 2250 km of road.

1) Heavy use: 2250 km x 500 tonnes/km/yr x 1 yr = 1,125,000 tonnes
2) Moderate use: 2250 km x 42 tonnes/km/yr x 3 years: 283,500 tonnes
3) Abandoned: 2250 km x 0.51 tonnes/km/yr x 23 years = 26,400 tonnes

Total = 1,434,900 tonnes from surface of roads from 1954-1980.
(= 1,581,000 English tons)

Adjustment factor applied to roads: 0.80 x 1,581,000 tons = 1,265,000 tons.

If roads were actually heavily used for two years instead of one (which depends on the harvest history and log hauling routes), the total amount eroded over the 23-year period would be:

2.2×10^6 tonnes (2,400,000 English tons) or adjusted sediment production of 1,920,000 tons.

In Table 1, the smaller amount is listed because the level of road use is not well known.

Skid Trails

Little quantitative information is available for erosion from skid trails. Best and others (1995) determined erosion due to rilling and water diversions on skid trails in the Garrett Creek watershed (this value does not include skid trail stream crossing failures or general surface lowering from sheetwash). There, on about 5 km2 of lands with logged coniferous forests, 29,182 tonnes of sediment came from erosion on skid trails, or 5836 t/km2. Best (1984) stated that 348 km2 of the Redwood Creek basin upstream of the Prairie Creek confluence was tractor yarded by 1978. An additional 20.5 km2 in Lost Man Creek was logged, and mostly tractor yarded. We applied the erosion rate from skid trails in Garrett Creek to all tractor-yarded lands (142 mi2) in the Redwood Creek basin:

368.5 km2 x 5836 t/km2 = 2,150,566 tonnes = 2,400,000 tons

Erosion from Inboard Ditches

Based on a study of Garrett Creek, a tributary of Redwood Creek (Best and others, 1995), 2086 tonnes of road material eroded from inboard ditches along 12.7 km of road, or 165 tons of material/km of road, from 1956 to 1980.

This erosion rate was applied to the 2250 km of haul roads in the Redwood Creek basin:
2250 km x 165 tonnes/km = 371,000 metric tonnes = 410,000 tons.

Erosion from Haul Road Stream Crossings

Stream crossing failures contribute significant amounts of road fill into stream channels. Various inventories have produced several estimates of this type of erosion in different terrains. The older the road and the more storms it has weathered, the higher the probability that a crossing will have failed. Eighty percent of the roads in the Redwood Creek basin were built before the large storms in 1972 and 1975, and 66% of them were built before the 1964 flood. Many crossings failed and were rebuilt, only to fail again. Weaver and Hagans (1987) measured failures of crossings in haul roads and skid trails on 2214 ha in Redwood National Park, and the average crossing failure volume was 48 m3. Measurements for skid trail crossings were not distinguished from haul road crossings, and this value is considered to be low for the watershed as a whole. Best (unpublished data) measured erosion at 140 stream crossings. He found the average failed crossing volume (n = 51) was 208 yd3 (160 m3). The Redwood National Park inventory of more than 900 stream crossings (Spreiter, 1995) listed the average volume eroded from all stream crossings as 230 yd3, which includes crossings with no failure volume. In Garrett Creek (Best and others, 1995) 111 crossings were inventoried. Of these, about 50% of the crossings failed during the study period, and the average failure volume was 74 - 186 m3 (97 - 243 yd3). There are several sets of road inventory data that have not been finalized yet, and so the appropriate value for sediment derived from failed stream crossings will be revised as new data become available. This value will also be refined as failure rates are stratified by age of road and slope position. In the present version of the sediment budget, we assumed a failure rate of 50% during the study period (1954 to 1980) and used a value of 200 yd3 an estimate of erosion from failed stream crossings in the Redwood Creek basin.

The next task was to estimate the number of stream crossings in the Redwood Creek basin. Field mapping and air photo interpretation during various studies (Bundros, Klein, Alpert; Redwood National Park, unpublished data) inventoried the number of stream crossings on 90 mi2 of the Redwood Creek basin (one-third of the basin area). The number of crossings ranged from 21 to 45 crossings/mi2. For this budget the value of 30 crossings/mi2 was used.

Upstream of park boundaries: 162 mi2 x 30 crossings/mi2 = 4860 crossings
Park lands: 116 mi2 - [24,315 acres of old growth, or 38 mi2] = 78 mi2
78 mi2 x 30 crossings/mi2 = 2348 crossings

For this basin, a total of 7200 crossings is equivalent to about 5 crossings/mile of haul road. Individual subbasins range from 2 to 14 crossings/mile of haul road, depending on the position and size of road and the drainage density of the terrain.

The estimated sediment input from haul road crossing failures during this time period is:
7200 crossings x 50% failure rate x 200 yd3/failed crossing = 720,000 yd3
720,000 yd3 x 1.62 tons/yd3 = 1,166,000 tons from 240 mi2 of roaded land.

(A bulk density of 120 lbs/ft3 or 1.62 tons/yd3 was used because of the rocky composition of road fill). This estimate is equivalent to a sediment production of 4860 t/mi2. This value is lower than that for the nearby upper mid-Grouse Creek basin measured by Raines and Kelsey (2.79 m3/ha, or 7800 t/mi2), but higher than that for upper Grouse Creek and Cow Creek (900 to 1000 t/mi2) (Raines and Kelsey, 1991).

Skid Trail Crossings

Various road and hillslope inventories (Best, Alpert, Spreiter; unpublished data) documented average skid trail crossings to be 25 to 50 yd3 in size. Several assumptions were used to estimate an erosion rate from skid trail crossing failures on tractor logged hillslopes:

1) Skid trail density is 16 to 42 km/km2 (Best, unpublished data), which is two to five times the haul road density. Some areas have skid trail densities 7.5 times haul road densities (Redwood National Park, 1981). So, we assumed skid trail crossing density is four times that of haul road crossings, or 120 crossings/mi2 of tractor-logged terrain.
2) Assume average crossing failure volume is 25 yd3.
3) Assume 75% of skid trail crossings failed during this time period (field observations seem to bear out a higher failure rate in skid trail crossings than in haul road crossings)
3) Best's land use report says about 35,000 ha of the Redwood Creek basin was tractor yarded, and an additional 2050 ha were cut in the Lost Man area, or 37,050 ha (= 143 mi2)

143 mi2 x 120 crossings/mi2 x 25 yd3 x 75% = 321,750 yd3 = 521,000 tons from failures of skid trail crossings.

Surface Erosion from Disturbed Ground

Weaver and Hagans (1987) estimated the mass of sediment eroded from bare ground based on sediment trough data (0.05 to 0.1 cm of ground surface lowering during the first winter following ground disturbance.) That rate of ground lowering was roughly similar to what Marron and others (1995) measured from erosion pins installed on bare ground (0.03 cm to 0.46 cm/yr). Weaver and Hagans stated that only 3600 ha of bare ground (1/3 of the harvested area of 10,770 ha) would actually contribute sediment from surface erosion to streams. The mass of sediment reaching streams can be calculated by using their mean lowering rate of 0.075 cm x 3600 ha = 270,000 m3 = 477,000 tons.

Next, this value was extrapolated to the remaining area of the drainage basin. Best (1995) states that between 1949 and 1978, 25,445 ha (62,849 ac) of the Redwood Creek watershed was logged upstream of Redwood National Park boundaries. This figure only includes the original logging of old-growth forests, and does not include later reentries and harvest of second-growth. By 1970, 65 percent of the original coniferous forests of the basin had been logged, and practically all of that was tractor-yarded. Cable logging became more common in steep areas adjacent to streams between 1970 and 1978, but less than 6% of the watershed was cable yarded (Best, 1984). For this rough estimate of surface erosion, erosion from disturbed lands on cable yarded cuts is treated the same as on tractor-yarded areas. The assumption is that only one-third of the disturbed ground contributed sediment to a stream channel (Weaver and Hagans, 1987).

0.33 x 25,445 ha = 8400 ha = 84 km2

84 km2 x .0075 m of surface lowering = 630,000 m3 = 1,008,000 tons

The Lost Man Creek basin was not included in Best's 1995 study. There, approximately 2050 ha were logged:

20.5 km2 x .0075 m = 154,000 m3 = 271,500 tons

Total amount of surface erosion:

272,000 -Lost Man Creek
477,000 - Redwood National Park lands
1,008,000- Land upstream of Redwood National Park boundaries.
1,757,000 tons

GULLIES

A) Prairie gullies:
From field measurements and air photo interpretation Walter (1985) estimated the sediment production from gullies on all prairies in the Redwood Creek basin, including both natural and road-related gullies (248,411 m3, or 440,000 tons) between 1954 and 1978.

B) Forested lands:
Gullies are a common erosional feature on lands that have had timber harvest and road construction. Most gullies are caused by stream diversions, where water flows across a road and down a hillslope that did not originally have a channel. Such diversions are commonly caused by plugged or misplaced culverts. Stream diversions on roads produced most of the largest gullies and the bulk of hillslope erosion from the roaded areas. For example, Weaver and others (1995) documented that 94% of the total volume of hillslope erosion in the South Copper Creek study site was caused by diversions. In addition, Best and others (1975) found that 66% of road-related fluvial erosion in the Garrett Creek watershed was caused by stream diversions.

1)Within Redwood National Park boundaries: Weaver and Hagans (1987) extrapolated field measurements of gully erosion on 22 km2 of logged lands to all logged lands within the park. Their estimate of sediment derived from gully erosion is 1,200,000 yd3 (2,100,000 tons).

2) Upstream of Redwood National Park's boundary: Weaver and Hagans's extrapolation (1987) used soil classifications to define high, moderate and low yield terrains for gully erosion. Popenoe (personal communication) categorized Hugo and Masterson soils as those most susceptible to fluvial erosion. In the Park Protection Zone and upper basin 15,272 acres (6183 ha) are underlain by these soil types, so the high yield rate of Weaver and Hagans (260 m3/ha) was applied to this area. Stable soils, in terms of gully erosion, are Trailhead and Orick soil types (Popenoe, personal communication) which produce only 3 m3/ha. Upstream of park boundaries only 476 ac (193 ha) are underlain by these soils. In the remainder of the upper basin (25,620 ha), soils were considered to be at moderate risk from gully erosion, and we applied Weaver and Hagans' value for moderate yields (64 m3/ha.) The estimate of gully erosion for lands upstream of the park and for the Lost Man Creek basin (excluding prairies), is:

6183 ha x 260 m3/ha = 1,608,000 m3
193 ha x 3 m3/ha = 579 m3
25,620 ha x 64 m3/ha = 1,640,000 m3
2,045 ha x 64 m3/ha = 131,000 m3 (estimate for Lost Man basin)
3,379,579 m3 = 5,967,000 tons

Total gully yield for Redwood Creek basin:

440,000 tons - prairies
2,100,000 tons - in Redwood National Park
5,967,000 tons - upstream of park, and Lost Man Basin
8,507,000 tons

STREAMBANK EROSION

Streambank Erosion along tributaries

The length of stream channels of various stream orders was determined by using Redwood National Park's geographic information system, based on blueline streams shown on USGS 1:24,000 topographic maps, with extensions of small channels based on contour crenulations. The amount of streambank erosion for each order stream was extrapolated from measurements by Raines and Kelsey (1991) in the adjacent basin of Grouse Creek. Field observations in tributary basins of Redwood Creek and cross-sectional survey data in third- and fourth-order streams (1974 to 1988, unpublished data) support these extrapolated values. These values of streambank erosion in tributaries do not include streamside landsliding (which is documented in a later section). The time frame of streambank erosion is difficult to pinpoint exactly. Undercutting of young tree roots and the prominence of bare banks suggest recent erosion, but not precise timing. The value of sediment production from tributary streambank erosion for Redwood Creek could be refined by stratifying tributaries by bedrock and land use, and by making more intensive field measurements, but this step has not been completed yet.

Stream Order	Miles of Channel (Length in Meters)	Streambank Erosion (m3/m)*	Sediment Production (m3)	Sediment Mass (tons)
1	1529 (2.46 x 10^6)	0.17	418,296	738,500
2	473 (761,000)	1.63	1,240,400	2,190,000
3	183 (295,000)	1.57	463,150	818,000
4	86.2 (139,000)	0.20	27,800	49,000
5	61.2 (98,500)	0.31	30,500	53,900
			TOTAL	3,849,400

* Based on Raines and Kelsey (1991) streambank erosion values for Grouse Creek.

Mainstem Bank Erosion

The active channel width of Redwood Creek was defined by the width of bare or sparsely vegetated gravel bars and the low flow channel of Redwood Creek. The active channel width increased greatly in several reaches of Redwood Creek during the 1964 flood, and to a lesser extent, during the 1972 and 1975 floods (Nolan and Marron, 1995). Channel widening does not automatically translate into bank erosion, however, because much of the channel widening was due to an excessive amount of gravel being deposited on surfaces that were formerly covered with trees and shrubs. Also, streamside landslides were tabulated separately, and erosion of the toes of such slides was included under that category. Although cross section measurements yield the most accurate values for bank erosion, cross section data are not available to assess the effects of the 1964 and 1972 floods. In addition, cross section monuments were commonly established on stable points, such as bedrock outcrops, so cross section surveys may not be representative of typical bank conditions in a reach.

Bank erosion along Redwood Creek was documented in two ways. The first was by field mapping of erosion features. Field evidence of bank erosion included undercut tree roots and toppled streamside trees. This estimate is a minimum, however, because once the tree is washed away, little evidence for the amount of lateral retreat remains. The second method used sequential aerial photographs from 1954, 1958, 1965 and 1978 to measure bank erosion. The problem with using air photos is that determining accurate scales from older air photos was difficult. The exact location of streambanks was commonly obscured by shadows from large streamside conifers. It was also difficult to determine accurate bank heights. Bank height information was gleaned from the recent cross section surveys and field mapping. Channel widening through the erosion of three large gravel bars during the 1964 flood accounted for 25% of the total mainstem bank erosion. Although the alluvium in these bars originally was derived from upslope erosion processes, these were stable bars that had been deposited prior to 1954. Thus, counting erosion of these bars as sediment production during this time period is not double- counting the volume of sediment. The mass of sediment derived from streambank erosion along Redwood Creek between 1954 and 1980 is 2,070,000 tons.

MASS MOVEMENT

Streamside landslides along mainstem of Redwood Creek

Kelsey and others (1995) determined the volume of material contributed by streamside debris slides and earthflows along the mainstem of Redwood Creek. Landslide volumes were measured in the field, with supplemental measurements from air photos. Between 1954 and 1980, 4,000,100 m^3 (7,100,000 tons) of sediment entered Redwood Creek from these slides.

Landslides in tributary basins:

Pitlick (1995), through a combination of field mapping and air photo interpretation, determined the contribution of streamside debris slides in 16 tributary basins in the Redwood Creek. Almost 90% of the slides occurred post-1954, and these slides contributed 3,900,000 tons of sediment to tributary channels. He also classified tributary basins and their associated contribution of landslide material during the period 1954-1978 as:

Redwood dominated vegetation, Low relief: - 5000 t/km2
Redwood dominated vegetation, High Relief: - 13,800 t/km2
Douglas fir dominated vegetation, High Relief: - 26,100 t/km2

We extrapolated those rates of sediment production from streamside landslides to tributary basins which were not sampled and mapped during Pitlick's study.

Douglas fir, High Relief basins: 142 km2 x 26,100 t/km2 = 3,706,200 tonnes
Redwood, Low Relief basins: 42.5 km2 x 5000 t/km2 = 212,500 tonnes
Redwood, High Relief basins 2.9 km2 x 13,800 t/km2 = 40,020 tonnes
Lost Man Creek, also Redwood, Low Relief: (40.89 km2 x 5000 t/km2 = 204,450 tonnes

Total debris slide input from unsampled tributaries: 4,163,000 tonnes (4,600,000 tons).

Earthflows

The most areally extensive mass movement features in the watershed are earthflows (Nolan and others, 1976; Harden and others, 1978). The total area covered by active earthflows represents about 10% of the Redwood Creek watershed upstream of the confluence of Redwood and Prairie Creeks and very active earthflows comprise 2% of this area (Harden and others, 1978). The earthflows classified as "very active" can be considered streamside landslides in that they deliver sediment directly to major channels.

Earthflows are slow-moving (0 to 20 feet per year) persistent landslides. They are generally grass-covered rather than forested, and are often gullied (Gully erosion on these features was counted under "Prairie gullies." Studies in and near the Redwood Creek watershed by Kelsey (1978; 1980), Harden and others (1978), Nolan and others (1979a), Iverson (1984) and Iverson and Major (1987) have shown that earthflows deliver sediment to stream channels through both mass movement and fluvial processes and that earthflow movement is related to annual rainfall and patterns of groundwater flow. These previous studies have found that earthflows, despite their large areas, contribute relatively little sediment to Redwood Creek . Long-term data collection at the Minor Creek earthflow supports this interpretation. The Minor Creek earthflow contributes sediment directly into Minor Creek, a major tributary channel. The average volume of material contributed annually to Minor Creek by the landslide can be computed as the product of width, depth, and annual movement rate. Approximate width of the landslide near its toe is 260 feet. Depth to the failure surface is about 16 feet, and the long-term average rate of movement is about 1.6 feet per year (Iverson and Driedger, 1993). The annual average sediment volume transported downslope to the channel is therefore about 6656 ft3 or 250 cubic yards. Assuming a bulk density of 1.59 tons per cubic yard, based on data of Iverson (1984), the average mass of sediment contributed to the stream annually is about 400 tons. ≈ 25 T/Ac

If the 25-acre Minor Creek earthflow is considered representative of the 3,050 acres of very active earthflows in the entire Redwood Creek watershed (Harden and others, 1978), total earthflow sediment production can be estimated at approximately 50,000 tons per year, or 1,350,000 tons from 1954 to 1980. The estimate of annual sediment production is about 3% of the average annual sediment load of the creek. This calculation supports earlier findings that earthflows are not major sediment-producing features in the Redwood Creek watershed.

Forested Block Slides:

Forested blockslides are a type of slow-moving landslide typically located near shear zones on schist terrain. They behave somewhat like earthflows, but natural movement rates are typically slow enough to permit the establishment and maintenance of a coniferous forest. Sonnevil and others (1987) estimated 64,150 m3 (113,000 tons) of sediment was derived from Block slides from schist terrain within the park between 1954 and 1980. The area of park lands underlain by Redwood Creek schist is about 14,500 ha, or 145 km2.

(64,150 m3/145 km2 = 442 m3/km2)

We assumed that the same rate of blocksliding occurs on the schist terrain upstream of the park boundary: 3,846 ac of South Fork Mountain schist and 42,481 ac of Redwood Creek schist. We also assumed that forested Block slides will deliver sediment directly into stream channels.

46,327 ac = 18,755 ha = 187.6 km2

187.6 km2 x 442 m3/km2 = 83,000 m3 = 147,000 tons from upstream of park

+ 113,000 tons - park lands

260,000 tons

Debris torrents

The estimate of sediment production from landslides in the above section only considered those slides adjacent to high order (third to fifth order) channels. In some parts of the basin, especially those underlain by the Incoherent Unit of Coyote Creek (44,673 ac or 181 km2), debris torrents are common higher on the hillslopes and contribute sediment into lower order stream channels. The Garrett Creek study (Best et al, 1995) reported a rate of 4021 t/km2 of sediment from road-related debris torrents from 1956 to 1980, and in the adjacent basin of Grouse Creek Raines and Kelsey (1991) reported a similar rate for debris torrents of 4830 t/km2 during the same time period.

Based on the above values, an estimated yield from debris torrents for the Redwood Creek basin is:

181 km2 of susceptible terrain x 4500 t/km2 = 814,500 tonnes = 900,000 tons

During the January, 1997 storm several debris torrents were also generated from roads built on schist terrain. We assume that such debris torrents were generated in past large storms, although we have no measurements of past landslides. In Bridge and McArthur Creek basins (drainage area totaling 15.3 mi2), 51,000 yd3 of landslide material was delivered to stream channels by debris torrents in 1997 (Redwood National Park storm inventory report, 1997). This is an average of 3333 yd3/mi2. We applied this rate to all schist terrain in the basin (102.5 mi2): 102.5 mi2 x 3333 yd3/mi2 = 341,600 yd3 or about 460,000 tons. Because there were several large storms during the period covered by this sediment budget, this estimate may be low.

CHANGE IN CHANNEL-STORED SEDIMENT

Change in Sediment Storage in Tributaries:
Pitlick (1995) estimated the total amount of sediment stored in 74 tributaries to be 2 x 10^6 tonnes (2.2 x 10^6 tons). But this is not a change in storage, and the tributaries had already stored some sediment behind log jams and in gravel bars before the large floods of 1964, 1972 and 1975 occurred. We have no data on pre-1954 tributary sediment storage. Madej (1987) reported that 60-100% of recent flood deposits in tributaries were flushed out within 10 years of the flood, based on an analysis of tributary cross section data from 1974 to 1986. So, in this sediment budget we estimate that 80% of the amount of sediment that Pitlick measured in the tributaries was there before the flood, because the "excess" flood deposits would have been quickly flushed out of the steep tributary channels.

2,200,000 tons x 20% = 440,000 tons = Net addition to storage in tributary stream channels from 1954 to 1980

Change in Sediment Storage in Redwood Creek
Based on field measurements and air photo interpretation, Madej (1995) estimated that there was a net increase of 9.4 x 10^6 tonnes (10,400,000 tons) of sediment stored in the channel of Redwood Creek from 1947 to 1980. Most of this sediment was deposited during the 1964 flood. Details of field methodology and locations of sediment storage are listed in the 1995 report.

SEDIMENT OUTPUT

Bedload and suspended sediment have been measured near the mouth of Redwood Creek at the Orick gaging station since 1971. The U.S. Geological Survey publishes yearly summaries of these gaging efforts in their annual Water Resources Data reports. In addition, Knott (USGS, unpublished memo, 1981) estimated the probable sediment yields before gaging stations were established, for the period of 1954 to 1971. The total sediment output for Redwood Creek, including both bedload and suspended sediment discharge, for the period 1954 to 1980 was 45,000,000 tons.

= 10

Limitations to sediment budget calculations:

Many of the estimates included in this sediment budget were based on limited field data or were extrapolated from studies conducted elswhere. In addition, reentry of previously disturbed lands for harvest of second- and third-growth forests was not considered. Only one failure episode was considered because we could only document the most recent failure. For example, it is difficult to discern if road crossings or road reaches failed, were rebuilt, and failed again, although we know this sequence sometimes occurs on the landscape. The U.S. Geological Survey (in letter dated 1984) estimated a 20-30% accuracy of their daily suspended load measurements 95% of the time. Because there were no sediment records for the period 1954-1970, their estimates of sediment yield for that time period are necessarily subject to a greater (but unknown) error.

A sediment budget theoretically should balance; that is :
Sediment Input - Increase in Sediment Storage = Sediment Output.

The sediment budget as presented here does not balance perfectly. If we insert the numbers of sediment input, storage and output into the above equation, it may look like 14,500,000 tons of sediment is "missing," (which equals 32% of the total sediment output). This probably does not mean we are missing a sediment source that contributed 14,500,000 tons of sediment, however, because there is some source of error in estimating each element of the budget. These errors can easily be in the range of 30%. Nevertheless, the budget is a useful tool to indicate of the relative magnitude of different sediment sources. For example, landslides and road-related erosion are by far the dominant sources of material entering stream channels, whereas surface erosion and streambank erosion play a smaller role. As more field studies are conducted, these estimates may be refined and revised.

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