

**Draft Sensitive Watershed Nomination
and
Possible Land Management Practices
for Roads and Hillslope Areas of the
Redwood Creek Watershed**

Prepared for Redwood National and State Parks

By Pacific Watershed Associates

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Date: 9/18/99

To: Greg Bundros
Redwood National Park

From: William Weaver, Danny Hagans
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Subject: Sensitive Watershed Nomination and List of Possible Land Management Practices for Roads and Hillslope Areas of the Redwood Creek Watershed

Enclosed is the Sensitive Watershed Nomination, in loose leaf format with draft figures. Dave can finalize the figures by adding figure numbers. It can then be bound or not, depending on your needs. We have also included an electronic copy of both these documents in WordPerfect format.

Strategy - In addition to the Nomination document, we have included (attached) a brief listing and description of some possible land management practices (LMP) for limiting sediment delivery from roads (primarily) and hillslope areas within the Redwood Creek watershed. These were initially developed for the Navarro River watershed, but we have modified them for Redwood Creek. We have included this text as example contents of a possible "landowner guidance document" or "field guide" that could be developed to specifically assist private landowners in the Redwood Creek watershed. The "Handbook for Forest and Ranch Roads" (Weaver and Hagans, 1994) is another method of imparting information in a constructive format. Both these documents describe land management practices and how they are accomplished in a manner that is less threatening than new RULES. In addition, not everything can or should be solved with a rule. You might want to develop these and other ideas and use them as one of several constructive, cooperative methods you employ to work with landowners in the basin to accomplish your goals. These types of documents, together with train sessions or workshops, could be used to help landowners understand your (RNP) expectations. We believe your ultimate success in protecting downstream park resources must involve a number of complimentary strategies.

Rules - We have found that current specific requirements and methods of application of the Forest Practice Rules are not always sufficient to prevent continued or additional future impacts to park or other public trust resources (eg., anadromous fish). The Land Management Practices outlined below have been prepared to account for several (but not all) of the more important shortcomings in today's rules and practices. Additional mitigation measures, specifically for certain practices and certain areas of the watershed, can be developed and employed to prevent or reduce additional future erosion and sedimentation impacts. Some of the other potential changes that could be implemented are not items that are readily amenable to mitigation through LMP's. Rather, they involve regulatory procedures and other activities that involve the manner in which land use practices are implemented and monitored on-the-ground.

Rules do have a place in the control of accelerated sediment production and yield, and we have included a number of specific proposals for rule changes in the Nomination document. You have

seen most of these proposed rule changes in earlier drafts of this text. A number of recent proposals for rule changes have come before the Board to address some of the shortcomings that we recognized in our analysis. Copies of these proposals are available on the CDF web site if you do not already have them (we also have electronic copies). In addition, you may want to review the specific contents of the recently approved Habitat Conservation Plan for Pacific Lumber Company (PL). These new "rules" for PL cover most of the concerns we have discussed in the Sensitive Watershed Nomination, and they are relevant and may provide precedent for Redwood Creek. You can probably get a copy of the final HCP and the implementation agreement from P-L in Scotia. Call us if you want a contact.

Continuing issues and concerns - Forest operations of continuing concern (with reference to sediment problems) include: 1) certain harvesting and road building practices on selected steep, potentially unstable inner gorge slopes and steep stream side slopes, 2) abandonment of forest roads between forest harvest cycles, 3) lack of requirement for long term road maintenance, 4) the lack of a requirement to upgrade under-designed roads and drainage structures, and 5) the lack of a requirement for the identification of potential (future) erosion sites, including the implementation of cost-effective erosion prevention and erosion control work to correct existing and future sediment sources.

For erosion and sedimentation issues, a number of useful recommendations can be translated to mitigations and LMP's to address these concerns. Most of these have been included in the LMP's that we have attached. They cover such measures or needs as:

- 1) modification of harvesting practices and intensities on steep, potentially unstable inner gorge and stream side slopes,
- 2) conducting systematic erosion inventories of all roads (active and abandoned) within some designated watershed near or around proposed harvest areas, according to a reasonable schedule, so that future erosion sites can be identified and treated,
- 3) the need for regular road and drainage structure inspections and long term maintenance of all roads,
- 4) the need for temporary or permanent decommissioning of all roads which are not upgraded and maintained (including abandoned roads, and roads in certain sensitive watershed locations),
- 5) the need for all stream crossings with a diversion potential to be treated to eliminate the possibility for future stream diversion,
- 6) the need to upgrade and replace undersized culverts, and other drainage structure erosion control measures, according to some reasonable schedule,
- 7) the development of a Mass Erosion Hazard Rating (EHR) system, or a GIS-based slope sensitivity analysis for the entire watershed, which will identify areas which are in need of increased technical (geologic) review prior to certain land use operations,
- 8) the need for a geologist to review all proposed harvest and road building plans for steep and potentially unstable slopes in the watershed (as identified by the mass EHR or sensitivity analysis).

Procedures - Some problems do not readily lend themselves to the development of LMP's, and are therefore included in proposed regulatory changes in the Nomination text. Addressing and resolving these issues could also provide an increased level of protection to park resources. Other measures are aimed at "procedural issues." These measures are best addressed through direct negotiation and discussions with the responsible agencies and/or the affected forest landowners. Some of these problems require rule changes, and others may require changes in the way agencies carry out their responsibilities.

Several of these procedural issues or problems include:

- 1) the aggressiveness of implementation of the existing Forest Practice Rules (in many cases, the problem may not be "lack of enforcement" of the Rules...rather, it is the way in which flexibility in the Rules is employed, or not employed, to provide necessary protection to sensitive areas - this results in the uneven application of rules in areas and situations where more conservative, protective practices should be employed),
- 2) CDFG and NCRWQCB have limited staff and effectively do not participate in field reviews of timber harvesting and road building plans (this may be changing),
- 3) even when they are involved, CDFG and NCRWQCB (and the park) have limited "meaningful" input to the review process, in that they do not retain voting or veto power over specific plans or practices that are approved during the CDF review team process,
- 4) the need for increased RPF authority, responsibility, and accountability for the on-the-ground management of harvesting operations,
- 5) an improved CWE analysis procedure that results in meaningful on-the-ground mitigations, and
- 6) the continuing need for monitoring of both timber harvest practices (as they are occurring) and for long term monitoring of harvest areas and road systems, with monitoring results providing feedback into improved on-the-ground practices.

LMPs - A number of specific proposals for regulatory rule changes have been included in the text of the Sensitive Watershed Nomination. In addition, the following land management practices (LMP) have been included in this description of example techniques that are available for reducing downstream impacts from upstream land use activities through a non-regulatory framework. For brevity, we have not included the technical drawings and figures that were also included in the Navarro River watershed LMP document. These and other practices might well be included in a "voluntary" field guide for Redwood Creek landowners.

Practice (LMP)

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Sensitive Watershed Nomination for the Redwood Creek Watershed, Humboldt County, California

I. Nominator

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II. Identification of Nominated Watershed

Name of watershed or major streams:	Redwood Creek watershed, upstream from Redwood National Park, tributary to the Pacific Ocean near Orick, California
Planning watershed identification numbers:	many
U.S.G.S. topographic quadrangles:	Lord Ellis Summit Snow Camp Mountain Coyote Peak, and others
County:	Humboldt County
Township and range:	(See location map)
Approximate size of nominated area:	107,840 acres (169 mi ²)

III. Summary of Resources that are Significantly Threatened by Further Timber Harvest and Related Operations

Perhaps the most superlative, world renown groves of coastal redwood trees on earth exist on a series of narrow alluvial floodplains along the downstream third of the Redwood Creek channel southwest of Orick, California. These nationally significant resources were given National Park status and protection in 1968 and the park received international recognition as both a designated World Heritage Site and International Biosphere Reserve in 1982. The redwood ecosystem, and the natural resources it contains, are considered to have international significance and to be irreplaceable world treasures. These resources are a national trust and the citizens of the state and nation share in the responsibility for their protection and preservation.

Past floods and past and on-going forest operations on privately managed lands in the middle and upper Redwood Creek watershed, upstream from Redwood National Park, continue to impact and threaten valued park resources. Excessive watershed erosion and downstream sedimentation have caused channel aggradation, bank erosion, riparian vegetation mortality, toppling of old growth redwood trees from the Tall Trees Grove and other reaches, elevated summer water temperatures and serious declines in the populations of native salmonids. Rapid and substantial declines in anadromous fish habitat and fish populations in the Redwood Creek basin prompted Nehlsen et al. (1991) to classify the basin's fall chinook salmon stocks, coho salmon stocks and cutthroat trout stocks as being at moderate risk of extinction. The authors further contend that summer steelhead stocks in Redwood Creek are at high risk of extinction from both habitat damage and over fishing (Higgins et. al., 1992).

IV. Summary of Mitigation Measures Proposed to Provide Resource Protection

A variety of prevention and mitigation measures have been recommended for implementation to augment the current Forest Practice Rules. The intent of the proposed mitigations is to strictly limit erosion and sediment yield from roads and harvest areas upstream from Redwood National Park, and to improve fish habitat, while still accommodating timber harvesting and related activities on privately owned and managed timber lands.

The recommendations fall into four general categories: procedural, road-related, harvest-related, and watercourse protection measures. Perhaps the most productive measure is the inclusion of Redwood National Park as a formal voting and technical member of the CDF Review Team for timber harvesting plans within the Redwood Creek basin. Among a variety of technical improvements in forest practices, we have also called for the delineation of long term road management plans for private timberland owners in the watershed, to be submitted as a part of the cumulative effects analysis procedure, as a part of proposed Sustained Yield Plans or Habitat Conservation Plans, or as a separate planning and implementation document.

We have called for a complete inventory of potential erosion sources along all active and abandoned roads within the Redwood Creek basin, and the planning and implementation of road upgrading and road closure measures to "storm-proof" all roads. We have proposed requirements for long term maintenance (or alternatively, closure) for all seasonal and permanent roads. We have suggested several measures to provide additional watercourse protection and winter operations which will reduce erosion and delivery of fine sediment. Finally, we have proposed some restrictions on harvesting and other operations on steep and inner gorge slopes along stream channels. These recommendations are aimed at reducing landslide sediment contributions during the next large storm and eventually improving riparian and aquatic habitat throughout the Redwood Creek watershed.

Sensitive Watershed Nomination for the Redwood Creek Watershed, Humboldt County, California

Part I: Natural Resources Threatened by Timber Harvesting and Related Operations

Background

Redwood Creek drains a 280 square mile watershed in the mountainous, coastal region of northern California. It is one of several major streams and rivers that flow from the Klamath Mountains and Coast Ranges into the Pacific Ocean. The creek originates near elevations of 5,000 feet and flows approximately 55 miles in a narrow, elongated drainage basin north-northwest to the Pacific Ocean near Orick, California (Figure 1). In its historic, pristine condition, the mountainous Redwood Creek basin was extensively forested. In 1963, the world's tallest measured tree, along with several others nearly as tall, were discovered in redwood groves on alluvial soils of the lower Redwood Creek basin.

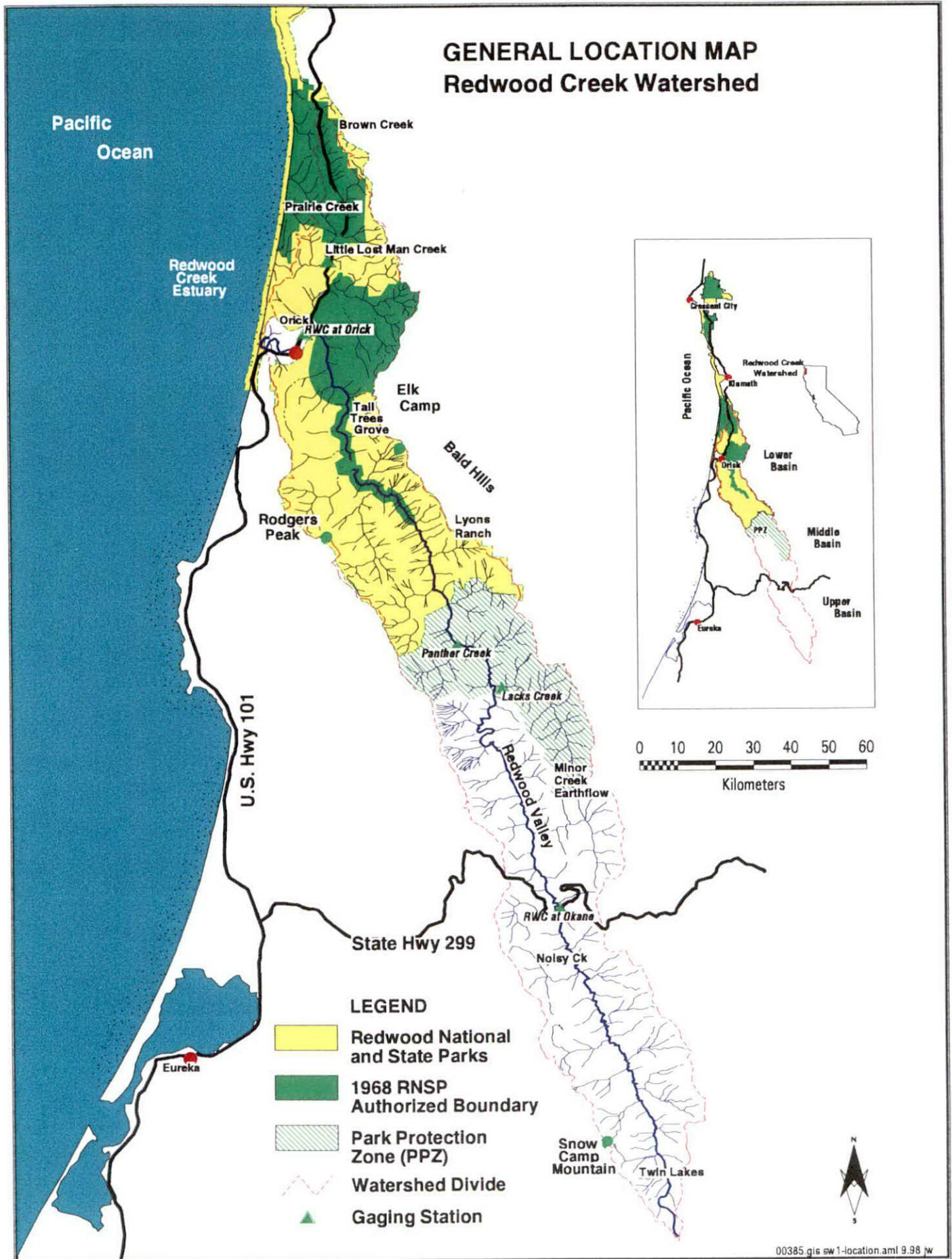
Early harvesting of the coastal redwood forests in portions of the lower Redwood Creek basin near the turn of the century used relatively primitive methods but were followed by rapid mechanized extraction of timber resources throughout the basin beginning in the 1940's. Spruce forests in the coastal strip near the basin's estuary were removed for uses in the war and to open lower floodplain areas for grazing and agriculture. Following World War II, timber harvest became the dominant land use in the upper half of the watershed. The post-war housing boom put great demands on the predominantly Douglas-fir forests of the upper basin. As the demand for specialty lumber increased, and more proximate forests had been logged, timber operations also increased in the redwood dominated coastal forests of the lower Redwood Creek basin.

Spurred by concerns of rapid timber harvesting in the 1960's and the discovery of the world's tallest measured trees, Congress established Redwood National Park in 1968. The park embraced a narrow, 1/4 mile-wide corridor of land along Redwood Creek which included superlative alluvial redwood groves containing the world's tallest known trees. The need to preserve entire watersheds, rather than just the magnificent alluvial groves of redwoods, became more and more apparent over time. Protection was recognized to require more than just ownership of redwood trees as downstream sedimentation effects threatened alluvial groves and showed few signs of improving. By 1978, when the National Park was expanded to include a number of tributary sub-basins in the lower watershed, approximately 90% of the conifer forests in the Redwood Creek basin, exclusive of Prairie Creek, had already been harvested (Best, 1984).

National Park Status

Redwood National Park was established in October 1968 to preserve significant examples of primeval coastal redwood (*Sequoia sempervirens*) forests and the associated streams and forests.

GENERAL LOCATION MAP Redwood Creek Watershed



The law which established the park (PL 90-545) fused three existing state parks into a 31 mile long national park through the addition of about 28,000 acres of privately owned lands. Parts of several watersheds were included in the original national park boundaries - roughly half of the watersheds of Lost Man Creek and Mill Creek (Del Norte County). Less than 10 percent of the Redwood Creek watershed was included in the park and this created a situation for potential adverse impacts from land uses upstream and upslope of the park (Figure 1).

Adverse impacts from land uses outside the park did occur and the Congress addressed these inherent problems in 1978. The "solution" was provided through public law 95-250 which expanded the national park boundaries by 48,000 acres to provide a more meaningful park for protection of natural resources of the initial national park (Figure 1). The creation and later expansion of Redwood National Park resulted in the inclusion of approximately 43,000 acres of cutover timberlands in the park. These lands, representing nearly 45 percent of the 106,000 acres included within the park boundaries, were intensely modified by pre-park logging activities.

Problems associated with cutover lands were addressed in the 1978 expansion legislation by authorization of up to \$33 million dollars for a watershed rehabilitation program. The long term goal of the land rehabilitation program is to reduce sedimentation from past logging, to return the downstream portion of the Redwood Creek basin to a reasonable facsimile of the natural state and to protect irreplaceable park resources.

World Heritage Status

Since its creation in 1968, and its later expansion, Redwood National Park has developed into a national park of world stature. The Park and its resources becomes more valuable to future generations as other old growth forests on private lands quickly disappear. In 1982, as recognition of its national and international significance, Redwood National Park was named to the elite status of a World Heritage Site by the 21 member United Nations World Heritage Convention Committee under the auspices of UNESCO. It is one of 112 select natural and cultural sites in 33 separate countries around the world which are protected for their outstanding universal value to humankind.

The selection of the Park as a natural heritage site is based on fulfillment of one or more qualifying criteria. World Heritage Sites must be outstanding examples representing the major stages of the earth's evolutionary history; be outstanding examples representing significant ongoing geological processes, biological evolution, and man's interaction with his natural environment; contain superlative natural phenomena, formations or features or areas of exceptional natural beauty; or contain the most important and significant natural habitats where threatened species of animals or plants or outstanding universal value still survive. Redwood National Park meets virtually all these qualifying elements.

Redwood National Park has within its boundaries the tallest known living specimens on earth. These redwood trees, located on the active flood plain of Redwood Creek, are the surviving remnants of a species dating back millions of years. Their international interest and appeal is evidenced by visitation from around the world and by the willingness of many to contribute substantial sums for the purchase, preservation and protection of dedication groves. The Park

serves as a major refuge for these magnificent trees and the flora and fauna which they are associated. They are considered to have international significance and to be irreplaceable treasures.

The World Heritage designation was established in 1972 because of global concerns over environmental deterioration and threatened loss of irreplaceable natural and cultural resources. In agreeing to accept the designation, each nation holds in trust for the rest of the world those parts of the world heritage that are found within its boundaries, that the world community has an obligation to support any nations discharging this trust, and that mankind must exercise the same sense of responsibility to the works of nature as to the works of man. The international honor bestowed upon Redwood National Park is a national trust and the citizens of the state and the nation share responsibility for protecting and preserving this natural resource for the enlightenment, use and enjoyment of future generations.

International Biosphere Reserve Status

Redwood National Park has also been designated as the California Coast Ranges International (CCRI) Biosphere Reserve by UNESCO. It is one of 243 units established in 65 countries which provide a worldwide network of protected areas where conservation is linked directly with sustainable development. The biosphere reserve designation recognizes the importance of an area in conserving the natural ecosystems and genetic resources of one of the world's unique natural regions. Through the biosphere reserve network, national parks are encouraged to function as mainstays of a region's environmental and economic health. Managers are encouraged to extend their horizon of concern beyond the park's boundary and to explore avenues of local, regional and international cooperation in underwriting its security. The biosphere reserve concept is a modern management approach and a new tool for fostering support for the protection, conservation and management of the world's outstanding natural resource areas.

Ideally, a biosphere reserve contains a core zone in which the conservation of natural ecosystems, and biological diversity, together with baseline ecological monitoring, is emphasized. The core area is typically a natural or minimally disturbed ecosystem which includes centers of endemism and genetic richness or unique natural features of scientific interest. Surrounding the core area are other zones which may include an experimental research area, an area(s) of modified or degraded ecosystem that is suitable for restoration (rehabilitation) to natural or near natural conditions, and a traditional use area. Overall, the biosphere reserve, such as Redwood National Park, serves as a bench mark for measurements of long-term changes in the biosphere and provides opportunities for ecological research, education, demonstration and training.

Activities within the core area and in surrounding areas can lay the scientific groundwork for attaining sustainable economic development that has minimal impact on natural ecological processes and genetic resources. Establishment of the CCRI Biosphere Reserve, with Redwood National Park as a core area and including a large watershed rehabilitation area and a comprehensive scientific research program, fits this model exceptionally well. Practical, applied research and education in conservation and rehabilitation can be applied to improve management of the upstream areas under private ownership. Working biosphere reserves can improve the

security of protected natural areas, like Redwood National Park, through better cooperation and understanding and through scientific research and improved management of adjacent areas. If genetic conservation is to be successful in weathering both natural and man-induced environmental change, a more flexible system of conservation and management is needed in which areas of undisturbed natural ecosystems, like the Park, are surrounded by sympathetic and compatible, sustainable land use. The indigenous fauna and flora within the core area are viewed as important reservoirs of genetic material. Such reservoirs are crucial to enhancing the stability and diversity of regional ecosystems and may provide for the re-establishment of populations in impacted areas where they have been eradicated. Such reservoirs can provide the seed for recovery of nearby areas as they re-establish their natural function.

Natural resources

The designations of National Park, World Heritage Site and International Biosphere Reserve are testament to the outstanding and unique natural resources of Redwood National Park. The most recognized of the Park's important natural resources are the superlative redwood groves growing on alluvial terraces and flood plains along the lower main stem of Redwood Creek. It is largely because of these redwoods, and the international attention they received when they were formally discovered in the early 1960's, that protective legislation creating the Park was assured. Yet these same groves are subject to impacts brought about by increased flooding and sedimentation effects which have their origins in the upper portions of the watershed, beyond the protective boundaries offered by their national and international status.

The health of the Park's most important alluvial redwood groves has been clearly linked to stream flow, sediment transport and channel morphology of the main stem of Redwood Creek, and these processes are most closely linked to events and conditions of the middle and upper drainage basin (Janda, et. al, 1975; Nolan and Marron, 1995; Hagans, et. al, 1986). The trees along Redwood Creek are sensitive to increased peak flows, aggradation, undercutting, and drowning associated with accelerated erosion and sedimentation from upstream watershed areas (Nolan and Marron, 1995). Trees along Redwood Creek have been toppled in past floods aggravated by increased sedimentation and others have been killed by permanent flooding of their root systems. Many trees are currently at risk from lateral channel migration and flooding, including those in the world famous Tall Trees Grove, if elevated sediment yield from the upper watershed persists and continues to cause aggradation in lower basin stream channels.

Redwood trees are not the only element of the forest ecosystem which continues to be threatened by human activities and physical processes occurring in the watershed. Redwood National Park (including Prairie Creek) occupies approximately the lower 40 percent of the drainage basin, and consequently receives and bears the brunt of increased sedimentation and altered flood flows which originate from upstream areas. Aside from documented impacts to riparian resources and alluvial redwood groves over the last four decades, human activities have caused a substantial decline in the ability of Redwood Creek to produce and support its unique and diverse native fish population (Ridenhour and Hofstra, 1994).

Redwood Creek contains a fish fauna that is relatively unique at this time for the streams of California (Ridenhour and Hofstra, 1994). Aside from the lingering effects of past hatchery operations in the Prairie Creek watershed, the basin is free from the effects of non-native species that have heavily impacted other nearby watersheds, such as the Eel River. At the same time, it still contains remnants of most of the diverse native fish populations that once inhabited the watershed in great numbers. Coho, winter chinook, winter and summer steelhead and cutthroat trout are still present, albeit in far fewer numbers than only a few decades ago.

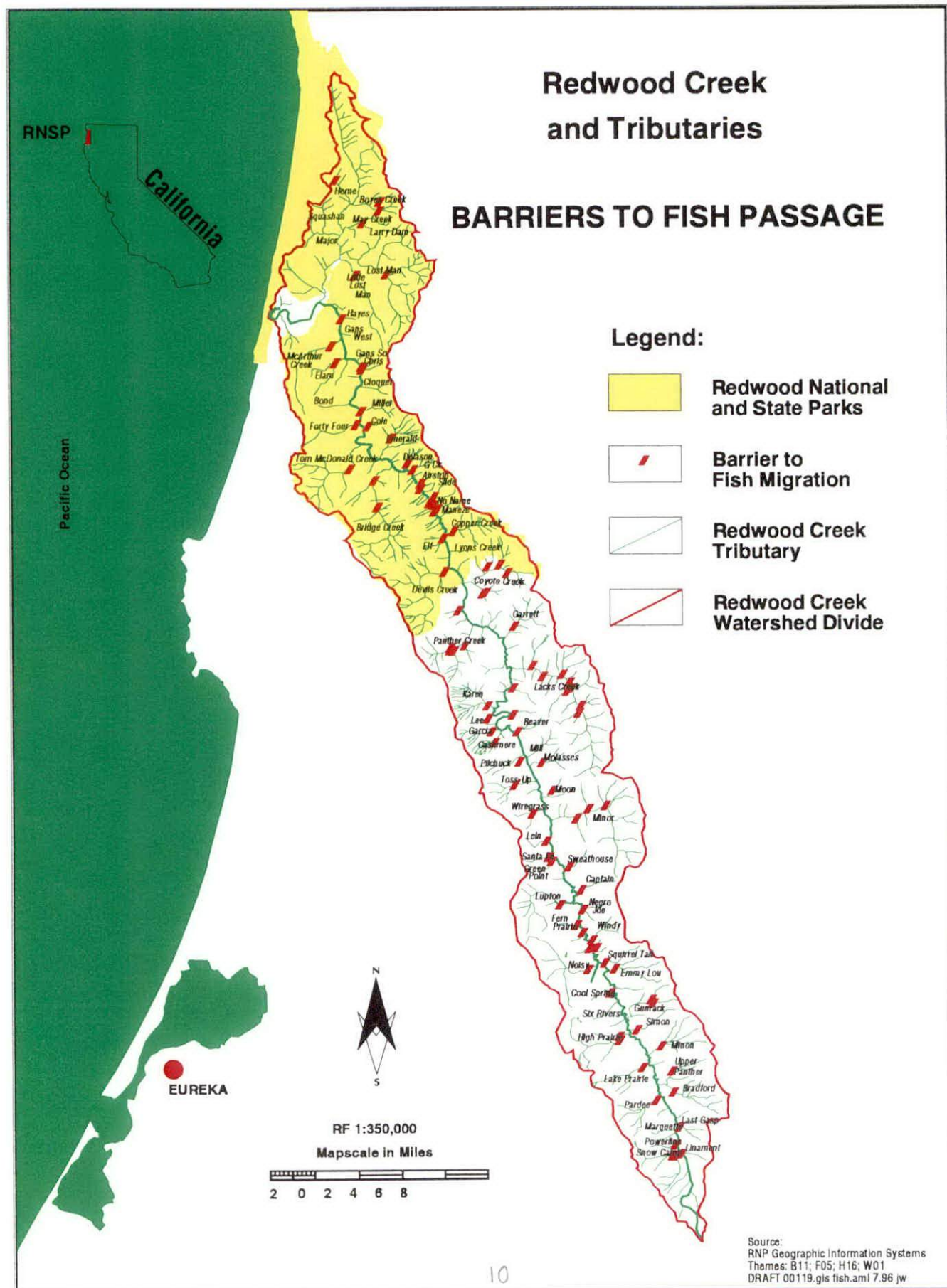
The magnitude of declines in salmonids in Redwood Creek has been significant. Information suggests that runs of anadromous salmon and steelhead had declined to approximately 10 percent of their former numbers by the mid-1970's (Denton, 1974). Reviewing recent population data, Nehlsen et al. (1991) have identified Redwood Creek's fall chinook salmon, coho salmon and cutthroat trout as being at moderate risk of extinction, and summer steelhead as being at high risk of extinction. Higgins et al. (1992) have identified Redwood Creek chinook and coho salmon stocks to be "stocks of concern" and summer steelhead stocks to be at high risk of extinction. Other species, such as the endangered tidewater goby, are dependent on a healthy, productive, naturally functioning estuary. Much of the salmonid declines and decreases in productivity of the Redwood Creek basin, including the estuary, can be attributed to the activities of humans (Hofstra and Sacklin, 1987; Ridenhour and Hofstra, 1994).

By the nature of its length, the main stem of Redwood Creek at one time provided the greatest potential opportunity for spawning and rearing habitat. Because of natural barriers, only a limited length of most tributaries are available to anadromous salmonids (Figure 2). Human activities which have impacted the main stem, as well as the tributaries, have likely had significant impacts on the anadromous salmon, trout and smelt because of the changes in the habitat required for their production and sustenance (Ridenhour and Hofstra, 1994). Loss of riparian shade canopy and cover, filling of pools, altered channel morphology (brought about by excessive and persistent sedimentation), increased rates of coarse bedload transport and influxes of fine sediment, cemented and embedded spawning gravels, decreased summer flows and aquatic habitat volume, increased water temperatures, loss or removal of organic debris (Klein et al., 1987), reduced invertebrate production, sedimentation of nursery habitat in the estuary (Hofstra and Sacklin, 1987), and increased vulnerability to predation (especially in the levee section of the lower river) are all in-basin factors which have been identified as elements responsible for the fisheries decline and failure to recover to any substantial level (Ridenhour and Hofstra, 1994).

Part II: Justification for Additional Protection

Background

The Redwood Creek watershed is one of the most thoroughly studied drainage basins in the western United States. Scientific studies conducted by the U.S. Geological Survey and the National Park Service between 1970 and 1979 provided the data and information necessary to link natural processes and the effects of land use on downstream erosion and sedimentation processes. Janda's (1975) landmark treatise on the status and condition of the Redwood Creek watershed as of 1973 provided the launching platform for two decades of quantitative



investigations on the causes and effects of erosion and sedimentation processes throughout the drainage basin. These studies, conducted on a number of topics and by a variety of researchers, continue to the present. They provide a nearly unmatched scientific research record on the causes and effects of erosion and sedimentation processes throughout the watershed (Nolan et al. 1995).

The park was established, in part, to provide permanent protection to the outstanding alluvial groves of the Redwood Creek basin. It became clear soon after the initial acquisition that simply purchasing the land and the trees would not provide the protection necessary to ensure survival of the most superlative alluvial groves along Redwood Creek. Not only was their survival tied to the health and condition of the immediate ecosystem, but, because of their tenuous location, processes and events occurring in the middle and upper drainage basin also threatened to impact their health and well being.

Shortly after the establishment of Redwood National Park, the Secretary of the Interior and the National Park Service launched a series of studies designed to understand the options available for protecting the park from the potential effects of upslope and upstream timber harvesting and erosion. The first of these studies (Stone et al. 1969) recommended restrictive buffers around the boundaries of the park and cooperative efforts to stabilize eroding lands in the upper Redwood Creek basin. A task force lead by Dr. Richard Curry (Curry, 1973) identified channel bank instability and landsliding as the main threats to the park's alluvial redwood groves and recommended increased efforts to change land management practices upslope and upstream from the park. These early investigations, conducted immediately after the creation of Redwood National Park, relied on a limited reservoir of available data for the watershed to describe natural processes and human-caused impacts to park resources (e.g., Stone et al. 1969). Threats to park resources, and the impact of human activities upstream and upslope from park lands, were largely inferred and the linkages between hillslope processes and stream channel impacts were poorly understood.

Understanding of the interactions among various geomorphic processes, human activities and watershed ecology was so incomplete that the Curry Commission (Curry, 1973) recommended initiation of an objective study of watershed processes needed to formulate management activities necessary for park protection. The U.S. Geological Survey, commissioned by the National Park Service, initiated the multi-year study in 1973 with three goals: 1) to describe park resources that are threatened by recent changes in watershed erosion and sedimentation, 2) to define the magnitude, frequency and duration of these threatening processes, and 3) to assess the impact of recent road construction and timber harvesting on those processes (Janda et al. 1975).

In his 1975 report, Janda outlines the status of the watershed and the nature of threats to park resources as of 1973. It is from this baseline that impacts and threats to park resources continue to be evaluated and measured. Have conditions changed since 1975? Are the current threats less than, greater than or are they unchanged from those that existed in 1975? How are past and current land use practices affecting park resources? Research conducted since Janda's initial evaluation of watershed conditions has provided a fairly clear picture of the current state of the basin and its stream channels; the nature, origin and level of continuing threats to park resources; the relationship between land use and downstream cumulative watershed effects; the connection

between upper basin processes and events and lower basin impacts; and the expected persistence of cumulative watershed effects.

Climate and hydrology

Climatic events, and the peak streamflows they produce, represent the driving mechanism which produces significant geomorphic response and watershed change in Redwood Creek (Harden, 1995; Harden et al. 1995; Weaver et al. 1995). They trigger widespread sediment production and delivery to the channel system, channel aggradation and rapid, dramatic changes in channel morphology; processes which have the greatest potential to dramatically impact park resources.

Redwood Creek is dominated by a Mediterranean climate with mild, wet winters and cool, dry summers. Most (>75%) of the estimated 80 inches mean annual precipitation (Rantz, 1969) falls in the five months from November through March; 90% falls from October to May (Coghlan 1984). Annual precipitation has a relatively wide range from 50 inches (1939) to over 93 inches (1938) as measured at Prairie Creek State Park in the lower basin (Janda 1975). Variation in annual precipitation is also significantly dependent on altitude, proximity to the ocean and slope aspect. Orographic influences are thought to exert a significant control on precipitation. For example, in 1974 annual rainfall on ridges at the pre-expansion south park boundary was 25% to 30% greater than at Prairie Creek State Park (Iwatsubo et al. 1975). Even gages in relative close proximity display differences in annual precipitation. Average annual rainfall measured at 18 storage and 3 recording rain gages in or near the Redwood Creek watershed between 1976 and 1979 ranged from 42 to 66 inches (Kelsey et al. 1981).

Most precipitation in the basin falls as rain. Snow falls fairly frequently at altitudes greater than 1,600 feet and rarely at lower altitudes (Janda et al. 1975). Rain-on-snow runoff events have produced the largest floods in the basin, including the 1964 flood. Janda et al. (1975) found that the years 1865-68, 1900-04, and 1951-58 were particularly wet and that the years 1869-75, 1882-89, and 1917-1937 were relatively dry. Rainfall amounts during the period encompassing the recent large floods of 1955, 1964, and 1972 were not unusually large in comparison to long-term records (Janda et al. 1975). Rainfall was relatively low between 1975 and 1995. Within this period, the highest rainfall amounts were recorded in 1982, 1983, and 1986 (NPS, 1995).

Between 1953 and 1975, Redwood Creek experienced a series of large flood events (Table 1). The floods, especially the 1964 event, resulted in severe and lasting geomorphic changes within the watershed. These changes included the initiation of widespread landsliding, gullying, channel widening and channel aggradation. Many of these storms were regional in extent, and similar changes have occurred throughout northern California (Waananen et al. 1971; Lisle 1981).

For many years prior to these series of flood events, the climate of northwestern California was relatively benign (Coghlan 1984). Localized flooding occurred, some of it quite severe, but no major, region-wide storm event had occurred since 1890 (Harden et al. 1978). In spite of such brief respites, Coghlan (1984) indicated that hemispheric circulation patterns favoring the development of storms such as those that produced historical large floods in the basin (Table 1) are a normal and permanent part of the area's climate and that such flood events should be expected to occur in the future.

Table 1. Peak discharges and recurrence intervals of geomorphically significant storms in the Redwood Creek basin, 1950-1980 (Harden et al. 1978; Coghlan 1984; Harden 1995)

Date	Discharge (cfs)	Unit discharge (cfs/mi ²)	Recurrence Interval (years)
January 18, 1953	50,000	180	25-30
December 22, 1955	50,000	180	25-30
December 22, 1964	50,500	182	45-50
January 22, 1972	45,300	163	10-12
March 3, 1972	49,700	179	10-12
March 18, 1975	50,200	181	?

Prehistorical evidence supports the concept that large floods are a common and regular part of local drainage basin history. For example, direct evidence of late Holocene storms is found in the depositional record of Bull Creek, a tributary to the nearby Eel River. Zinke (1981) recorded a minimum of 15 major depositional events in alluvial deposits at the mouth of Bull Creek in the past 1,000 years. He documented 10 major depositional events in the last 600 years (1 every 60 years).

Coghlan (1984) has summarized the pre-1950 geomorphic record of local watersheds in relation to evidence for comparably significant flood events¹. Such evidence includes flood-deposited gravel bars, gravel waves (such as those deposited in local rivers by the 1964 flood) and widespread synchronous landslide deposits. The record reveals evidence for the occurrence of a number of large floods that could have significantly altered regional stream channel morphology and the depositional record. Over the last 400 years, there have been a minimum of five storms of similar recurrence interval to the 1964 event (1964, 1890, 1861, 1735 and 1590), and at least two of them are thought to have been larger (Coghlan 1984). This yields a storm frequency of at least one every 80 years.

The regional record since 1850 contains two periods of storminess and two periods of storm absence. Because of the anomalous (storm-free) nature of the early to mid twentieth century climate, the 1954 to 1980 statistics for Redwood Creek are closer to the long-term values than

¹ A "significant" flood event is one which results in substantial, lasting geomorphic change to a watershed and its stream channels. The largest flood event, in terms of peak flow, is not necessarily the most significant event. Flood duration and geographical distribution, rainfall intensity, antecedent moisture conditions and land use, in addition to peak discharge, are factors that affect the geomorphic significance of a flood event.

might be suspected from the short length of record (Coghlan 1984)². Based on available data, Coghlan (1984) has estimated a long-term recurrence interval for large floods on Redwood Creek to be 45 to 50 years. This applies to storms greater than or equal to that of December 22, 1964, both in terms of intensity and regional size. At least five such storms have been identified in the geomorphic record. Since 1855, there have been four or five storms of magnitude greater than or equal to that of the December 1955 flood. The estimated recurrence interval of the 1955 storm is placed at 25 to 30 years (Coghlan 1984).

Not all major storms leave geomorphic evidence, even though they may have had significant effects on channel geomorphology. For example, the flood of 1861 left only scattered deposits, in spite of being the largest runoff event observed in the past 130 years (Kelsey, 1977; Harden et al. 1978). Likewise, when significant floods occur in relatively close progression, the later of these floods may largely erase evidence of the earlier events. The process is analogous to alpine glaciers that may destroy depositional evidence of former advances that were not as large as the more recent event.

For example, field evidence indicates that nearly all the geomorphic deposits likely to represent the post-1950 storms were deposited between 1964 and 1975 (Coghlan 1984). Significant storms comparable to that of March 1972 are estimated to have a 10-year recurrence period, but field evidence for these events tends to be obscured in the geomorphic record. Thus, 200 or 300 years from now, only one event will be inferred during this period, when in fact there were six.

The flood-producing storms of the late 1800's were probably comparable to those from 1953 to 1975, both in terms of rainfall amounts and flood peaks (Harden et al. 1978). Considering the apparently unprecedented magnitude of the 1861-1862 floods, and the subsequent major flooding of 1867, 1879, 1881, 1888 and 1890, it appears that the floods of the late 1800's had the potential to be at least as geomorphically important ("damaging") as the more recent floods (Harden et al. 1978). The differing erosional response of the Redwood Creek basin, and other watersheds of the north coast, has been attributed to changes in runoff regimes, hillslope stability and stream sediment loads caused by human activities, primarily timber harvesting and road building (Harden et al. 1978). No other major changes in watershed conditions or differences in storm parameters were noted during this period which help might explain the exceptionally large watershed response.

Basin characteristics

General physiography - The 280 square mile Redwood Creek basin is located in the Coast Range Province of northern California and is contained entirely within Humboldt County. It flows to the Pacific Ocean near the town of Orick. The elongate drainage basin is approximately 56 miles in length and varies from roughly 4 to 7 miles in width (Janda et al. 1975). Total basin relief is approximately 5,300 feet and tributaries are characteristically rugged (Figure 3). The heavily

² With additional low precipitation years since Coghlan's (1984) report, the 1975 - present period is likely similar to that of 1954 - 1980.

SHADED RELIEF Redwood Creek Watershed

Pacific
Ocean

Redwood National
and
State Parks



 Watershed Divide
 Redwood Creek



0 5000 10000 15000 20000
Meters

sw10-shaded.aml 00385.gis 98-10-08

dissected drainage basin is characterized by high local relief, moderately steep to steep unstable hillslopes and narrow valley bottoms. The average slope gradient is about 26 percent (Janda et al. 1975), but more than half of the hillslopes are in excess of 35 percent steepness, and over 30 percent are steeper than 50% gradient (Table 2). Significantly, over 70 percent of the slopes steeper than 65% are located on sensitive stream side inner gorges areas.

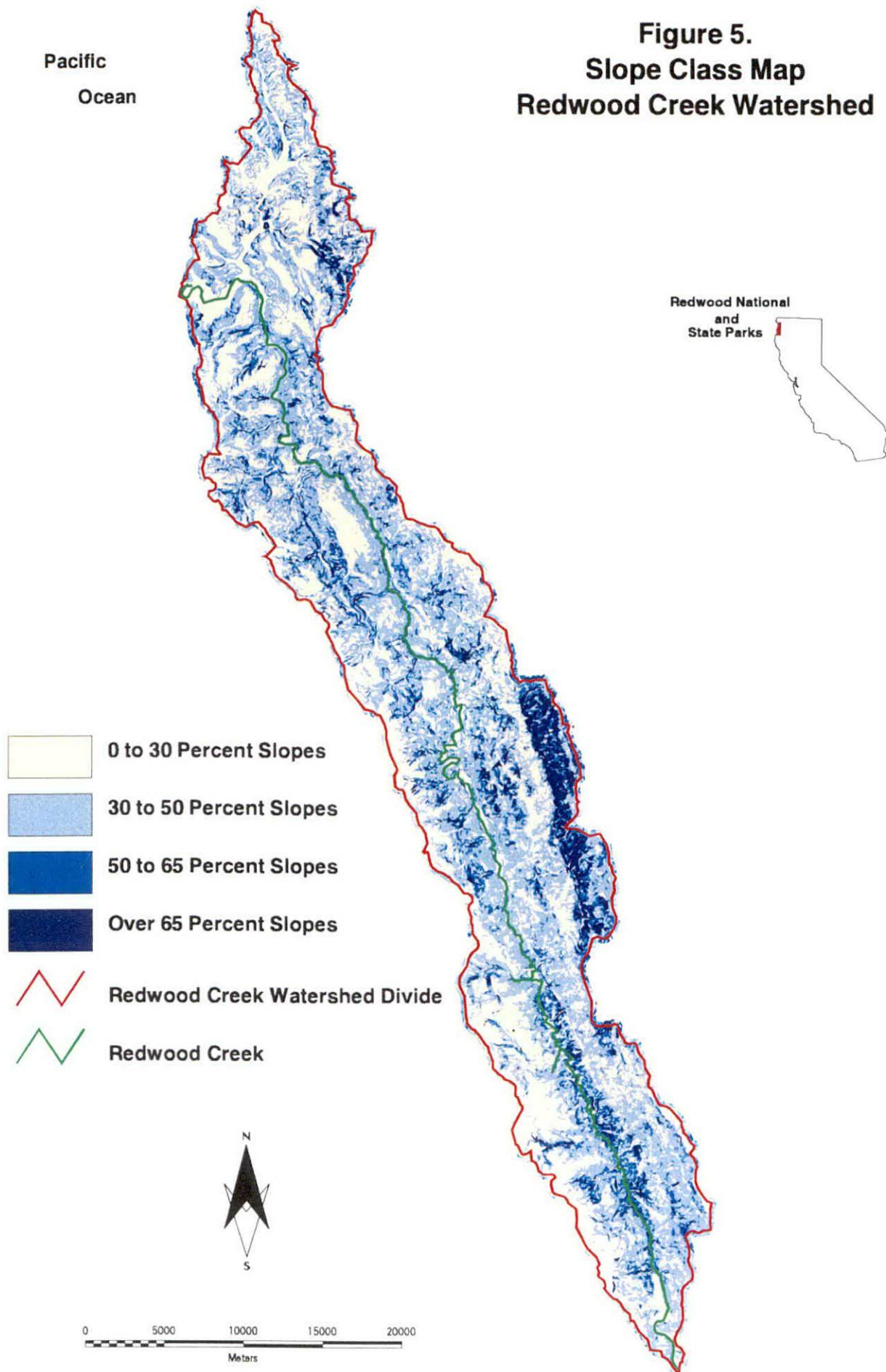
Table 2. Distribution of slope units of the Redwood Creek Basin upstream from R.N.P.			
Slope unit	Middle Basin (PPZ) - (acres)	Upper Basin (acres)	Total (acres)
<50%	16,300	55,800	72,200
50% - 65%	5,200	17,000	22,200
>65%	4,100	5,600	9,700
TOTALS	25,600	78,400	104,100
Streamside slopes >65% (steep inner gorge slopes)	3,200	3,900	7,200

The steepest slopes are found along the eastern side of the watershed (e.g., Lacks Creek and Minor Creek) in areas underlain by hard sandstone bedrock (Figure 4). In these areas, steep stream-side slopes often exceed 65 percent gradient. Debris slides and debris avalanches are largely restricted to slopes steeper than 50 percent, most of which occur as inner gorge slopes along incised stream channels (Janda et al. 1975). Most of the Redwood Creek basin has experienced substantial late Cenozoic uplift. This uplift, in concert with rapid channel downcutting, has resulted in the formation of steep, stream-side inner gorge slopes along the main stem Redwood Creek channel and most major tributary streams (Kelsey, 1988).

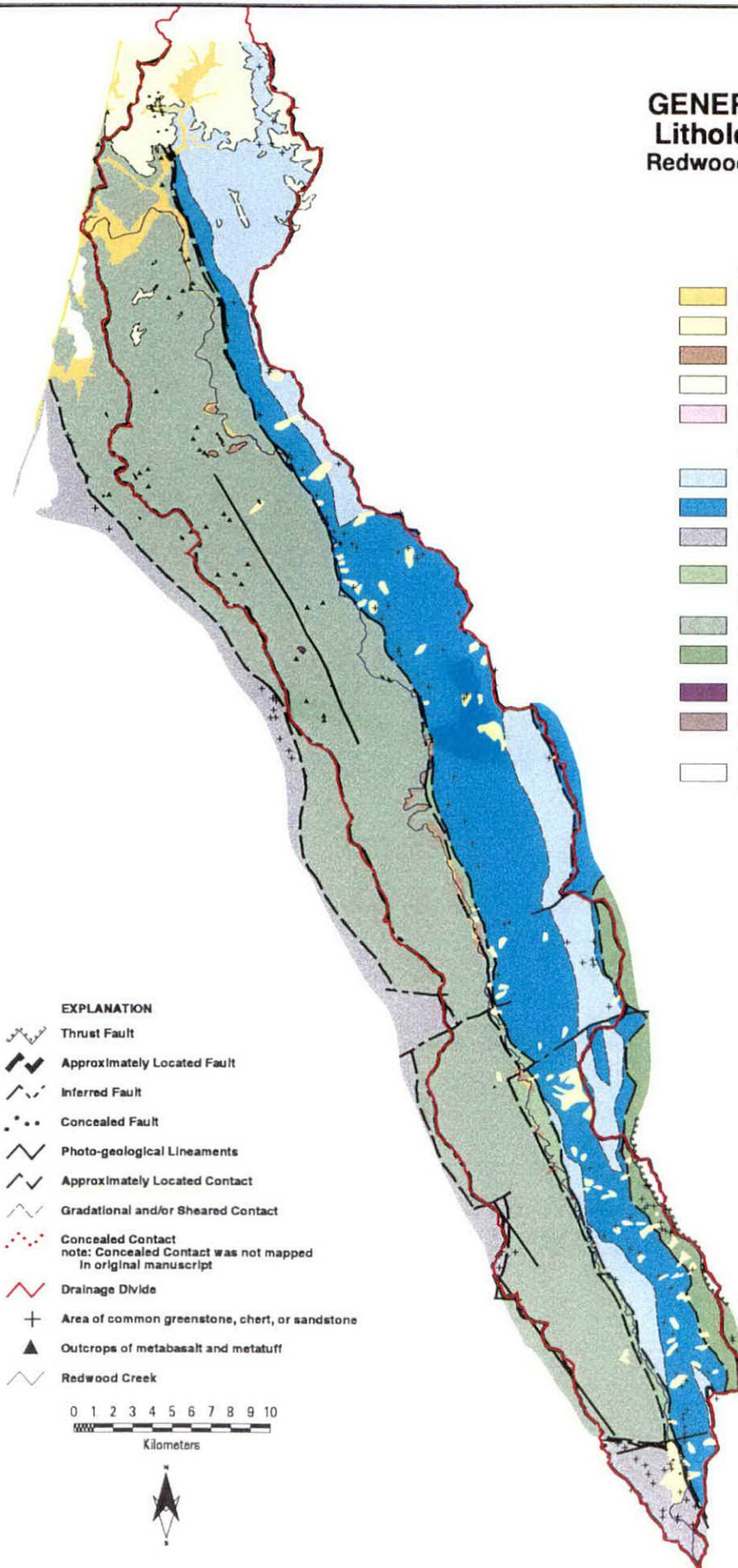
Geology - The basic geology of the Redwood Creek basin was most recently mapped and described Harden et al. (1982) and Cashman et al. (1995)(Figure 5). The basin is underlain by the Franciscan Complex of unmetamorphosed sandstone and siltstone, schist and scattered blocks of chert, conglomerate, and volcanic blocks. The basin is bisected by the Grogan Fault Zone (which defines the course of the main channel for much of its length) and several other parallel faults. Faults typically form the boundaries between lithologic units of the Franciscan Complex in the watershed. In general, slopes west of the Grogan Fault are underlain by schist and slopes east of the fault are underlain by sandstone and mudstone.

The distribution and spatial abundance of rock types in the Redwood Creek basin is depicted in Table 3. Harden et al. (1982) distinguished two basic sedimentary rock types east of the Grogan fault: the Coherent Unit of Lacks Creek and the Incoherent Unit of Coyote Creek. As the names

Figure 5.
Slope Class Map
Redwood Creek Watershed



GENERAL GEOLOGY Lithology and Faults Redwood Creek Watershed



DESCRIPTION of MAP UNITS

- [Ga] Modern Alluvium
- [Ql] Landslide Deposits
- [Qt] Stream Terrace Deposits
- [QTc] Coastal Plain Sediments
- [Ti] Tertiary Intrusive Rock
- FRANCISCAN ASSEMBLAGE
Sandstone & Mudstone**
- [KJf] Coherent Unit of Lacks Creek
- [KJfc] Incoherent Unit of Coyote Creek
- [KJfsc] Sandstone and Melange
Unit of Snow Camp
- [KJfg] Metamorphosed Sandstone and
Mudstone of the Grogan Fault Zone
Schist
- [KJfr] Schist of Redwood Creek
- [KJfs] South Fork Mountain Schist
- [t] Tectonic Blocks
- [Sp] Serpentine
- KLAMATH MOUNTAIN ROCKS**
- [Ju] Serpentinites, Metavolcanics,
and Metasedimentary Rocks

Table 3. Mapped bedrock units of the Redwood Creek Basin upstream from R.N.P.			
Bedrock Unit	Middle Basin (PPZ) - (acres)	Upper Basin (acres)	Total (acres)
Kjfr (Redwood Creek schist)	8,120	34,370	42,490
Kjfc (incoherent unit of Lacks Creek (silt- and mudstones))	12,750	22,300	35,050
Kjfl (coherent unit of Lacks Creek (mostly sandstones))	4,110	6,740	10,850
Kjfg (meta sandstones and mudstones of Grogan fault)	110	3,760	3,870
Kjpsc (Snow Camp Mtn. sandstone and melange)	0	3,710	3,710
Ql (landslide deposits)	500	2,540	3,040
Qt (stream terrace deposits)	10	760	770
Qal (modern alluvium)	20	440	460
Ju (Klamath Mtn. rocks)	0	380	380
unmapped	30	200	230
s (serpentine)	10	0	10
t (tectonic blocks)	5	0	5
TOTALS	25,665	75,200	100,865

imply, the Incoherent Unit of Coyote Creek is largely composed of poorly bedded, highly fractured and sheared mudstones that are highly susceptible to both fluvial erosion and mass soil movement. Slopes display a rolling, subdued topography similar to that formed elsewhere on the Franciscan melange.

The Coherent Unit of Lacks Creek is composed of well indurated, interbedded sandstone and mudstone and the resulting units are relatively more resistant to erosion. It forms steep slopes and over 60% of steep inner gorge slopes in the basin are underlain by this rock type (Table 4). Slopes underlain by the incoherent unit are susceptible to gully and earthflow activity while slopes in the coherent terrain are much steeper and dominated by rapid, shallow landsliding processes.

Table 4. Mapped bedrock units on inner gorge slopes of the Redwood Creek Basin upstream from R.N.P.			
Bedrock Unit	Middle Basin (PPZ) - (acres)	Upper Basin (acres)	Total (acres)
Kjfr (Redwood Creek schist)	200	920	1,120
Kjfc (incoherent unit of Lacks Creek (silt- and mudstones)	510	700	1,210
Kjfl (coherent unit of Lacks Creek (mostly sandstones)	2,530	1,960	4,490
Kjfg (meta sandstones and mudstones of Grogan fault)	10	290	300
Kjfs (Snow Camp Mtn sandstone and melange)	0	20	20
Kjfs (South Fork Mtn. schist)	0	10	10
Ql (landslide deposits)	10	15	25
Qt (stream terrace deposits)	5	10	15
Qal (modern alluvium)	0	5	5
Ju (Klamath Mtn. rocks)	0	0	0
unmapped	0	0	0
s (serpentine)	0	0	0
t (tectonic blocks)	0	0	0
TOTALS	3,265	3,930	7,195

The aerially most extensive rock unit in the basin is the Schist of Redwood Creek (Table 3; Figure 5). It covers approximately 42% of the middle and upper watershed areas, and is the predominant rock type found west of the Grogan Fault. It consists of both metasedimentary rocks (mudstones and sandstones) as well as metavolcanics (basalts and tuffs). Most outcrops show extensive deformation and fracturing resulting in rock incompetence that contributes to high erodibility (Hagans et al. 1986) and slope instability (Kelsey et al. 1995).

Soils - Upland soils of the Redwood Creek basin were mapped at a scale of 1:62,500 as a part of the California Cooperative Soil-Vegetation Survey completed in 1962 (Alexander et al. 1959-

1962). Soil-vegetation relationships were typically used to infer soil types from nearby sampled sites in other watersheds. More modern soil mapping has been undertaken in the lower Redwood Creek basin (USDI, 1992) and revised map units, land use interpretations and soil series descriptions have been developed based on 24 pedons for these areas (Popenoe, 1987). Additional, modern mapping of the upper basin awaits a new National Resource Conservation Service (NRCS; formerly the Soil Conservation Service) soil survey.

Differing lithologies and weathering stages have resulted in the development of distinctive soil units in the basin. These soil units, in turn, display different sensitivities to fluvial erosion and mass soil movement. In the lower basin, the depth of the regolith appears to be controlled by small scale relief (swales, ridges, etc) rather than hillslope position (upper, middle, lower) (Popenoe, 1985). In contrast, the degree of soil development appears to be more related to basin position with greater clay accumulation and iron oxidation in soils in upper, gentler slope positions. Increasing clay and iron content, in turn, have been associated with lower rates of soil erodibility (Durgin and Tackett 1981). Weaver et al. (1995) also identified increasing clay content and rock fragment content as significant natural deterrents to gully erosion on disturbed sites in the Redwood Creek basin.

In addition to specific land use variables, physical soil characteristics have been identified as strongly influencing rates of gully erosion and sediment yield from cutover and roaded lands in the lower basin (Weaver et al. 1995). Rocky, shallow soils are preferentially developed on the indurated bedrock of the Coherent Unit of Lacks Creek while clay- and iron-rich soils appear to be preferentially formed on the low gradient upland slopes and ridge-tops of the Schist of Redwood Creek. Both soil types resist gullyng.

In contrast, soils developed on the Incoherent Unit of Coyote Creek often occupy large, poorly drained amphitheaters with relatively high drainage density and poorly incised stream channels. These soils are typically characterized by relatively low clay content (<35%) and low rock fragment content (<35%), poor drainage, mottling and areas of slope instability. In lower basin study sites, high gully yields were exclusively limited to relatively deep soils which contain comparatively low concentrations of clay and rock fragments (Weaver et al., 1995).

Erosional processes - Over the last 20 years, extensive research has been performed throughout the Redwood Creek watershed to characterize the nature, cause, magnitude and effects of natural and accelerated erosion and sedimentation in the basin. Serious, quantitative studies began with USGS studies in the 1970's (Janda et al. 1975; Nolan et al. 1976; Harden et al. 1978; Janda 1977; Iwatsubo and Averett 1981; Marron 1982, Marron et al. 1995; Nolan and Marron 1995) and continued with a variety of National Park Service sponsored investigations following the 1978 expansion of park boundaries (for example, Kelsey et al. 1981; Pitlick 1982; Coghlan, 1984 ; Best 1984; Madej 1984; LaHusen 1984; Ricks 1985; Sonnevill et al. 1987; Walter 1985; Varnum and Ozaki, 1986; Hagans and Weaver 1987; Hofstra and Sacklin 1987; Iverson and Major 1987; Ozaki 1988; Lisle and Madej 1992; Madej 1992; Kelsey et al. 1995; Pitlick, 1995; Weaver et al. 1995). Work has been conducted on both park lands in the lower basin as well as on private forest lands upstream from the park.

Previous erosional studies have documented and quantified each of the erosional processes contributing sediment to Redwood Creek and its tributaries. The importance of each erosional

process, in relation to the protection of park resources, is dependent on the timing and quantity of sediment that is delivered to Redwood Creek. Erosion which occurs on lands upstream from the park, while perhaps important to the productivity of the lands where it occurs, is of little consequence to park resources unless it is delivered to stream channels that eventually feed Redwood Creek and pass through the park.

The dominant processes contributing to sediment yield in the Redwood Creek basin include several types of mass soil movement (landslide) and fluvial processes. Certain soil types and bedrock materials in the watershed are indicative of, or susceptible to, mass movement processes while others are sensitive indicators of susceptibility to fluvial erosion processes (Table 5; Figures 6 and 7). Nearly 40% of the watershed is underlain by unstable bedrock types (Table 3) or these "sensitive" soils (Table 5). Similarly, over 40% of the steep inner gorge slopes in the basin are underlain by sensitive soil units which are prone to either mass soil movement or severe gullyng (Table 6). Land use activities in these areas are especially prone to accelerating naturally high rates of erosion, landsliding and sediment yield.

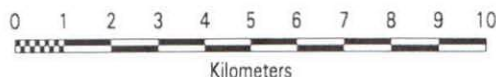
Table 5. Distribution of sensitive soil units of the Redwood Creek Basin upstream from R.N.P. (see also Figures 6 and 7)			
Soil Map Unit	Middle Basin (PPZ) - (acres)	Upper Basin (acres)	Total (acres)
Atwell (mass movement)	1,490	4,870	6,360
Yorkville (mass movement)	580	1,460	2,040
Colluvium (mass movement)	1,140	300	1,440
McMahon, Kinman, Orick, Sites, etc. (impaired drainage)	950	2,160	3,110
Hugo (fluvial)	5,740	6,030	11,770
Masterson (fluvial)	4,510	10,760	15,270
SUBTOTAL (sensitive soils)	14,410	25,580	39,990
Non-sensitive soils	11,230	53,450	64,670
TOTALS (all soils)	25,640	79,030	104,660

GENERALIZED EROSION PROCESSES BASED UPON SOIL TYPES Lower Redwood Creek Watershed

This map integrates soils mapping within Redwood National Park (in house) with published maps (California Cooperative Soil Survey-Soil Vegetation Survey) in the upper Redwood Creek basin. Soil types were grouped according to dominant geomorphic process, which are displayed here. Soil mapping in the upper basin is older, less detailed and less spatially accurate than that in the lower basin.



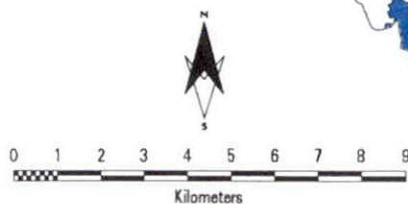
-  Existing Landslide
[Soil-Veg: 700S]
-  Susceptible to Fluvial Erosion
[Soil-Veg: 812, 821, 840]
[RNP: 121, 124, 125, 135, 224, 227, 228, 235, 238, 324, 327, 328, 338, 335, 424, 428, 438, 325]
-  Contains Active Earthflows
[Soil-Veg: 752, 823]
[RNP: 122, 123, 133, 323, 423]
-  Susceptible to Slumps and Soil Creep
[Soil-Veg: 839, 855, 91x, 849]
[RNP: 112, 120]
-  Relatively Resistant to Fluvial Erosion and Mass Movement (Older Landforms, Upper Surfaces, More Resistant to Erosion) [Soil-Veg: 813 - 816]
[RNP: 101, 115, 136, 200, 208, 214, 218, 318, 418, 308, 315, 414, 418, 312, 300, 307, 309, 329, 229, 219, 209, 319]
-  Susceptible to Debris Slides
(Course Soils having impaired drainage formed on Schist)
[Soil-Veg: 823m] [RNP: 421, 431]
-  Alluvial Soils
(Susceptible to inundation, deposition and re-working)
[Soil-Veg: 700w, 100 200 200w]
[RNP: 100, 102, 119, 213, 400, 401, 402 999]
-  Other
[Soil-Veg: 835, 834, 847, 7118] [RNP: 302]
-  No Data
-  Watershed Divide
-  Redwood Creek



GENERALIZED EROSION PROCESSES BASED UPON SOIL TYPES Upper Redwood Creek Watershed

-  Existing Landslide
[Soil-Veg: 7006]
-  Susceptible to Fluvial Erosion
[Soil-Veg: 812, 821, 840]
[RNP: 121, 124, 125, 135, 224, 227, 228, 235, 238, 324, 327, 328, 338, 335, 424, 428, 438, 325]
-  Contains Active Earthflows
[Soil-Veg: 752, 823]
[RNP: 122, 123, 133, 323, 423]
-  Susceptible to Slumps and Soil Creep
[Soil-Veg: 839, 855, 91x, 849]
[RNP: 112, 120]
-  Relatively Resistant to Fluvial Erosion and Mass Movement
(Older Landforms, Upper Surfaces, More Resistant to Erosion)
[Soil-Veg: 813 - 816]
[RNP: 101, 115, 136, 200, 208, 214, 218, 318, 418, 308, 315, 414, 418, 312, 300, 307, 309, 329, 229, 219, 209, 319]
-  Susceptible to Debris Slides
(Course Soils having impaired drainage formed on Schist)
[Soil-Veg: 823m]
[RNP: 421, 431]
-  Alluvial Soils
(Susceptible to inundation, deposition and re-working)
[Soil-Veg: 700w, 100 200 200w]
[RNP: 100, 102, 119, 213, 400, 401, 402 999]
-  Other
[Soil-Veg: 835, 834, 847, 7118]
[RNP: 302]
-  No Data

 Watershed Divide
 Redwood Creek



This map integrates soils mapping within Redwood National Park (in house) with published maps (California Cooperative Soil Survey-Soil Vegetation Survey) in the upper Redwood Creek basin. Soil types were grouped according to dominant geomorphic process, which are displayed here. Soil mapping in the upper basin is older, less detailed and less spatially accurate than that in the lower basin.

Table 6. Distribution of sensitive soil units on inner gorge slopes of the Redwood Creek Basin upstream from R.N.P.			
Soil Map Unit	Middle Basin (PPZ) - (acres)	Upper Basin (acres)	Total (acres)
Atwell (mass movement)	90	225	315
Yorkville (mass movement)	0	5	5
Colluvium (mass movement)	740	125	865
McMahon, Kinman, Orick, Sites, etc. (other impaired drainage)	5	0	5
Hugo (fluvial/gully)	555	775	1,330
Masterson (fluvial/gully)	165	295	460
SUBTOTAL (sensitive soils)	1,555	1,425	2,980
Non-sensitive soils	1,690	2,475	4,165
TOTALS (all soils)	3,245	3,900	7,145

Many hillslopes in the Redwood Creek watershed are inherently unstable as a result of steep slope gradients created by recent uplift and subsequent stream channel incision, low shear strength of pervasively sheared and fractured bedrock, and seasonal saturation of soils and regolith. Several mass movement processes are active, including soil creep, slow persistent landslides (earthflows) and rapid episodic landslides (Nolan et al. 1976; Harden et al. 1978; Kelsey et al. 1981; Pitlick 1982; Kelsey et al. 1995). The historic distribution of these processes is primarily related to lithology, hydrology, slope steepness and land use.

Harden et al. (1978) concluded that deep gravitational *soil creep*, as well as near-surface soil displacement from freeze-thaw and biogenic processes, are relatively ineffective at delivering sediment to Redwood Creek and its tributaries.

The most aerially extensive of the active mass movement features found within the drainage basin are *earthflows* (Nolan et al. 1976; Harden et al. 1978). These “soil glaciers” of slow moving landslide material cover about 10 percent of the watershed surface, and very active earthflows

(some moving up to 20 feet per year) comprise approximately 2% of this land (Harden et al. 1978). Earthflows are largely bedrock controlled and are found preferentially on incompetent, highly fractured bedrock (the Incoherent Unit of Coyote Creek) on south and west facing slopes in the basin (Harden et al. 1978). Studies in and near the Redwood Creek watershed by Kelsey (1978), Harden et al. (1978), Nolan et al. (1979), 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.

Previous studies have also shown that earthflows, despite their large size and apparent activity, cumulatively deliver relatively little sediment to Redwood Creek (Harden et al. 1978; Nolan et al. 1979; Kelsey et al. 1995). Detailed monitoring and instrumentation of the active Minor Creek earthflow (Iverson 1984; Iverson and Major 1987) supports this finding. Average long term movement rates of 1.6 feet per year for this well studied earthflow (Iverson and Driedger 1993) translates to approximately 250 cubic yards delivered annually to Minor Creek, a major mid-basin tributary to Redwood Creek (NPS, 1995).

If the Minor Creek earthflow is considered representative of the 3,050 acres of very active earthflows in the basin, average annual contributions from all such mass movement features totals only 3 percent of the average annual sediment load of Redwood Creek measured at the Orick gaging station. Studies elsewhere (Kelsey 1978) suggest that fluvial erosion from axial and marginal gullies on active earthflows may actually contribute significantly more sediment to stream channels than does mass soil movement.

Earthflow movement is a major process forming the physiography of large sub-basins and bowl areas on hillslopes underlain by weak, fractured bedrock in the Redwood Creek basin. Earthflow processes are thought to have played an even more significant role in landform evolution when climatic conditions were wetter than at present. These mass movement features, while natural, can be affected by human activities such as grazing, road construction, and other land use practices which alter hillslope water balances (Iverson 1984; Kelsey 1978). Land use practices which concentrate runoff or alter stream flows on earthflows can accelerate gullying (Walter 1985) and channel aggradation or undercutting by a large stream can reactivate movement or increase movement rates.

Forested **block slides**, another type of slow moving landslide found in the basin, are typically located near shear zones on schist terrain (Sonnevil et al. 1987). They behave much like earthflows, but natural movement rates are typically slow enough to permit the establishment and maintenance of a coniferous forest. Land use activities, such as timber harvest and road building, are thought to significantly increase the level of activity and rate of movement of forested blockslides (Sonnevil, et al. 1985). Movement rates may increase to the point that all large trees on the slide are toppled in a few years time. Because of their limited areal extent and number, forested blockslides probably contribute a relatively small proportion of the total sediment yield of Redwood Creek. However, their contribution to the sediment yield of some west side tributaries, especially in the lower basin, may be relatively important.

The most significant of active mass movement processes in the Redwood Creek basin are rapid landslides which deliver large quantities of sediment directly to stream channels during winter storm events. These include debris torrents/flows and debris slides (Harden et al. 1978; Nolan et al. 1979; Pitlick 1982, 1995; Kelsey et al. 1995). Those that are in close proximity to streams and those located on steep inner gorge slopes, have the greatest likelihood of delivering sediment to stream channels (Figure 8). Both debris torrents and debris slides in Redwood Creek have been found to be significantly affected by land use activities including timber harvest and road construction (Janda et al. 1975; Harden, et. al, 1978; Pitlick, 1982, 1995; LaHusen, 1984; Hagans, et. al., 1986). Other processes, such as natural debris avalanches and slumps, are relatively uncommon processes in the basin and are thought to contribute relatively little to total sediment yield (Harden, et. al. 1978).

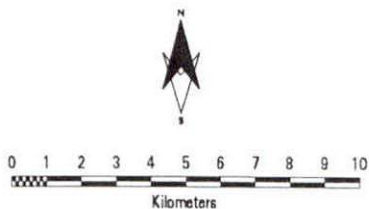
Debris flows and torrents are long, shallow, rapidly moving landslides that often originate on steep inner gorge slopes, below significant slope breaks and in steep headwater swales where subsurface water converges within colluvial deposits (LaHusen 1984). Some torrents originate where loose materials sidecast onto steep slopes become saturated during winter storms. Others occur where roads have been constructed across steep headwater swales and subsurface groundwater flows have been altered. Once initiated, debris torrents can travel thousands of feet downslope, increasing their mass by scouring native colluvial material, until they come to rest in relatively low gradient stream channels or on hillslope benches.

Debris slides are shallow translational landslides that typically involve the rapid failure of layers of soil and colluvium on steep slopes. In the Redwood Creek basin, debris slides are found on all bedrock types and are often associated with steep streamside slopes or logging roads built on steep hillslopes. Debris slides are clearly an important source of sediment to Redwood Creek and its tributaries, both because of their large number, their cumulative volume and their close association with steep streamside slopes and high gradient tributary streams where delivery rates are relatively high. The erosional landform map of Nolan et al. (1976) shows streamside landslides, most of which are debris slides, along much of the mainstem and major tributary streams of the middle and upper Redwood Creek basin. Sediment delivery from streamside landslides (mostly debris slides) has been estimated at about 291,000 tons per year along main stem and 176,000 tons per year along tributary stream channels (sample period 1954-1980; Kelsey et al. 1996). This represents approximately 60 percent of the long-term mean annual basin-wide sediment discharge at Orick (Madej et al., unpublished data).

Fluvial erosion has been determined to be a significant contributor to basin-wide sediment production and yield in the Redwood Creek watershed (Kelsey et al. 1981; Hagans and Weaver, 1987). Fluvial erosion includes processes such as rill erosion, gulying and bank erosion. In natural settings, fluvial erosion is concentrated on disturbed topography, such as active landslides, earthflows and burned areas. On forested slopes fluvial erosion may occur in subsurface macropores (pipes) and root channels (Janda et al. 1975; Ziemer 1992). On logged slopes, rill and gully erosion are commonly associated with ground disturbance in tractor yarded harvest areas and with the collection and concentration of runoff along thousands of miles of roads and skid trails (Janda et al. 1975). Large gullies have delivered thousands of cubic yards of eroded sediment to stream

DISTRIBUTION OF INNER GORGE Within the Upper Redwood Creek Watershed

- LEGEND**
-  Inner Gorge
 -  Redwood National and State Parks
 -  Streams (3rd and higher order)
 -  Mainstem Redwood Creek
 -  Watershed Divide
 -  Park Protection Zone (PPZ)



Inner gorge areas on this map were extracted from hillslope steepness maps created using 10m DEMs. The DEMs were produced using 7.5' USGS quadrangle vector contours. Polygons with a slope steepness of 65% and greater, and located within 100 feet of a 3rd-order or higher channel were included. Stream order is based on a contour-crenulation network (where topographic inflections in contours are traced to reflect channel and swale topography), and reflect a modification of the Strahler method.

channels in the basin, largely through the process of stream diversions at logging road and skid trail stream crossings.

Fluvial erosion is much more difficult to quantify than mass soil movement, because the location and size of specific features are not amenable to identification or measurement on stereo aerial photography. Fluvial erosion in the Redwood Creek basin is widespread but generally dispersed and composed of a large number of small linear features (gullies) or areas. For this reason, field studies aimed at quantifying the magnitude and causes of fluvial sediment production and yield in the Redwood Creek basin have used techniques such as terrain sampling (Hagans and Weaver 1987; Walter 1985), concentrated studies of relatively small sub-basins (Weaver et al. 1981) or residual analysis of larger sediment budget studies (Kelsey et al. 1981).

Previous studies have documented large increases in fluvial sediment production and yield from harvested and roaded hillslopes in the basin (Janda et al. 1975; Nolan et al. 1978; Walter 1985; Hagans and Weaver 1987; 1987; Weaver et al. 1995). Kelsey et al. (1981) estimated fluvial sediment yield to account for up to 68 percent of the total sediment delivered to stream channels in the upper basin (upstream from Highway 299). Based on large sample areas, Hagans and Weaver (1987) estimated that fluvial sediment production in the lower basin accounted for roughly half of total sediment yield to stream channels for the period 1954-1980. Madej (1997, unpublished data) has recently estimated fluvial sediment sources to account for approximately 34% of basin-wide sediment production. Fluvial sediment sources were estimated to include surface erosion from bare soil areas, stream crossing washouts and large gullies created when culverts plug and streams are diverted down roads and across unchanneled hillslopes.

Developing a quantitative *sediment budget* which describes sediment sources, delivery, storage and transport for a watershed is an accepted method to depict the importance of the various erosion processes active in a drainage basin. Several preliminary sediment budgets have been developed for portions of the Redwood Creek basin (Kelsey et al. 1981; Hagans and Weaver 1987) and sufficient data is now available from a suite of separate studies for computation of a generalized budget for the entire watershed. Madej (USGS, unpublished data) has prepared a detailed sediment budget for the Redwood Creek watershed which provides estimates of sediment production and yield from a wide variety of mass wasting and fluvial erosion processes (Table 7).

In a sediment budget the inputs of sediment, together with material which is stored in the channels, are balanced in equation form against the outputs or discharge of sediment from the basin outlet (sometimes available from USGS sediment sampling records). Major inputs include streamside landslides and fluvial hillslope erosion (including surface erosion) while sediment storage is represented by the material which has temporarily accumulated in the basin's main stem and tributary stream channels as bars, flood plains and aggraded streambeds (Madej 1984).

Fluvial erosion and yield is typically the least certain term in the sediment budget equation, largely because fluvial processes are dispersed across the landscape and are not visible or measurable on aerial photos. Because the other three terms (landslide inputs, sediment storage and basin-wide sediment yield) are better understood and more easily quantified, fluvial erosion is often computed as a residual term in the sediment budget equation.

Table 7. Sediment Budget for the Redwood Creek Watershed, 1954-1980 (Madej, 1997)		
Sediment Inputs	Mass (tons)	Total Contribution (%)
Fluvial and surface erosion:		
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 (bare ground)	1,757,000	4.3
Hillslope gullies (primarily stream diversions)	8,507,000	20.6
Streambank erosion - tributaries	3,849,400	9.3
- mainstem	2,070,000	5.0
Subtotal fluvial processes	22,271,600	54%
Mass wasting:		
Mainstem streamside landslides	7,100,000	17.2
Tributary streamside landslides (sampled basins, n = 16)	3,900,000	9.4
Tributary streamside landslides	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
Subtotal mass wasting.....	19,067,000	46%
TOTAL SEDIMENT INPUT	41,338,600	100%
Additions to Sediment Storage		
Main channel storage	10,400,000	96
Tributary channel storage	440,000	4
Subtotal storage.....	10,840,000	100%
Sediment Output		
USGS gaging and sediment data at Orick, CA	45,000,000	

In Redwood Creek, several independent studies have quantified the elements of fluvial erosion from the watershed's hillslopes. This allows for a more fact-based assessment of the importance of various fluvial processes. A variety of road-related fluvial erosion processes, including stream crossing erosion, skid trail erosion, and road surface erosion, have accounted for approximately 15% of total sediment delivery in the basin (Table 7). Surface erosion from bare soil areas (harvested areas, landslide scars, etc.) is estimated to account for just over 4% of the inputs. The single largest contributor to fluvial sediment input in the measurement period, totaling 20% of total sediment input from all sources, has been hillslope gullies. The occurrence of large gullies are primarily attributed to stream diversions which occur at logging road stream crossings when culverts are plugged or their capacity is exceeded.

Road-related fluvial erosion is more easily controlled or prevented than most all other sediment sources. By preventing stream diversions and by disconnecting roads from the stream system, most fluvial erosion can either be prevented or the eroded sediment can be prevented from delivery. In contrast, streambank erosion is a fluvial process that is less easily controlled or prevented. In Redwood Creek, streambank erosion accounted for just over 14% of total basin-wide sediment inputs during the measurement period.

Approximately 46% of basin-wide sediment inputs in Redwood Creek were derived from mass wasting processes. This included an estimated 273,100 tons/year from main stem landslides, 326,900 tons/year from tributary debris slides, and 133,300 tons/year from other mass wasting processes for a total mass movement influx of approximately 733,300 tons/year for the 26 year period from 1954 through 1980. Aerial photography and field evidence suggest that most of these "pulse" or "episodic" inputs occurred during the storms of 1955, 1964, 1972 and 1975.

Volumetrically, nearly 38% of total sediment input came from streamside debris slides (Table 7). Most of these landslides occurred on steep inner gorge and streamside slopes. Another 8% originated from deep seated landslides (earthflows and blockslides) and smaller mid-slope landslides and debris torrents. Landslides are difficult, or impossible, to control once they have been initiated. Debris slides typically fail and deliver sediment over a very short period of time, and they may give little indication of their inherent susceptibility to potential failure. For this reason, prevention is clearly the most effective means of reducing sediment inputs from mass wasting processes.

Once sediment has been delivered to a stream channel, it is either transported through the system, or it is stored within the channel network in a variety of short-term and long-term storage "compartments." The bulk of stored sediment that is found within the Redwood Creek watershed was initially deposited in stream channels during the 1964 flood (Madej 1984). Most of the coarse sediment currently stored in the watershed (96%) currently resides in and along the main channel of Redwood Creek (Table 7). With few exceptions, tributaries have largely scoured their channels and flushed previously stored sediment into the main stem where it has been redeposited (Pitlick 1982, 1995). Stored sediment in the main stem has shifted position over time, but the bulk of it still remains in and alongside the active channel and it is expected to remain in storage for decades to come (Madej 1992). Averaged over the longer time period, the average annual

increase in sediment storage during the period of record (1954-1980) is computed to be about 416,900 tons/year, or about 26% of the sediment inputs during the same time period (Table 7).

Data from U.S. Geological Survey stream gaging and sediment sampling records have been used to estimate the average annual total sediment load during approximately the same time period (1960's and 1970's). Average annual sediment discharge, as measured at the Orick gaging station, has been estimated at 1,860,000 tons/year (computed by Knox (USGS), as referenced in Harden et al. 1978). This figure is useful because it estimates sediment yield during a period which contained three years with peak flood flows of approximately 20- to 50-year recurrence intervals (1964, 1972, 1975) along with intense forest land use.

The summary final sediment budget is depicted in Table 8. Mean annual sediment production, delivery and discharge, as shown in the table, are mean numbers that probably never occur in any given year during the period of record. That is, average sediment discharge rates are controlled by the effects of a few, highly episodic events which account for most long term sediment movement within the basin. Landslide and gully erosion processes, which account for the bulk of documented erosion and sediment delivery in the Redwood Creek watershed, are storm-driven processes. Similarly, sediment storage in tributaries and the main stem channel is highly episodic and dependent on large pulses of sediment from the hillslopes followed by long intervals of gradual routing through the channel system. These episodic erosion and sedimentation events are separated by relatively long periods of comparatively low sediment production and discharge.

Table 8. Summary sediment budget for the Redwood Creek watershed, 1954 - 1980.			
Mass wasting	+ fluvial erosion	- channel storage	= sediment discharge
733,300 tons/year	856,600 tons/yr	416,900 tons/year	1,173,000 tons/year
46%	54%	26%	100%
(% of total annual basin-wide inputs)		(% of annual yield)	(total output at Orick) ³

It should be noted that fluvial hillslope erosion represents approximately 84% of the estimated sediment inputs to the Redwood Creek basin. This has important implications for future land management, for park protection and for the management and control of sediment delivery to stream channels throughout the basin. Sources of fluvial sediment production and delivery are much more easily controlled or prevented than are mass movement processes, and a suite of cost-effective measures have been developed for implementation on private and public lands throughout the Pacific Northwest over the last decade.

³ This is the "derived" figure, based on measured inputs and changes in sediment storage. Measured sediment yield past Orick, based on USGS gaging records, is computed at 1,730,800 tons/year.

Past Timber Harvest and Road Building Practices

Forest Practice regulations - 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 established 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 that would guide timber harvest practices for nearly a decade became effective.

Although the Forest Practice Act of 1973 recognized forest values of recreation, wildlife, fisheries, and water quality, it emphasized the management, replenishment and maintenance of forest lands. Significant amendments became effective in October of 1983 that established watercourse and lake protection zones (WLPZs), new standards for logging roads and landings, and erosion control requirements. The WLPZs provided new definitions of streams based on their biological productivity and placed certain restrictions on timber harvest and heavy equipment operations in areas immediately adjacent to most Class I (fish-bearing) and Class II streams. Additional amendments to road construction and WLPZ rules have been added in the 1990s.

Recent efforts across several fronts have identified changes which are needed in the Forest Practice Rules in order to provide additional protection to water quality and dwindling anadromous fisheries (eg., Little Hoover Commission, 1994). A scientific review panel, commissioned by the Resources Agency and the National Marine Fisheries Service, has prepared an analysis of the current Forest Practice Rules and forwarded recommendations for a number of specific measures and rule changes that are needed to protect salmonid habitat (Rynearson et. al., 1999). In addition, Northern California watersheds that have been identified as "impaired" by the Environmental Protection Agency, including Redwood Creek, are now undergoing analysis and the preparation of Total Maximum Daily Load (TMDL) allocations, and the development of implementation plans aimed at accelerating the recovery of water quality. Agencies with responsibilities for the protection of listed species (eg., coho salmon) are also developing and forwarding proposals to the Board of Forestry for widespread changes in the Forest Practice Rules.

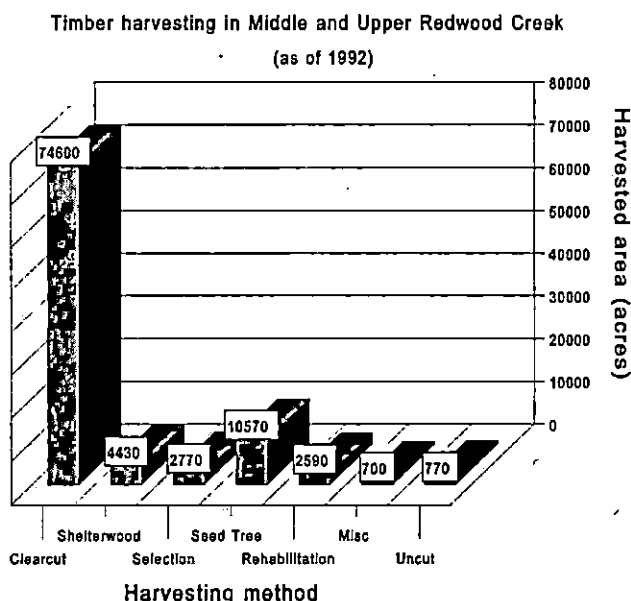
Past timber harvesting - Timber harvest has been the most widespread land use in the Redwood Creek watershed in historic times. Logging began as early as the 1850's, but commercial harvesting to supply markets outside the local area started in the 1930's. Early logging operations were localized along the southern margins of the lower basin where rail access had been developed. Typical harvest areas can be seen in Panther Creek, just upstream from the south park boundary where advanced second growth timber now exists. Early harvests consisted of large clearcuts, yarding was done with steam donkeys and logs were transported south by rail.

Large-scale logging in the basin began after the Second World War, when both tractors and gasoline-powered chain saws became 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). Approximately 62 percent of this area had been logged as of 1978 (Best, 1984) and over 85% of the conifer forests upstream from what are now park lands had been harvested (Figure below, and Table 9). Logging in the basin was most intensive between 1949 and 1962, when about 31 percent of the basin was logged (Best, 1984).

Prior to 1978, 95% of the logging in the middle and upper watershed consisted of clearcutting. Typically, clearcut logging consisted mostly of tractor yarding wide tracts of land, including entire subwatersheds and tributaries, in short periods of time (Janda et al. 1975).. Over 90% of the yarding prior to 1978 was done by tractors (Table 9) which created widespread ground disturbance and disruption of natural hillslope drainage. The extent and intensity of historical ground disturbance caused by timber harvest and road construction in the Redwood Creek watershed has been extreme (Janda, 1977). By the mid-1970's not only had 60% of the watershed been harvested in a 25-year time period, but most harvesting consisted of sequential tractor yarded clearcuts hundreds of acres in size (Janda, 1977).



Logging from 1978 through 1995 involved smaller, more dispersed patch-cuts. Only 30% of the area logged during this period was clearcut (Table 8). During this time period, tractor yarding was still the preferred method for moving logs across the hillslope. Improvements in regulations have also resulted in operations that are better tailored to site-specific conditions. Increasingly, timber harvesting in the upper Redwood Creek watershed has been in advanced second-growth stands. Many areas have been logged two or more times, sometimes using different yarding techniques. The remaining old growth in the basin is scattered primarily as residual stands of seed trees and as small old growth stands in steep, unstable areas, such as inner gorge slopes along upper Redwood Creek and along its major tributary streams (Janda 1977).

Few remaining old growth forest areas remain in the middle and upper basin. Most large trees are those that remain from past seed tree harvests. Most future harvesting will occur in areas of second growth forests and hardwood forests that have grown since the initial old growth harvesting. The legacy of past land use, including widespread tractor logging and road

Table 9. Timber harvest and related land use in the Middle and Upper Redwood Creek basin - pre-1978 and 1978-1992⁴ (Best, 1984; RNP written comm., 1995)			
Cutting Method	Land use data as of 1978 (acres)	Land use data from 1978-1992 (acres)	Land use data (total acres)
Uncut conifer forest	9,910	770	770
Clearcut	65,485	9,140	74,625
Shelterwood	unknown (unk)	4,425	4,425+
Selection	2,770	0	2,770
Seed Tree	unk	10,575	10,575+
Rehabilitation	unk	2,590	2,590+
Miscellaneous clearing	700	NA	700
TOTAL CUT	68,955	26,730	95,685
Yarding Method			
Tractor	62,645	26,260	88,905
Cable	5,610	3,730	9,340
Tractor/cable	700	1,820	2,520
TOTAL	68,955	31,810	100,765
Road Construction and usage in THP's		Road length (miles)	
New	unk	127	
Rebuilt	unk	111	
Existing	unk	236	
Streams and stream crossings in THP's			
Streams (miles)	unk	381	
Stream crossings (#)	unk	1,421	

⁴ From 1993 through 1997, an additional 7,700 acres of timber harvesting occurred in the watershed. The bulk of the new harvesting consisted of clearcutting (1,790 acres), rehabilitation cutting (1,528 acres), seed tree removal (1,388 acres) and alternative prescriptions (1,168 acres). Of this harvesting, 4,857 acres were tractor yarded, 1,144 acres were cable yarded, 935 acres utilized a combination of cable and tractor yarding, and 705 acres were yarded by helicopter. Twenty nine miles of new road was built and another 29 miles of old road was reconstructed. 102 new stream crossings were constructed, and 113 were reconstructed.

construction, will still influence sediment production from these areas, as will the advent of reentry, harvesting and road reconstruction. Studies in the lower Eel River basin suggest that landslide rates in recently harvested second growth areas underlain by Franciscan bedrock are more common and larger than those in areas of advanced second growth forests (PWA, 1998). Pitlick (1982, 1995) found that slides in managed areas were no more common but were larger than those in uncut inner gorge slopes. Both studies suggest that second growth logging of steep inner gorge locations will set the stage for additional sediment production by landsliding.

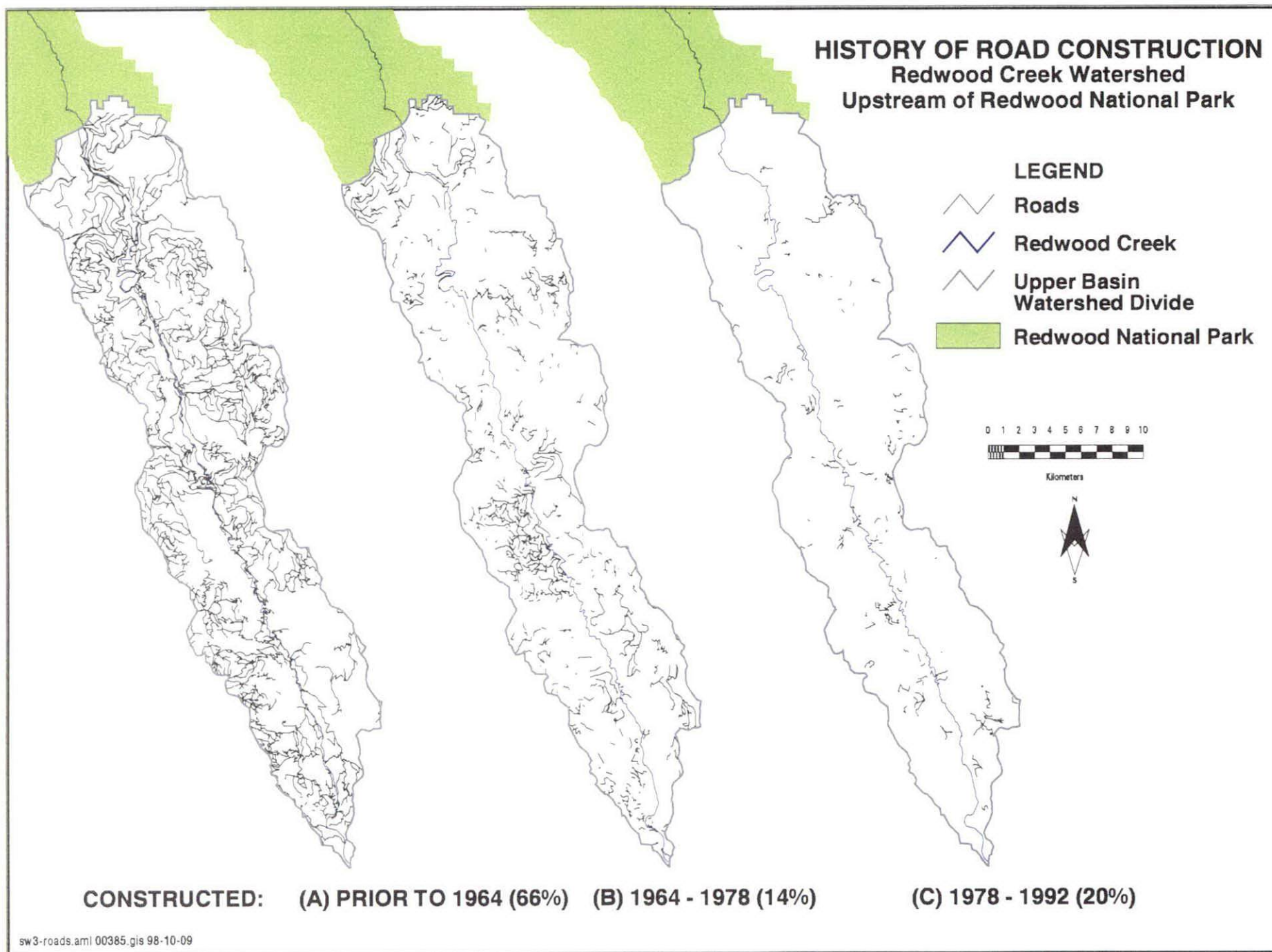
Recent harvesting (post-1978) - Timber harvest plans filed with the California Department of Forestry and Fire Protection since 1978 were analyzed to assess trends in logging since park expansion. During the period 1978-92, a total of 31,836 acres of private timberlands were logged in the Redwood Creek watershed. This total is equivalent to 18% of the entire watershed area, or about 30% of the 108,000 acres located upstream from the current park boundary. Of this total, 24,139 acres (76%) were logged using intensive silvicultural methods that remove all or almost all trees from most logged areas (Table 9). Over 26,200 acres were logged using tractor yarding methods, which causes greater ground disruption than other yarding methods (Table 9).

Roads - Roads are a major cause of accelerated erosion (Kelsey et al. 1981; Hagans and Weaver, 1987; Weaver et al. 1995). The erosion potential of roads is related to maintenance, location, and design (Janda et al. 1975; Best, 1984; Klein, 1987). Common erosion problems associated with roads include stream diversions at stream crossings, stream crossing washouts, failure of unstable fills and sidecast materials (along roads and landings), triggering of native hillslope failures, failure of undercut cutbanks, and interception and diversion of surface and subsurface water by cutbanks and inboard ditches. Poor road location and construction methods, and inadequate road maintenance, have been identified as the source of some significant accelerated erosion and sediment yield experienced in the basin (Janda et al. 1975; Pitlick 1982; Hagans and Weaver 1987; Weaver et al. 1987, 1995).

Middle and upper basin road construction history over three time periods is depicted in Figure 9. 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). Another 127 miles were constructed between 1978 and 1992 (Figure 9; Table 10). About 300 miles of roads and 3,000 miles of skid trails were included within present park boundaries as a result of park expansion in 1978 (Steensen and Spreiter 1992). In addition, about 20 miles of state highway and county roads cross the watershed, including several miles of abandoned state highway.

Roads upstream of the park boundary as of 1992 totaled about 1,110 miles⁵ (Figure 10). 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 (Figure 9; Table 10). Because 80% of the roads in the Redwood Creek watershed were constructed before 1978, most have been built to lower standards than those of the present forest practice rules as amended in 1983. Of the total

⁵ Information on the road network upstream of the park is based on analysis of sequential aerial photographs with limited field verification.



Pacific
Ocean

Map of Existing Roads in the Redwood Creek Watershed, 1992

Redwood National
and
State Parks



-  Redwood National
and State Parks
-  Watershed Divide
-  Existing Road Network
-  Redwood Creek



0 5000 10000 15000 20000
Meters

Table 10. Roads in the Redwood Creek Basin upstream from RNP as of 1992⁶			
Age class	Middle Basin (PPZ) - (miles)	Upper Basin (miles)	Total (miles)
pre-1964	141	590	731
1964-1975	33	122	155
post-1975	59	167	226
TOTALS	233	879	1,112

1,110 miles of roads upstream of the park, about 65% were judged to be drivable as of 1992 (Table 11). Approximately 55% of the roads in the basin are abandoned (not maintained). These abandoned roads are more likely to fail during a large storm than are maintained roads as a result of plugging and rusting of culverts, undersized culverts, failure of unstable fills and diversion of streamflow (LaHusen 1984; Hagans et al. 1986; Hagans and Weaver 1987; Weaver et al. 1995; Furniss, et. al., 1997; Furniss et. al., 1998).

Table 11. Maintenance status of roads in the Redwood Creek Basin upstream from RNP as of 1992			
Maintenance status	Middle Basin (PPZ) - (miles)	Upper Basin (miles)	Total (miles)
Abandoned, not driveable	118	243	361
Effectively abandoned, but may still be driveable	49	157	206
Maintained	33	457	490
Unclassified	33	22	55
TOTALS	233	879	1,112

About 75 percent of total road miles constructed upstream of the park is found on relatively gentle slopes of 50% or less, 18 percent were constructed on slopes between 50% and 65%, and 7 percent were constructed on slopes greater than 65% (Table 12). A significantly greater

⁶ From 1993 through 1997, an additional 29 miles of new seasonal and temporary roads have been constructed, and another 29 miles of road have been reconstructed, in the Redwood Creek watershed.

Table 12. Maintenance status of roads on inner gorge slopes in the Redwood Creek Basin upstream from R.N.P.			
Maintenance status of inner gorge slopes	Middle Basin (PPZ) - (miles)	Upper Basin (miles)	Total (miles)
Abandoned, not driveable	11	21	32
Effectively abandoned, but may still be driveable	6	5	11
Maintained	1	6	7
TOTALS	18	32	50

percentage of effectively abandoned roads are located on steep slopes, compared to maintained roads. About 5% of total road miles are in steep (>65%) inner gorge areas adjacent to stream channels where road failures are most common and the impacts of failures are most serious (Table 13). Of the 50 miles of roads constructed on steep inner gorge slopes in the middle and upper Redwood Creek basin, 43 miles (over 85%) had been effectively abandoned by 1992 and 32 miles (64%) were no longer driveable.

Table 13. Maintenance status of roads in the middle and upper Redwood Creek Basin upstream from Redwood National Park (as of 1992)									
Maintenance status	Middle Basin (PPZ) (miles)			Upper Basin (miles)			Total (miles)		
	<50%	50-65%	>65%	<50%	50-65%	>65%	<50%	50-65%	>65%
Abandoned, not driveable	75	27	16	331	90	29	406	117	45
Abandoned, driveable	31	10	7	117	30	9	148	40	16
Maintained	47	7	3	198	35	9	245	42	12
Unclassified	0	0	0	5	0	0	5	0	0
TOTALS	153	44	26	651	155	47	804	199	73

Roughly one-third of the road network upstream of the park has been constructed on notoriously unstable bedrock units such as the incoherent unit of Coyote Creek and the sandstone and melange unit of Snow Camp Mountain (Table 14). About 40% of the network was constructed on “sensitive” soils that are susceptible to landsliding (81 miles), gully erosion (301 miles), or impaired drainage (15 miles)(Table 15). On average, nearly 80% of roads constructed on “sensitive” soils had been abandoned as of 1992, while only 52% of roads built on non-sensitive soil units were abandoned.

Table 14. Maintenance status and geologic setting of selected roads in the middle and upper Redwood Creek Basin upstream from Redwood National Park (as of 1992)				
Maintenance status	Road miles on selected geologic units (mi)			
	Coherent Unit of Lacks Creek	Incoherent Unit of Coyote Creek	Metasediments of the Grogan Fault zone	Redwood Creek and South Fork Mountain Schist
Abandoned, not driveable	53	146	28	303
Abandoned, driveable	17	77	5	92
Maintained	16	98	14	138
Unclassified	0	0	0	1
TOTALS	86	321	47	534

Based on records of Timber Harvest Plans (THPs) filed for commercial timber lands in the Redwood Creek watershed, a total of 127 miles of new roads were constructed and 111 miles of existing roads were rebuilt for logging within THP units between 1978 and 1992⁷. 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. The high proportion of roads and stream crossings that required rebuilding suggests that road failures have been frequent along these abandoned routes. Roads used for timber harvest during this period included over 1,400 stream crossings (Table 9). Roughly 50% of these crossings were on smaller Class III streams, and many required rebuilding due to partial or complete failure. From 1993 to 1997, another 102 new stream crossings were constructed and 113 were rebuilt on haul roads in timber harvest areas of the basin.

⁷ From 1993 through 1997, an additional 29 miles of new seasonal and temporary roads have been constructed, and another 29 miles of road have been reconstructed, in the Redwood Creek watershed.

Table 15. Maintenance status of roads located on sensitive soils in the Redwood Creek Basin upstream from Redwood National Park

Maintenance status of roads	Roads on sensitive soil units (mi)				
	Soils highly prone to mass soil movement	Soils highly prone to gullyng	Soils with slow permeability and impaired drainage	All roads on sensitive soils	Non-sensitive soils
Abandoned, not driveable	38	185	5	228	290
Abandoned, driveable	16	56	4	76	108
Maintained	27	59	6	92	179
Unclassified	0	1	0	1	2
TOTALS	81	301	15	397	579

Although a more thorough and precise analysis of the maintenance status and condition of roads upstream of the park will require field inventories, the road analysis based on aerial photographs usefully indicates the extent of potential problems. On the basis of road maintenance status, hillslope gradient, geology, and soil types, stream crossing failures are likely to occur about one-third of the 1,110 road miles upstream of the park during any given large storm. Most roads in the watershed were designed under much less restrictive standards than exist today, and are thereby more susceptible to flood damage and potential failure. Only a small proportion of the present road network upstream of the park was constructed under existing Forest Practice Rules (Table 10; Figure 9).

Impacts of Past Practices and Large Storms

Basin response - A number of research studies conducted in the Redwood Creek basin by both the U.S. Geological Survey and the National Park Service have documented the response of hillslopes and stream channels to the combined effects of land use and storms (Janda et al. 1975; Harden et al. 1978; Pitlick 1982, 1995; Kelsey et al. 1978; Kelsey et al. 1995; LaHusen 1984; Hagans and Weaver 1987; Hofstra and Sacklin 1987; Iverson and Major 1987; Madej 1992; Nolan and Marron 1995; Walter 1985). The conclusion reached by researchers in the basin is that past land use has had a profound effect on erosion rates and sediment yield in the basin over at least the last three decades, and that these effects are persistent and recurring. Not only did land use have an effect at

the time and location of the original disturbance, but that effect is often displaced in both space and time from the original land use disturbance. The Redwood Creek basin has been left with a legacy of past practices and their impacts (most of the watershed was cut and most of the roads were built prior to the modern Forest Practice Rules)(Hagans and Weaver, 1987).

Specific land use practices in the basin have caused multiple on-site and off-site geomorphic effects which will only become apparent years following the original land use disturbance (Janda 1977; Hagans and Weaver 1987). Different processes have contributed differently to total sediment yield (Table 16). This relative contribution of each sediment production mechanism also likely changes with location in the drainage basin (for example, upper basin fluvial sediment yields have been estimated to be significantly higher than in the lower watershed (Kelsey et al. 1981; NPS 1995)).

Table 16. Measured sediment sources in the <u>lower</u> Redwood Creek basin (1954-1980, excluding Prairie Creek (Hagans and Weaver, 1987)		
Sediment source	Volume (m ³)	Proportion of total yield (%)
Gullies	1,157,400	37
Eroded stream crossings	225,600	7
Surface erosion	124,400	4
Streamside landslides	1,600,000	52
TOTAL	3,107,400	100

In the undisturbed state, *surface erosion* in the basin was confined to natural sites of bare soil. These typically included active landslides, eroding stream banks and earthflow gullies. Extensive ground disturbance created by widespread tractor yarded clearcuts and road construction in the basin created extensive areas of bare soil, and erosion rates increased dramatically (Marron et al. 1995). Surface erosion processes are thought to have accounted for an estimated 4% of total sediment yield from the lower Redwood Creek basin from 1954-1980 (Hagans and Weaver, 1987).

Today, while ground disturbance from yarding activities is significantly lower than in the 1970's and 1980's, fine sediment production is still thought to represent a significant and deleterious process in Redwood Creek (Ridenhour and Hofstra 1994). Timber harvesting plans submitted from 1978 and 1992 showed there to be approximately 3.7 stream crossings for every mile of road in the basin. With over 1,100 miles of identified road (Table 10), there are likely in excess of 4,100 stream crossings and an estimated 100 to 385 miles of road-side ditch delivering runoff and eroded sediment directly to Redwood Creek and its tributaries.

Fluvial erosion associated with forest land use practices includes both stream crossing washouts and gully erosion. Research in the basin has shown that both processes are very important contributors to basin-wide sediment production and yield (Hagans et al. 1986; Weaver et al. 1995; Kelsey et al. 1981). In the lower basin, where fluvial processes are thought to be less important compared to the upper basin (Weaver et al. 1995), stream crossing washouts have been documented to account for approximately seven percent of total sediment yield from 1954-1980. Stream crossings typically erode and wash out during large storms when culverts plug, when undersized culverts are overwhelmed with flood flows, or when log crossings rot and collapse.

Detailed erosion inventories have clearly revealed certain land management practices to be the actual cause of at least 80% of the increased fluvial erosion in the lower watershed (Hagans and Weaver 1987). Studies throughout the basin have identified large gullies formed as a result of stream diversions at logging road stream crossings to be the single largest source of fluvial sediment production and yield in the basin (Kelsey et al. 1981; Weaver et al. 1995). Stream diversions trigger hillslope gully, landsliding and scouring of natural channels. Large, individual gullies can deliver several thousand cubic yards of eroded sediment to local stream channels, and diverted streams can trigger landslides and debris torrents on steep inner gorge slopes. Diverted streams and increased sediment loads in natural stream channels often cause the receiving channels to undergo rapid downcutting and bank erosion. Road-related stream diversions are human-caused and easily preventable, provided efforts are made to locate and prevent their occurrence before a triggering storm event occurs.

The temporal distribution of **streamside landslides** in the Redwood Creek basin was first studied by Harden et al. (1978). Debris slides were seen to increase four-fold in number between 1947 and 1976, with most occurring between 1962 and 1966 (probably during the 1964 storm event). Similar, though less abrupt increases in landsliding were associated with subsequent storm events in the basin. Observations since 1978 suggest that few streamside landslides have been initiated in the relatively dry period since 1975. Landslides are thought to represent from 20% to over 50% of basin wide sediment production and yield during the three decade period of major land use and storms in the watershed (NPS 1995; Hagans et al. 1986; Weaver et al. 1995). As with fluvial erosion, they occur episodically, in response to large storm events.

A clear cause-and-effect relationship between land use and mass wasting is far more difficult to establish than for fluvial processes. Analysis of streamside landslides along the main stem of Redwood Creek (Kelsey et al. 1995) and along its major tributaries (Pitlick 1982, 1995) reveals that human influences have likely been significant. Both studies found that all the large, volumetrically significant landslides occur on steep slopes of the inner gorge adjacent to the main channel and its main tributaries. Pitlick (1982, 1995) found that the landslides associated with both roads and harvested areas along steep tributary inner gorge slopes were roughly equal in number to those in uncut areas but they accounted for nearly 80% of the total volume of landsliding. Landslides associated with roads accounted for 40% of the total mass erosion volume. LaHusen (1984), in an investigation of debris torrenting following a moderate size storm in the lower basin, found that debris flows were highly correlated with road construction in geomorphically sensitive terrain. The most suspect terrain included steep colluvial-filled swales, and inner gorge slopes located immediately below the major break-in-slope.

Although virtually all major instances of landsliding in the basin have been triggered by storm events, storms and logging together were found to be the causes of widespread landslide activity (Kelsey et al. 1995; Pitlick 1982; LaHusen 1984). These human influences are expected to continue to occur, both as a result of older harvesting, as well as continuing timber harvesting on steep inner gorge slopes throughout the basin. Because triggering storms have not occurred in the Redwood Creek watershed since 1975, streamside slopes have likely been "primed" for future failure by two decades of continued harvesting and road construction, and occasional moderate size storms. The effects of these continuing land use activities will not show until the next major storm and flood event.

Stream channel morphology along the main stem of Redwood Creek, as well as in tributary watersheds, has witnessed significant changes over the last four decades. The types of off-site impacts to stream channels that have been quantitatively documented include: 1) increases in the overall volume of stored sediment, 2) increases in the volume of stored sediment in "compartments" displaying long residence times, 3) increased incidence of bank erosion, and decreases in pool numbers (Madej, 1987; Madej 1992; Hagans et al, 1987).

Changes in channel geometry are not as persistent in steep, lower order tributaries (where stored sediment is quickly re-eroded and flushed), as compared to small streams on the hillslopes and low gradient main stem reaches. The lack of persistence is a result of high stream power and efficient sediment mobilization and transport in steep tributary streams (Pitlick 1982, 1995). These main tributary channels have stored between 5% and 30% of the sediment delivered to them during major storms (Hagans et al. 1986). In contrast, small channels on hillslopes may be permanently "guttered" or gullied by large increases in sediment transport or stream discharge caused by stream diversions. Similarly, low gradient main stem reaches can act as long-term repositories for eroded sediment which originated in upland watershed areas. This stored sediment can affect channel and valley morphology for centuries (Madej 1992, 1995).

In contrast to the steep tributary streams, the geomorphic effects of increased watershed erosion and sediment delivery to the main channel has had dramatic and persistent impacts on channel morphology. Pools have filled, gravel bars have widened, and sediment has been deposited on floodplains to accommodate this influx of sediment (Madej 1992, 1995). More sediment has been supplied to the low gradient main stem that it can successfully transport through the system. The most severe channel aggradation occurred in the upper reach, but this relatively high gradient section had removed roughly half the sediment deposited in the 1964 flood within 20 years. Residents in the upper watershed consistently report recovery of the upper main stem, where boulders that have been buried by sediment for 20 years are now emerging as the gravels are removed from the channel (Van Kirk 1994). The lowest gradient channel segments, those within Redwood National Park including those in the vicinity of the Tall Trees Grove, are still aggrading and receiving sediment reworked from upstream reaches which are now recovering (Madej 1992, 1995).

It is clear that widespread erosion and sedimentation, such as that which occurred during the 1964 storm, and of which over 40% has been associated with stream diversions at logging road stream crossings, can affect volumes of channel-stored sediment for many years to come (Hagans and

Weaver 1987; Weaver et al. 1995). In fact, studies suggest that the persistence of recently deposited sediment in the upper reaches ranges from 25 to 100 years, and sediment in the lower basin is expected to remain in storage for up to 100 years, or more (Madej 1995).

Another indicator of changes in stream channel morphology brought about by increased watershed erosion is the occurrence of bank erosion. In one 18 mile lower-basin section of the main stem of Redwood Creek, for example, 51 locations of active bank erosion (erosion for over 20 linear feet of bank) were identified (Hagans et al. 1986). These sites were on relatively straight reaches where natural erosion is not typically expected. At 71% of these locations the channel remained wider for decades following the initial erosion. In lower Redwood Creek, where channel aggradation is still on-going, one bank eroded by 120 feet between 1973 and 1977 with little subsequent recovery. Channel changes in the lower main stem within Redwood National Park include widened channels, elevated and smoothed channel beds, reduced pool numbers and depths, reduced canopy, dead riparian vegetation, toppled alluvial redwood trees (at the Tall Trees Grove), and increased stream temperatures are expected to persist for many decades - until excess sediment has moved through the lower basin (Hagans et al. 1986).

In summary, hillslopes and stream channels within the Redwood Creek basin have responded in a variety of ways to both natural geomorphic processes and land use activities. Geomorphic processes, including both erosion and sedimentation, have been dramatically affected by human land use activities, especially forestry-related activities beginning in the 1950s. The nature, magnitude, causes and persistence of these effects have been thoroughly documented by a variety of researchers (Nolan et al. 1995). They include both on-site effects (at the location of the land use) and off-site effects (both downslope and downstream from the disturbance). Large storms have been the main triggering event for watershed change in Redwood Creek, and the geomorphic response of the landscape has manifested itself with both physical and biological changes. The resulting impacts are often displaced in both time and space from the disturbance event. Past land use practices continue to affect erosion and sedimentation processes in the watershed, and these effects are expected to continue to have a negative effect on both geomorphic processes and aquatic habitat for many decades.

Aquatic and fishery resources - Outside of Prairie Creek, the main tributaries to Redwood Creek are short and steep. There is relatively little habitat available, in the best of conditions, for anadromous salmonids (Ridenhour and Hofstra, 1994). Brown (1988) found 58 miles of the mainstem and 50 miles of tributaries accessible to anadromous fish. Most of the tributaries have natural barriers close to Redwood Creek (Figure 2). In all locations, large amount of fines in the gravels and high rates of bedload transport are thought to have reduced the suitability of spawning habitat. Increased sedimentation has reduced nursery habitat by widening and shallowing summer flows, thereby increasing summer water temperatures and reducing cover. Riparian vegetation, reduced through direct harvesting or channel widening, has also affected stream temperatures (Ridenhour and Hofstra, 1994). Increased sediment transport and reduced large woody debris, such as have occurred in Redwood Creek, can result in a reduction in cover, a potential reduction in macroinvertebrate food production available to fish and increased predation (Klein et al. 1987). Historical accounts of fish populations and channel conditions (Van Kirk 1994) suggest salmonid

populations were still relatively high through the late 1960's, but that significant declines have since occurred.

Redwood Creek was already considered damaged and in poor condition in 1966 for the production of anadromous fish (Fisk et al. 1966; Denton 1974). Sixty-four of the 84 miles of stream in the watershed were considered "damaged." Ridenhour and Hofstra (1994) have identified upper basin logging and the channelization of lower Redwood Creek between flood control levees as the two most serious causes of impacts on fish habitat in the basin. Declines in fish populations have been partially attributed to poor land use practices that have changed the streams from "deep, tree-lined channels with frequent pools and long riffles carrying cool water" into streams that are "shallow, warm, and barren of streamside vegetation" (Denton 1974; Higgins et al. 1992). These conditions are especially prevalent in the lower basin where Redwood Creek passes through Redwood National Park.

Conclusion

Redwood National Park was established, in part, to provide permanent protection to the outstanding alluvial groves of the Redwood Creek basin. The designations of National Park, World Heritage Site and International Biosphere Reserve are testament to the Park's outstanding and unique natural resources. The health of the Park's most important alluvial redwood groves has been clearly linked to stream flow, sediment transport and channel morphology of the main stem of Redwood Creek, and these processes are most closely linked to events and conditions of the middle and upper drainage basin, beyond the protective boundaries offered by their national and international status (Nolan et al. 1995). In addition to the documented impacts to riparian resources and alluvial redwood groves, human activities have contributed to a substantial decline in the ability of Redwood Creek to produce and support its unique and diverse native fish population, including anadromous salmon and trout (Ridenhour and Hofstra 1994).

The Redwood Creek watershed is one of the most thoroughly studied drainage basins in the western United States. Several decades of scientific studies conducted by the U.S. Geological Survey, the National Park Service, and others have provided a clear picture of the current state of the basin and its stream channels; the nature, origin and level of continuing threats to park resources; the relationship between land use and downstream cumulative watershed effects; the connection between upper basin processes and events and lower basin impacts (including impacts on park resources); and the expected persistence of cumulative watershed effects. These studies, conducted on a number of topics and by a variety of researchers, continue to the present (e.g., Nolan et al. 1995). They provide a nearly unmatched scientific research record on the causes and effects of erosion and sedimentation processes throughout the watershed.

Part V: Suggested Prevention and Mitigation Measures

Background

A variety of research projects have been conducted in the Redwood Creek watershed over the last 20 years to identify practices that have been most responsible for accelerated erosion and downstream sedimentation. Field research, inventories and formal inspections have been

conducted both on cutover lands within Redwood National Park as well as on private forest lands throughout the remainder of the watershed. Many of these investigations have focused on the causes and effects of land use related erosion and mass soil movement.

Some results, and the recommendations stemming from this research, have general and immediate application throughout the State and within the Coast Forest District on both private and public forest lands. These include the cause, effect and prevention of stream diversions at culverted road crossings, and erosion prevention techniques for road decommissioning and treating temporary roads (especially the removal of temporary stream crossings). These and other measures have gradually found their way into the Forest Practice Rules. Other recommendations have not yet received general application or are more specifically targeted to the setting and problems of the Redwood Creek basin.

An ongoing program to review land use practices (primarily timber harvesting and related activities) upstream from Redwood National Park was initiated in 1976 and continues today. Part of this program includes an overall analysis of current land use practices and forest practice rules (as they continue to evolve) as well as the development of general and site-specific mitigations aimed at reducing cumulative watershed effects on downstream areas within the park. When land owner permission can be secured, NPS geologists or hydrologists attend pre-harvest field inspections to locate potential or on-going erosion sources and recommend prevention and mitigation measures to the landowner and/or Department of Forestry and Fire Protection for incorporation into the approved THP. To date, NPS technical personnel have participated in over 200 field inspections of proposed timber harvesting plans.

Proposed prevention and mitigation measures

I. Intent and general requirements

Protection and mitigation measures outlined for the Redwood Creek watershed necessarily focus on minimizing surface erosion, gullyng, and mass wasting which delivers fine and coarse sediment to all watercourses, as well as maximizing canopy retention and reestablishment and retention of large woody debris and large streamside trees and snags for eventual recruitment within Watercourse and Lake Protection Zones. A variety of specific measures have been listed here. Others which carry out the intent and purpose of these measures may be formulated and recommended from time to time based on the results of on-the-ground pre- and post-harvest inspections and as a result of continuing research, studies, investigations, inspections and documented observations in the Redwood Creek watershed.

II. Submission, review and inspection of proposed timber harvesting plans

A. Long term Transportation Management Plan (TMP) - Each timberland owner who intends to conduct commercial timber management within the Redwood Creek watershed shall prepare a long term Transportation Management Plan (TMP) for their ownership. The TMP shall identify all haul roads that have been constructed within the ownership,

including both maintained and currently abandoned routes. The TMP shall also identify the location and classification (permanent, seasonal, temporary) of all existing and planned roads that will be used and maintained for long term forest management.

As a part of the TMP, existing roads which are to be retained shall be identified for upgrading to current drainage standards, roads which are classified as temporary shall be scheduled for temporary decommissioning, and roads which are to be permanently closed shall be scheduled for permanent decommissioning. Upon filing and acceptance of the TMP by the CDF&FP, road upgrading and decommissioning shall be undertaken at a rate of least 10% of the road network per year until all work is completed. New roads to be constructed as a part of the TMP may be built as they are needed for resource management activities. A road inspection and maintenance plan, identifying both schedules, standards and practices, shall be prepared for all roads within the ownership.

The TMP should identify a long term road network which will result in low environmental impacts and low annual maintenance requirements and costs, while still satisfying the landowner's management goals. Operations which deviate from the accepted TMP shall be justified in the timber harvesting plan and may, at the request of the CDF review team, require a revision of the written TMP. Plans shall be revisited and revised every 10 years, or sooner if plans or conditions change.

B. Formal NPS involvement in CDF timber harvesting review process - Redwood National Park shall be designated a formal, voting member of the CDF review team for the purposes of reviewing timber harvesting plans submitted for operations within the Redwood Creek basin. The National Park Service shall have all the rights and responsibilities of all other official members of the review team, including, but not limited to:

1. receiving copies of proposed THP's, including exemptions, amendments, fire plans and related documents and correspondence, submitted by land owners and accepted for filing by CDF,
2. receiving and being included in consideration of scheduling for office reviews, field inspections and other deadlines related to plans in the Redwood Creek basin,
3. permission to attend and/or perform preharvest inspections, operations inspections, completion inspections and monitoring inspections on all proposed, on-going or past timber-related operations in the Redwood Creek watershed, and
4. ability to recommend and vote on mitigations, on an equal footing with other official review team members, and to write non-concurrences when justified.

B. Recognition and treatment of cumulative effects - Research conducted within the Redwood Creek watershed over the last 2 decades has thoroughly documented a variety of cumulative watershed effects within tributaries and along the main stem of Redwood Creek. These include effects related to excessive fine and coarse sediment, elevated summer water temperatures and

low levels of large woody debris, among others. In recognition of these findings, proposed timber harvesting plans shall acknowledge the existence of cumulative watershed effects in the basin and shall include mitigations (including, but not limited to, those contained in these special rules) to address these sources of impact. Timber harvesting plans shall include analyses and specific provisions and mitigations for attaining a negative net discharge (NNG) of sediment as a result of the proposed land management operations. Sediment reduction measures aimed at attaining the NND may be identified and implemented anywhere within the Redwood Creek watershed.

III. Road construction, reconstruction, maintenance and closure

A. Road inventories - As a part of the Transportation Management Plan, TPZ landowners within the Redwood Creek watershed shall perform a complete inventory and erosion potential analysis of forest and ranch roads historically used for timber hauling in the basin. At least 10% of each ownership within the basin, or 200 acres, whichever is greater, shall be inventoried by technically trained and qualified personnel each year until all roads and sediment sources have been assessed. Landowners shall develop and implement cost-effective erosion prevention work along all roads as a part of THP off-site mitigation, as they are included within the boundaries of proposed timber harvesting plans, as they are used as appurtenant roads for log hauling, or as they are included as a part of an approved TMP (see above). Landowners shall develop a prioritized list of roads for eventual closure and erosion-proofing which currently deliver or threaten to deliver large quantities of sediment to Redwood Creek or its tributaries.

B. Road classification - As a part of the TMP, all landowners of TPZ land shall classify forest roads within their ownership as either all-season, seasonal, temporary or abandoned (as defined in the Forest Practice Rules).

C. Road upgrading - All existing all-season, seasonal and active temporary roads on TPZ lands shall be upgraded to current design standards. Among other things, upgrading shall include the following practices and standards:

1. replacing Humboldt log crossings and undersized culverts (even if they are currently functioning),
2. employing a minimum 24" culvert diameter for stream crossings, and a minimum 18" culvert diameter for ditch relief installations,
3. upgrading all stream crossing culverts to pass the 50-year flood discharge (using an accepted computational method) including organic debris,
4. eliminating diversion potentials at all stream crossings which display a diversion potential by dipping the road through the crossing or by installing a permanent "critical rolling dip" on the down-road hinge line,
5. installing trash barriers to prevent culvert plugging and downspouts to prevent outfall erosion (where conditions warrant),
6. excavating and removing unstable road and landing fill (sidecast) which could otherwise fail and enter a watercourse (as identified by a geologist), and

7. eliminating ditch and road surface contributions of water and sediment runoff to stream crossings by road outsloping, or the installation of up-road rolling dips or ditch relief culverts immediately adjacent each stream crossing.

All road upgrading shall be accomplished according to the schedule submitted as a part of the TMP and specific NND-THP plans for the ownership. Upgrading work on all roads shall be completed in not less than 10 years. CDF&FP shall encourage landowners to employ temporary roads, rather than all-season or seasonal roads, that can be permanently or temporarily decommissioned (closed) following timber harvest operations.

D. Roads within WLPZ - All roads and road segments located largely within a WLPZ (not including designated stream crossings) shall be targeted for eventual decommissioning as a part of the long term TMP. In the unusual circumstance where a road must remain in the WLPZ, it shall be upgraded and maintained to minimize sediment erosion, mass soil movement and sediment delivery to streams. Methods to be used include road surfacing (rocking or paving), outsloping, construction of rolling dips, installation of ditch relief culverts and downspouts, ditch armoring, sidecast excavation, bank stabilization and other methods.

E. Culvert sizing - Culvert sizing for all new, reconstructed or upgraded stream crossings on every all-season, seasonal and temporary road shall include written peak flow calculations based on rainfall intensity data available from Redwood National Park. Culverts shall be designed to pass the 50-year flow, including organic debris and sediment, expected at the crossing site. Discharge calculations and culvert sizing methods must employ standard, quantitative techniques. Culvert size shall be based on barrel-full capacity and the accommodation of floatable organic debris and shall not employ additional head-wall height.

F. Road inspection and maintenance - All roads shall be classified as maintained or abandoned. All abandoned roads shall be decommissioned according to the schedule outlined in the approved TMP. All maintained roads shall receive regular inspection and maintenance annually, during winter storm events, and following storms exceeding the 5-year recurrence interval (as gaged on Redwood Creek at Orick). The inspection and maintenance plan shall be included in an approved TMP for the ownership (see above). Maintenance shall include both preventive summer maintenance (winterizing) and winter storm maintenance. Inspections, and needed maintenance, shall be performed on the following sites:

1. road and landing sidecast slopes (check for signs of potential instability)
2. road surface and ditch inspections (check for signs of concentrated runoff, erosion, and sediment delivery to streams),
3. ditch relief culverts (check for signs of plugging), and
4. stream crossings (check for signs of culvert plugging, undersizing, outlet erosion, and inlet plugging, as well as other signs of potential erosion or crossing failure).

G. Road closure (decommissioning) - Currently unused, unmaintained and/or abandoned roads (those which have not been used for hauling within the preceding three years) shall either be brought up to current standards or proactively closed. The schedule and priority for upgrading

and decommissioning shall be detailed in the TMP for the ownership, and all roads and sites shall be completed in not less than 10 years. "High risk" roads identified in the watershed road inventory shall be considered for permanent closure and erosion prevention as a part of THP mitigation (alternate, low impact routes may need to be developed) or as a part of the approved TMP. Road closure techniques include complete stream crossing excavation, permanent surface drainage (by outsloping or construction of deep cross-road drains), and removal or stabilization of potentially unstable sidecast along road and landings which has access to a stream channel. All excavated spoil shall be placed where neither runoff nor mass movement will cause it to enter a watercourse.

H. Feasibility analysis - Landowners shall provide a written feasibility analysis, including a written record of contacts with adjacent landowner(s), as a part of any proposed THP where new road construction is proposed to access timber resources which are already accessible from existing roads on adjacent ownerships.

I. Full bench roads - Construct full bench roads, with all spoil endhauled to stable storage locations, where roads are to be constructed or reconstructed across steep (>50%) slopes which extend continuously and without lessening, to a downslope stream channel. These conditions occur most commonly on approaches to stream crossings where sideslopes are steep (>50%) and along steep inner gorge slopes.

J. Unstable sidecast - Excavate all unstable or potentially unstable landing or road sidecast (including organic debris) resting on steep (>50%) slopes which extend continuously or have access to a stream channel. Unstable or potentially unstable sidecast may be found along roads of all ages. Unstable or potentially unstable sidecast is that which has been identified by a geologist or which shows evidence of scarps, cracks or other signs of potential failure.

III. Timber Harvesting and Related Activities

A. Harvesting on sensitive slopes - Defer or strictly limit timber harvesting on and within 500 feet upslope of *visibly unstable inner gorge slopes*, depending on site specific field reviews at the time of the pre-harvest inspection. Strictly limit harvesting on all *stable and potentially unstable inner gorge slopes* and on *steep (>50%) stream-side slopes* adjacent Class I and Class II streams. In these areas, utilize uncut buffers, light selection cuts or other methods which retain all understory vegetation and at least 75% of the existing basal area of overstory vegetation with re-entry intervals not less than 15 years apart.

B. Tractor yarding - Tractor yarding shall not occur on slopes exceeding 50%, except on existing stable skid trails (those not requiring physical reconstruction) as inspected and approved during the pre-harvest THP field inspection. No new skid trails shall be constructed on slopes exceeding 50%.

C. Winter operations - There shall be no winter period operations within the WLPZ except at designated crossings that are rocked or surfaced, and that remain stable. Only surfaced roads may be used for hauling during the winter period. A detailed, site-specific winter operating plan shall be submitted for any proposed winter operations which describes adequate sediment control measures for the road surface and for each crossing. All hauling operations shall immediately cease when turbid road or ditch water enters a stream. There shall be no winter period tractor operations, or road or landing construction or reconstruction (except as required to prevent erosion and sediment delivery to streams).

D. Watershed sensitivity analysis - Mass wasting and gully erosion sensitivity maps shall be prepared for the Redwood Creek watershed, and the results of this sensitivity mapping shall be employed to develop specific harvest and road building restrictions and/or mitigation requirements for sensitive terrain within the basin. Gully hazards can be predicted based on soil types, bedrock types, slope position and slope gradient. A mass wasting sensitivity can be developed based on bedrock type, soil type, slope gradient, geomorphic indicators and vegetative conditions.

E. Professional Forester responsibilities - All harvesting, yarding, and road building operations conducted on slopes over 50% or within a WLPZ shall be overseen by the responsible Registered Professional Forester (RPF). The RPF shall be responsible for personally meeting with the Licensed Timber Operator, prior to commencement of any harvest or road road-related operations, to discuss requirements outlined in the THP.

IV. Stream Protection

A. WLPZ on steep (>50%), unstable slopes - Extend the watercourse and lake protection zone which crosses landslides or visibly unstable slopes to at least 50 feet above the upper limit of observed instability. All trees within this zone shall be retained and left uncut.

B. Broad cast burning and site preparation - Watercourse and Lake Protection Zones on Class I or Class II streams shall not be broadcast burned.

C. Watercourse and Lake Protection Zones (WLPZ) - The WLPZ for all Class I and Class II streams shall include inner gorge slopes (slopes exceeding 65% which extend without lessening to the stream) and steep, unstable stream side slopes (>50%). Clear cutting shall not be permitted within the WLPZ of Class I and Class II streams.

D. Class III watercourse protection - Class III watercourses shall be protected with a WLPZ using the same requirements as for Class II watercourse protection (14CCR916.5 and Table 1, 14CCR916.5). Class III watercourses which exceed 65% slope gradient shall be inspected by a geologist, evaluated for landslide potential and protected from harvest and road construction if slopes are deemed unstable or potentially unstable.

E. Temporary stream crossings - All temporary stream crossings shall be removed by October 15 of each year, or they shall be designed to accommodate the 50-year flood discharge.

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Land Management Practices for Watersheds

*Descriptions of example techniques for controlling or
preventing watershed sediment production and delivery*

1. Inventory Existing and Future Road-related Sediment Sources

Description and Purpose

Roads¹ are a major source of erosion and stream sedimentation on most managed forest, ranch and agricultural lands, as well as in areas of land subdivision, development and construction. Roads developed for almost any purpose, including logging, ranching (grazing), farming and residential uses, can cause accelerated erosion and sediment delivery to streams. Road construction exposes large areas of bare soil which is subject to rapid erosion. Compacted road surfaces increase the rate of runoff, and road cuts intercept and bring groundwater to the surface. Ditches concentrate storm runoff and transport sediment to nearby stream channels. Culverted stream crossings can plug, causing fill wash outs or gullies where the diverted stream flow runs down nearby roads and hillslopes.

Roads built on steep or unstable slopes may trigger landsliding which deposits sediment in stream channels. Filling and sidecasting increases slope weight, road cuts remove slope support, and construction can alter groundwater pressures, all of which may trigger landsliding. Unstable road or landing sidecast materials can fail, often many years after they were put on steep hillslopes. Lack of inspection and maintenance of drainage structures and unstable road fills along old, abandoned roads can also result in soil movement and sediment delivery to stream channels.

Roads are considered one of the main human-induced, and controllable, sediment sources in the Redwood Creek watershed. Excessive fine and coarse sediment in the Redwood Creek watershed has been identified as a source of water quality degradation for both human uses and fish habitat. Sediment-related impacts to fish habitat include loss or reduction of pool volumes and numbers, reduced habitat complexity, and fine sediment impacts to spawning gravels. To prevent continued impacts, a comprehensive inventory of roads on each ownership or in each sub-watershed should be undertaken to identify and prioritize treatments for road-related sediment sources. Only those sources of erosion which could deliver sediment to a stream channel need be included in the inventory. The inventory will allow for the development and implementation of cost-effective erosion prevention work along all roads within the ownership or sub-basin. Treatments are meant to control erosion and, at the same time, reduce maintenance costs to the landowner.

¹ Roads are here defined as vehicle access routes developed for both commercial and non-commercial use. They include public and private roads developed (or now used for) residential access, recreation, commercial activities, and other land uses. Generally, they do not include off-road trails built for hiking or equestrian use, motorcycles, bicycles, or ATV's, or trails constructed by tractors for logging (yarding) or control of wildfires or prescribed burns. These routes have their own erosional impacts, but their construction and use is not described here.

Many types of roads exist in Redwood Creek and each has its own characteristic problems and needs. Roads have three major classes of impacts. First, roads alter the way water moves down the hillslope, often increasing runoff and diverting flow. Roads also increase the risk of landsliding, especially when they are constructed by sidecasting on steep slopes. Finally, road surfaces accumulate runoff during heavy rains and often discharge this muddy water to stream crossing culverts.

Roads can be classified as permanent, seasonal or temporary, and as abandoned or maintained. Permanent roads (usually rock surfaced) are subject to winter use and fine sediment erosion. Seasonal and temporary roads are usually unsurfaced and can be damaged by wet weather use. Roads can also be classified as abandoned (unused, and sometimes overgrown) and active (open and maintained) routes. Abandoned roads need to be "put-to-bed" to eliminate unnecessary erosion. Maintained roads should be brought up to current standards to ensure that they will weather large storms without causing significant erosion.

When all roads within a sub-basin or ownership have been inventoried, it will be possible to develop a prioritized list of roads for eventual closure (decommissioning) and erosion-proofing (upgrading) based on their potential for sediment delivery to streams. The analysis and inventory should identify and quantify all potential sediment sources, and provide a list of recommended treatments and treatment costs.

Planning Criteria and Applicability

Road erosion inventories for existing and potential sediment sources must be conducted in a systematic, organized manner. That is, a number of specific, pre-defined observations must be recorded, certain measurements taken, and technically accurate conclusions drawn in the field. Without the core of necessary, accurate information, the inventory data will lack the "authority" needed to provide meaningful, relevant, cost-effective solutions to the most important erosion problems in the watershed or on the ownership.

Road inventories are one part of a three prong strategy for identifying, and controlling or preventing road-related erosion within an ownership or a watershed. First, roads are inventoried and a transportation plan for the watershed (or ownership) is prepared. Secondly, all abandoned and high risk roads are identified and scheduled for temporary or permanent decommissioning. Finally, all retained roads are upgraded to current standards to minimize both chronic and episodic (storm-related) erosion and sediment delivery. This third step is sometimes called "storm-proofing."

Inventories are typically performed by a trained geologist or erosion control specialist, or by field technicians who have received field training and whose work is overseen (for quality control) by a professional. All roads, both abandoned and maintained, are inventoried for active and potential sediment sources. Information collected during the survey includes basic location and site data, data on the nature and magnitude of erosion and the potential for sediment delivery to a stream channel, and data needed to develop treatments and estimates for equipment and labor tasks, including costs. Inventory information typically includes stream crossings; unstable fill slopes

(which could fail by landsliding); cut banks, ditches and road surfaces which drain to streams; and other erosion features (including gullies and cutbank landslides) which could deliver sediment to a stream.

Methods and Materials

It is necessary to follow an organized, systematic series of steps in assessing sites of existing and potential road-related erosion. As the first step, an air photo analysis of the watershed or ownership is conducted to help reveal the location of all abandoned and maintained roads, and to determine the road construction history (date of construction) of each road to be inventoried in the field. It is important to identify all the roads that have ever been constructed in the watershed or in the area in question, whether they are currently maintained and driveable, or are now abandoned and overgrown with vegetation. For larger landowners, a preliminary transportation plan is developed at this time, outlining the best long term permanent and seasonal road network needed to manage natural resources.

In the second step, major, potentially treatable or preventable sources of erosion and sediment yield are identified through field inventories and prioritized for treatment during field mapping.

For the detailed field assessment, acetate overlays are attached to 9" x 9" aerial photographs and used to record site location information as it is collected in the field. Information recorded on these overlays includes road location, site number and location (road mileage), type or classification of site, erosional features (stream-side landslides, debris torrents, potential debris slides, gullies and gullied stream channels, washed out stream crossings, etc.), stream channels, stream crossings, landings and all culvert locations. GPS (global positioning) technology (if available, can also be used to identify the location of sites for GIS (computer mapping) applications.

A computer database (data form) is filled out with detailed information about each site of potential sediment yield identified in the field. Ideally, the database form is a standard design that all landowners in the watershed will use to characterize problems and develop treatment prescriptions. Depending on the classification of a site (stream crossing, debris slide, gully, road and cutbank erosion, stream side slides, etc.), different portions of the database form are filled in with the relevant information. Basic information is collected for every site. The detailed data collected in the field includes, at the very least, the following information: 1) a unique site number, 2) the location of the site, 3) the type of erosion problem, 4) an estimate of the volume of sediment that would be eroded and delivered to a stream if treatment is not undertaken, 5) the recommended treatment (including estimates of equipment and labor time) and 6) estimated costs.

In the field, identified sites are first classified according to their potential for sediment delivery to stream channels. It is typically the larger sites that account for most of the accelerated (land use related) sediment yield from a watershed. Very small sites are often not worth inventorying. Therefore, it is important to identify a lower threshold of sediment yield below which a site is not identified in the field inventory. In most watersheds, this minimum site size may range from 10 yds³ to 50 yds³, depending on the watershed. It is often sufficient to identify those sites where

there is a potential to yield at least 25 yds³ of sediment to a stream channel, as well as the more diffuse sediment sources such as road surfaces, ditches and cutbanks.

During road system inventories, special attention should be paid to all stream crossings, all stream crossings with a high diversion potential (DP) (where flow would divert down the road if the culvert plugs) and stream crossings with a high failure potential (FP)(e.g., undersized culverts). Based on past inventory work, each of these categories of stream crossings are assumed to have a high potential for delivering sediment to stream channels. Erosion and failure of stream crossings on abandoned and unmaintained roads, in particular, is likely to eventually occur when culverts plug during large storms. Once erosion has been initiated, sediment lost from these locations will be delivered directly into small streams and, eventually, to the larger fish-bearing streams.

Visibly unstable fillslopes, unstable log landings and unstable hillslopes crossed by either abandoned or maintained logging roads should also be described, especially if they threatened to deliver sediment to a down slope stream channel. To be visibly unstable, the identified site usually exhibits tension cracks, vertical scarps, excessive sidecast on steep slopes and in swales, springs, leaning trees, or other geomorphic evidence suggesting past or pending slope failure.

Once sites are identified and prioritized, general prescriptions for erosion control and erosion prevention are developed for each major source of treatable erosion that, if left untreated, would likely result in sediment delivery to streams. During the field inventory of existing and potential erosion sources, a more detailed analysis of each significant site is performed. This step includes an analysis of the most effective and cost-effective erosion prevention and/or erosion control work that could be applied to each of the sites recommended for treatment, including all sites classified as having a high, moderate or low priority for treatment. *Recommended treatments are generally prescribed only for sites with a potential for future erosion and sediment yield because they are the only ones capable of delivering sediment to downstream fish-bearing stream channels.* Cost-effectiveness evaluation will provide a method for prioritizing all inventoried sites and defining where work should be implemented first.

The analysis of each recommended treatment site includes generalized heavy equipment and labor-intensive prescriptions, as well as procedures, cost estimates and equipment times needed for effective treatment. The sites selected for eventual treatment are the ones that are expected to generate the most cost-effective reduction in sediment delivery to the drainage network and the mainstem stream channel. Sites which may experience erosion or slope failure, but which are not expected to deliver sediment to a stream channel, are not recommended for treatment to protect fisheries resources. General treatments are cataloged in the computer database during field examination of each site. The specifics of the recommended treatments, as well as costs and logistics (equipment types, excavation volumes, equipment hours, etc.) are outlined in this step.

If a sediment source assessment is done well, the logical next step will be for skilled equipment operators, laborers, and erosion control specialists to implement those projects deemed most cost-effective and most beneficial to long term watershed health and the protection of fisheries resources. Implemented projects can consist of both erosion control and erosion prevention

work. As a final step in the process, a revegetation program is then implemented on areas exposed by the heavy equipment during erosion prevention work. Revegetation should incorporate both short term erosion control (developing a rapid ground cover) as well as long term revegetation to reestablish the native vegetation.

Maintenance

With the use of trained personnel, the erosion inventory methodology will be accurate in identifying many existing and future sediment sources along roads. However, as time passes new sites of erosion or potential erosion are likely to express themselves and a regular program of road inspection (especially of culverts and fillslopes) and maintenance is needed to minimize future sediment yield from roads in the watershed. The road inventory, once completed will need updating, with new sites added as they become apparent and old sites removed as they are finally treated.

Effectiveness

Perhaps the most critical step in implementing work outlined in the erosion inventory is determining where money should be spent first. In other words, with limited funding (as is always the case) what is the most important thing to do first? Sites that have been recommended for treatment should be ranked in order of their relative "***cost-effectiveness***." Requiring proposed work to meet pre-established cost-effectiveness criteria is critical to developing a defensible and objective watershed protection and restoration program. *The cost-effectiveness of treating a work site is defined as the average amount of money spent to prevent one cubic yard of sediment from entering or being delivered to the stream system.* It is usually expressed in units of "\$/yd³" (dollars spent to prevent a cubic yard of sediment from entering a stream channel).

Cost-effectiveness is determined by dividing the cost (\$) of accessing and treating a site, by the volume of sediment prevented from being *delivered* to local stream channels. For example, if it would cost \$2,000 to access and treat an eroding stream crossing that would have delivered 500 yds³ (had it been left to erode), the predicted cost-effectiveness would be \$4/yd³ (\$2,000/500 yds³). By using this evaluation methodology a variety of different techniques and proposed projects can be compared against each other using the same criteria: reducing accelerated erosion and keeping eroded sediment out of the watershed's streams.

Sketches/Drawings attached.

Overview of Watershed Assessment and Implementation Process

Goal: To identify, prioritize and cost-effectively treat those future sediment sources most likely to impact fish bearing streams if left untreated.

Basin Selection: Biological criteria dictate priority of basins selected for physical assessment.

Assessment Process:

1. Conduct sequential aerial photo inventory
 - a. road construction history (relative to storm history)
 - b. harvesting or other land use history
 - c. sources of erosion and sediment production
2. Perform field inventories of potential sediment sources
 - a. roads and landings
 - b. landslides
 - c. gullies and stream channels
3. Develop treatment prescriptions
 - a. develop site-specific prescriptions
 - b. estimate heavy equipment & labor tasks & times
4. Prioritize sites for treatment
 - a. predict cost of treating each site
 - b. predict sediment savings
 - c. compute cost-effectiveness

Implementation:

1. Implement erosion prevention projects
 - a. "storm-proof" or "erosion-proof" active road systems
 - upgrade stream crossings*
 - upgrade culvert sizing*
 - eliminate diversion potential*
 - treat unstable road fills (esp. headwater swales)*
 - excavate unstable road and landing sidecast*
 - install pre-crossing ditch-relief culverts*
 - outslope road surfaces / remove ditches*
 - surface roads*
 - b. decommission inactive, unneeded and abandoned roads
 - excavate stream crossings*
 - excavate unstable road and landing sidecast*
 - treat unstable road fills (esp. headwater swales)*
 - decompact roads and landings*
 - outslope surfaces and/or install cross-road drains*
 - c. treat gullies, eroding streams and landslides
 - redivert streams back into natural drainages*
 - disperse or divert upslope road runoff*
 - apply needed erosion control treatments*
 - plant to revegetate and reforest*
2. Develop and implement needed land use changes
 - a. road planning and location
 - b. road construction practices
 - c. road reconstruction practices
 - d. road maintenance practices
 - e. road abandonment practices
 - f. winter operations
 - g. harvesting practices

Check? _____

EXAMPLE ROAD INVENTORY DATA FORM (6/13/97 VERSION)

ASAP? _____

GENERAL INFO.

Site #:	Planning :	Watershed:	Photo:	Sketch?:
Road:	Mileage:	Maintained:	Abandoned:	Driveable?:
Inspector(s):	Date:	Year built:	Maintenance?(Y):	
Treat? (Y,N):	Sed. Yield (Y,N)	Upgrade?(Y):	Decommission?(Y):	

PROBLEM (circle)-

Landslide (fillslope, cutbank or hillslope)

Stream crossing

Gully

Road bed (rd surface, ditch, cutbank)

Ditch Relief CMP

Other

Landslide -	road fill failure:	landing fill failure:	deep-seated landslide:
	cutbank slide:	already failed:	potential failure:
	dist. to stream (ft):	slope(%):	
Stream -	culvert (Y):	bridge (Y):	Humboldt (log) (Y):
	diameter (in):	pipe condition(O,C,R,P) ----->	inlet: outlet: bottom:
	headwall hgt (in):	cmp slope (%):	stream class (1,2,3):
	% washed out:	D.P. (Y, N):	diverted (Y,N)?:
	channel grad(%):	channel dimensions:	W: D: sed. transport (H,M,L):
			ditch/rd length (ft) - L: R:
			plug potential (H,M,L):
Erosion -	Erosion Potential (H,M,L):		
	Past erosion (field-yds):	Delivery (%):	Size W: D: L:
	Future eros (field-yds):	Delivery (%):	Size W: D: L:

Comment on problem - _____

SOLUTION

Treatment immediacy (H,M,L):

Complexity (H,M,L):

Mulch area (ft²):**Treatment-**

excavate soil (Y):	install critical dip (Y):	add TR/DS (Y):
(ft):		
repair/clean cmp (Y):	install/repl cmp (Y): (dia.): (ft):	<u>rock surface</u> (Y): (ft):
reconst. fill (Y):	<u>clean or cut ditch</u> (Y): (ft):	<u>outslope rd</u> (Y):
(ft):		
<u>rolling dips</u> (Y): (#):	<u>remove berm</u> (Y): (ft):	<u>inslope road</u> (Y): (ft):
check cmp size (Y):	other (Y):	none (Y):
Tot vol excav (field-yds):	Vol put back in (yds):	Vol removed (yds):
Vol stockpiled (yds):	Volume endhauled (yds):	Exc prod rate (yds/hr):

Hours-

excavator:	dozer:	dump truck:	grader:
loader:	backhoe	labor:	other:

Comment on treatment: _____

2. Decommissioning Abandoned Roads

Description and Purpose

Good land stewardship requires that roads either be maintained or intentionally closed ("put-to-bed"). The old practice of abandoning roads, by either installing barriers to traffic (logs, "tank traps" or gates) or simply letting them naturally revegetate, is no longer considered acceptable. These roads continue to fail and erode for decades following abandonment. The proper word for proactive road closure is "decommissioning²." Properly decommissioned roads no longer require maintenance and are no longer sources of erosion and sediment yield to a watershed's streams. The impacts of reopening old, abandoned roads so that they can be correctly decommissioned can be evaluated on a case-by-case basis, but the benefits (large reductions in long term erosion) almost always far outweigh the negative effects (small, short-term increases in erosion from bare soil areas).

Road decommissioning need not be an expensive procedure. Most of the road (perhaps 80 to 90%) requires very little treatment, often limited to ripping and draining. The short term costs of excavating stream crossings (the single most costly procedure) can be balanced against decades of cost savings of no longer having to perform road maintenance or emergency repairs when culverts wash out or cutbanks fail. When needed, decommissioned roads can then be reopened for use by regrading the surface and reinstalling the crossings.

Planning Criteria and Applicability

A critical first-step in the overall risk-reduction process is the development of a watershed transportation analysis and plan. In developing this plan, all roads in an ownership or sub-watershed should be considered for either decommissioning or upgrading, depending upon the risk of erosion and sediment-delivery to streams. Not all roads are high risk roads and those that pose a low risk of degrading aquatic habitat in the watershed may not need immediate attention. It is therefore important to rank and prioritize roads in each sub-watershed, and within each ownership, based on their potential to impact downstream resources, as well as their importance to the overall transportation system and to management needs.

Currently unused, unmaintained and/or abandoned roads should either be brought up to current standards and maintained, or they should be proactively closed (decommissioned) (upgrading procedures are described in another RLMP). Road decommissioning techniques include complete stream crossing excavation, permanent surface drainage (by outsloping or construction of cross-road drains), and removal or stabilization of potentially unstable sidecast along roads and landings which could be delivered to a stream channel. All excavated spoil should be placed where neither runoff nor landsliding will cause it to enter a stream. Decommissioning does not necessarily

²Decommissioning has been defined as "removing those elements of a road that reroute hillslope drainage and present slope stability hazards. Another term for this is 'hydrologic obliteration'" (USDA, 1993). It involves such tasks as fully excavating stream crossing fills (not just "culvert removal"), excavating unstable sidecast and road fill, decompacting road surfaces and installing road surface drainage (e.g., cross road drains or road outsloping). The decommissioning of unneeded, neglected, and high-impact roads may be one of the most urgent and significant restoration needs, based on the magnitude of ongoing and potential effects to aquatic ecosystems. Unstable, erodible and high risk (e.g., riparian) roads are prime candidates for decommissioning. Unneeded roads that pose little or no threat to aquatic resources should not be targeted for decommissioning on the basis of aquatic protection or watershed restoration.

suggest permanent closure. Most decommissioned roads can be rebuilt and reopened at a future date, if they are needed, by simply reinstalling the stream crossings and regrading the former road bed. If they are to be permanently closed, they should be ripped (decompacted) and replanted.

Methods and Materials

General heavy equipment treatments for ***road decommissioning*** are relatively new, but the basic techniques have been tested, described and evaluated (Harr and Nichols, 1993; Weaver and others, 1987a; Weaver and Sonnevill, 1984). Decommissioning essentially involves "reverse road construction," except that full topographic recontouring of the road bed is not normally required to accomplish sediment prevention goals. In order to protect the aquatic ecosystem, the goal is to "hydrologically" decommission the road; that is, to minimize the effect of the road on natural hillslope and watershed runoff. From least intensive to most intensive, decommissioning work will include at least some of the following tasks³ (Table 1 also lists a number of possible heavy equipment treatments and their typical applications):

1. *Road ripping or decompaction*, in which the surface of the road or landing is "decompacted" or disaggregated using mechanical rippers (usually ripping teeth mounted on the back of a bulldozer). This action reduces surface runoff and often dramatically increases revegetation rates.
2. *Waterbars and cross-road drains* are installed at 50, 75, 100 or 200-foot intervals, or as necessary at springs and seeps, to disperse road surface runoff, especially on roads that are to be decommissioned. Cross-road drains are large ditches or trenches excavated across a road or landing surface to provide drainage and to prevent the collection of concentrated runoff on the former road bed. They are typically deeper than waterbars and do not allow for vehicle access.
3. *In-place stream crossing excavation (IPRX)* is a decommissioning treatment that is employed at locations where roads or landings were built across stream channels. The fill (including the culvert) is completely excavated and the original stream bed and side slopes are exhumed (uncovered). Excavated spoil is stored at nearby stable locations where it will not erode, sometimes being pushed several hundred feet from the crossing by tractor(s). A stream crossing excavation typically involves more than simply removing the culvert, as the underlying and adjacent fill material must also be removed and stabilized.
4. *Exported stream crossing excavation (ERX)* is a decommissioning treatment where stream crossing fill material is excavated and spoil is hauled off-site for storage. Spoil is moved farther up- or down-road from the crossing, due to the limited amount of stable storage locations at the excavation site. This treatment frequently requires dump trucks to end-haul spoil material to the off-site location.
5. *In-place outsloping (IPOS)* ("pulling the sidecast") calls for excavation of unstable or potentially unstable sidecast material along the outside edge of a road prism or landing, and

³Many of these and other erosion prevention and erosion control techniques are described in the "Handbook for Forest and Ranch Roads" (PWA, 1994c).

Table 1. Sample heavy equipment techniques for decommissioning forest roads.

Treatment	Typical equipment	Typical use or application
Ripping or decompaction of road bed	D-7 or D-8 size bulldozer with rear-mounted hydraulic ripper	improve infiltration; decrease runoff; assist revegetation
Construction of rolling dips and cross-road drains	D-6 or D-7 size bulldozer	drain springs; drain insloped roads; drain landings
Partial outsloping (local spoil site; fill against the cutbank)	Hydraulic excavator and bulldozer	remove minor unstable fills; disperse cutbank seeps and runoff
Complete outsloping (local spoil site; fill pushed up against the cutbank)	Hydraulic excavator and bulldozer	used for removing unstable fill material where nearby cutbank is dry and stable
Exported outsloping (fill hauled away and stored down-road at a stable site)	Hydraulic excavator and dump trucks; bulldozer at spoil site	used for removing unstable road fills where cutbanks have springs and cannot be buried
Landing excavations (usually with local spoil storage)	Hydraulic excavator and bulldozer	used to remove unstable material around landing perimeter
Stream crossing excavations (usually with local spoil storage)	Hydraulic excavator and bulldozer	complete removal of stream crossing fills (not just culvert removal)
Truck end-hauling of spoil materials	Hydraulic excavator and bulldozer	hauling excavated spoil to stable, permanent storage location where it will not discharge to a stream

replacement of the spoil on the roadbed against the adjacent cutbank, or within several hundred feet of the excavation site. Placement of the spoil material against the cutbank usually blocks access to the road and is used in road decommissioning. In road upgrading, or where a decommissioned road is to be rebuilt in the future, the excavated material can be used to build up the road bed and convert an insloped, ditched road to an outsloped road. Otherwise, you'll need to haul the spoil away to a disposal site (see below).

6. *Exported outsloping (EOS)* is comparable to in-place outsloping, except spoil material is moved off-site to a permanent, stable storage location. Where the road prism is very narrow, where there are springs along the road cutbank, or where continued use of the road is anticipated, spoil material is typically not placed against the cutbank and material is end-hauled to a spoil disposal site. This treatment frequently requires dump trucks to end-haul spoil material. This is typically a decommissioning treatment as part or all of the roadbed is removed.

Only in relatively few instances does road decommissioning have to include full recontouring of the original road bed. Typically, potential problem areas along a road are isolated to a few locations (perhaps 10% to 20% of the road to be decommissioned) where stream crossings need to be excavated, unstable landing and road sidecast needs to be removed before it fails, or roads cross potentially unstable terrain and the entire prism needs to be removed. Most of the remaining road surface simply needs permanently improved surface drainage, using decompaction, road drains and/or partial outslowing. The road surface should receive revegetation treatments in locations where eroded sediment could be delivered to a stream (such as the side slopes to excavated stream crossings), but much of the decommissioned alignment can be left to naturally revegetate from nearby seed sources.

Successfully decommissioning most roads will cost a fraction of complete or total topographic road obliteration, and can be significantly less expensive than road upgrading. Costs are highly dependent on the frequency and nature of the potential erosion problems along the alignment.

Labor intensive (hand labor) erosion control treatments are often needed on sites where heavy equipment has been used to perform road decommissioning. Hand labor is used to stabilize and revegetate soils exposed by heavy equipment operations. Only the most effective and cost-effective labor techniques should be prescribed. These include mulching, seeding and planting. In general, heavy equipment will perform most of the significant erosion prevention and erosion control work in drainage basins and along road networks.

Maintenance

Decommissioned roads do not need maintenance, if the work is done properly. One of the goals of decommissioning is to remove the road from the list of active routes that require maintenance. It is possible that some minor hand maintenance of erosion control structures will be needed after the first winter, but the road is no longer open for equipment access. If revegetation efforts were unsuccessful, portions of the site may need replanting.

Effectiveness

Like most erosion control and erosion prevention tasks, the effectiveness of each technique used in road decommissioning can be measured by the amount of sediment which is being prevented from entering the stream system. Most decommissioning treatments have a routinely high level of effectiveness. As with any erosion control and erosion prevention treatment, the level of effectiveness is often dependent on several factors: 1) site conditions (how difficult is the road, and its specific sites, to treat?), 2) how well has the site been described, quantified and laid-out by the inventory crew and 3) operator skill (how experienced and skilled is the operator at this type of work). Difficulties or shortcomings with any of these elements can reduce treatment effectiveness and cost-effectiveness.

Sketches/Drawings

Typical measures are attached.

3. Decommissioning High Risk Roads

Description and Purpose

Certain roads in the Redwood Creek watershed, as elsewhere, are in high risk locations where soils are very erodible and/or slopes are unstable and sediment is delivered directly to fish-bearing streams or their tributaries. These include roads located on steep inner gorge slopes, certain roads within riparian zones, and roads originally constructed on unstable or highly erodible terrain. Many of these roads would never be constructed in the same locations today. High risk roads are also frequently high maintenance roads that require substantial annual effort and expense just to keep open. High risk roads identified during the watershed road inventory should be considered for permanent closure (decommissioning) and erosion prevention. Alternate, low impact routes may need to be developed at the same time to provide stable, low impact access to these areas for future management.

Planning Criteria and Applicability

Recognizing and selecting high risk roads for decommissioning is done during the inventory phase of road assessment. When roads are inventoried in the field, it usually becomes apparent which, if any, routes fall into the high risk category. Before roads are recommended for decommissioning, a transportation plan for the watershed or for the individual landowner parcel is prepared (with their assistance and concurrence). This plan spells out the best locations for all permanent, seasonal and temporary roads. The transportation plan is prepared after completing the field inventory of erosion sources and it considers both the potential impacts of the roads on the aquatic ecosystem as well as management needs of the landowner. Only then can workable plans be prepared for both road upgrading and road decommissioning.

Based on potential threats to the aquatic ecosystem, a variety of roads qualify as "best-candidates" for decommissioning. These often include roads built in riparian areas, roads with a high potential risk of sediment production (such as those built on steep inner gorge slopes and those built across unstable or highly erodible soils), roads built in tributary canyons where stream crossings and steep slopes are common, roads which have high maintenance costs and requirements, and abandoned roads. General techniques for decommissioning (described below) are well documented and tested, and costs and procedures for each type of activity have been established through similar projects in the northcoast region.

Methods and Materials

Roads which are of low relative priority for decommissioning include those which follow low gradient ridges, roads traversing large benches or low gradient upland slopes, and roads with few or no stream crossings. Roads that are no longer needed for land or resource management (including abandoned roads; see previous LMP) may or may not fall into a high risk classification for removal because of where they are located in the watershed. For example, many dead-end spur roads which lead to cable yarding landings high on the hillslope fit into this category of low priority forest roads for decommissioning. Even though these routes might be relatively easy and inexpensive to close permanently, they are not high priority candidates for immediate decommissioning since their removal will do little to protect the downstream aquatic ecosystem.

These types of low impact seasonal and temporary roads may be identified for closure, but their removal from the transportation system may do little to protect or remove real threats to the aquatic ecosystem. It is important to identify more substantial, permanent and "high risk" roads for removal if they pose a significant threat to the aquatic system. Estimating the future sediment yield and treatment cost-effectiveness of projects along all roads (as described above) will help identify which roads in the watershed are truly the best targets for decommissioning.

General heavy equipment treatments and labor tasks for road decommissioning have been described in a previous RLMP ("Decommissioning Abandoned Roads"). Once the roads are selected for closure, the specific procedures are the same. As with all decommissioning, the goal should be to "hydrologically" decommission the road; that is, to minimize the adverse effect of the road on natural hillslope and watershed hydrology, and, hence, on the aquatic ecosystem. Typically, only a small portion of a road will require intensive treatment, even where high risk roads are being decommissioned.

Maintenance

Decommissioned roads do not need maintenance, if the work is done properly. One of the goals of decommissioning is to remove the road from the list of routes requiring maintenance. If revegetation efforts are unsuccessful, portions of the site may need replanting.

Effectiveness

Most decommissioning treatments have a high level of effectiveness. The level of effectiveness is often dependent on several factors: 1) site conditions (how difficult is the road, and its specific sites, to treat?), 2) how well has the site been described, quantified and laid-out by the inventory crew and 3) operator skill (how experienced and skilled is the operator at this type of work). Difficulties or shortcomings with any of these elements can reduce treatment effectiveness and cost-effectiveness.

In sections of high risk roads, it is very likely that landsliding is already occurring and/or erosion rates are already high. Road decommissioning, in these cases, will prevent substantial future erosion and sediment yield but it is unlikely to stop or solve all on-going erosion and sediment loss. Successful treatment of these sites will often be dependent on long term revegetation and site stabilization.

Sketches/Drawings

Typical measures are attached to previous LMP.

4. Road Upgrading Practices

Description and Purpose

Road upgrading consists of a variety of techniques employed to “erosion-proof” and to “storm-proof” a road and prevent unnecessary future erosion and sedimentation. Erosion proofing and storm-proofing typically consists of stabilizing slopes and upgrading drainage structures so that the road is capable of withstanding both annual winter rainfall and runoff as well as a large storm event without failing or delivering excessive sediment to the stream system. Work includes such activities as upgrading stream crossings and culvert sizes, eliminating diversion potential, treating or excavating unstable road fills, improving road surface drainage and surfacing roads (including rock surfacing and paving).

The goal of road upgrading is to strictly minimize the contributions of fine sediment from roads and ditches to stream channels, as well as to minimize the risk of serious erosion and sediment yield when large magnitude, infrequent storms and floods occur. This is accomplished by upgrading all existing permanent, seasonal and active temporary roads, and their drainage facilities, to current design standards to minimize unnecessary erosion and sediment delivery.

Planning Criteria and Applicability

Upgrading should be performed so that all public and private roads, including ranch, agricultural, forestry and residential roads, are brought up to the same standards. If roads are not decommissioned, then they should be targeted for upgrading, regular inspection, and maintenance. Among other things, upgrading should include replacing Humboldt (log) crossings and undersized culverts, upgrading stream crossing culvert sizes to pass the 50-year flood discharge, eliminating diversion potentials at all stream crossings which display a high diversion potential, installing trash barriers and downspouts (where necessary), and eliminating ditch contributions of water and sediment runoff to stream crossings (by employing techniques such as road outsloping, and/or the installation of rolling dips or ditch relief culverts).

Depending on the land use, permanent roads may be needed for long term resource management, for site inspection and maintenance, for fire control, for access to facilities or homes, and for other purposes. Roads which are best suited for retention need to be identified in the transportation planning process for each ownership and sub-watershed. To be protective of fish habitat and the aquatic ecosystem in the watershed, this planning first considers the erosional consequences of road retention, and then the expressed needs for access and for management activities.

Retained roads (those to be upgraded and maintained) are those that are expressly needed for management or as a component of the overall transportation network of a watershed or an ownership. They are typically, but not exclusively, located on stable terrain, where the risk of fluvial erosion, stream crossing failure, storm damage and mass soil movement (landsliding) is lowest. Each retained road is then upgraded and redesigned as necessary, to make them largely self-maintaining or requiring low levels of maintenance.

Methods and Materials

Erosion from roads can be classified into two broad categories: chronic and episodic. Chronic erosion is that which happens every year, regardless of the number of large storms or floods which occur during the winter. It is the result of our disturbing or exposing the land (soil) and concentrating runoff over these exposed slopes. Humans, through a wide variety of land management actions and grading activities, cause runoff to concentrate almost everywhere on the landscape so this type of erosion is widespread. In contrast, episodic erosion is that which is triggered by large storms and flood events. It commonly includes such processes as stream crossing wash outs and landsliding. Both types of erosion can be largely prevented, or strictly minimized, by employing protective land management practices and mitigations.

Chronic erosion - Roads, by their very nature, cut across the natural topography and thereby cause runoff to collect, concentrate and divert. This results in soil erosion. Roads intercept subsurface flow, and collect and concentrate runoff from rainfall. Ditches, berms and insloped roads cause runoff to collect and concentrate. This concentrated runoff can cause erosion in the ditch, on the road, and/or where it is discharged from the road into stream crossing culverts or ditch relief culverts. The best way to control or prevent this type of erosion is to disperse runoff so that it does not collect in sufficient quantities to cause erosion and deliver sediment to streams. Rolling dips, ditch relief culverts and road outsloping are mechanisms that can be used to disperse surface runoff from roads, and thereby minimize or prevent chronic erosion. Fine sediment contributions from roads, cut banks and ditches can also be minimized by utilizing seasonal closures for hauling and travel, by road surfacing, and by converting ditched insloped roads to outsloped alignments (especially at and near the approaches to stream crossings).

Road outsloping is the best method for dispersing runoff. Rain that falls on the road surface flows directly off the road without ever concentrating. Road outsloping is generally limited to roads with a gradient of 10%, or less. Most roads in the Redwood Creek watershed are insloped and ditched. *Ditch relief culverts* are often installed to break-up ditches so that ditch flow is not able to erode the ditch or the slope area where the culvert discharges. *Rolling dips*⁴ are designed to do the same thing, except that they can be constructed to collect just road surface runoff (if they do not intercept the ditch), or both the ditch flow and road surface runoff (where they connect into the ditch system). The more of these diversion structures there are, the better the dispersion of runoff from the road and the less likely that runoff will create serious erosion or deliver eroded sediment to a stream.

If runoff from ditch relief culverts or rolling dips is seen to cause excessive gullying of the fill where it is discharged, it simply means that too much water is being collected and discharged at these points, and that additional dips or culverts are needed to further break-up the runoff. Minor rilling or gullying of the outer road fill is to be expected, but it is not significant if the eroded sediment is not discharged into a stream. Unless the road is outsloped (so that there is no

⁴ Rolling dips are generally not employed on paved public roads where driving through water might present a hazard. Constructing rolling dips is appropriate, and often preferable, to the use of ditch relief culverts on many forest, ranch and agricultural roads.

concentration of runoff), it is important to create enough discharge points so that outlet erosion and erosion below each outlet point is minimal and road runoff does not discharge sediment to a stream channel. Outlet points for rolling dips and culverts need to be located as far from streams as possible, and in locations where runoff will not cause landsliding or deliver eroded sediment to a stream.

A variety of "upgrading" techniques are available to make these stable, well located roads as "erosion-proof" as is possible. Fine sediment contributions from roads, cut banks and ditches in watersheds are minimized by utilizing seasonal closures for hauling and travel, by road surfacing, by converting ditched insloped roads to outsloped alignments (especially at and near the approaches to stream crossings), by adding rolling dips to drain and disperse road surface runoff, and by adding rolling dips or ditch relief culverts immediately adjacent stream crossings (to reduce extension of the drainage network and eliminate ditch contributions to sediment yield).

Specific techniques employed to storm-proof roads include increasing culvert size to accommodate the 50-year flood discharge (or greater), replacing large culverts with bridges, replacing culverted fills with wet or dry fords, eliminating the potential for stream diversion at all high risk stream crossings, stabilizing or removing unstable fills and sidecast, road surfacing (rocking or paving) and realigning road segments to avoid instabilities and recognized headwater swales where landsliding and debris torrenting is likely to occur.

A variety of preventive watershed treatments have been developed for erosion-proofing and storm-proofing (upgrading) roads and landings throughout the Pacific Northwest. Recommended treatments often include such treatments as simple waterbarring, construction of rolling dips, road surfacing and redesigning road surface drainage patterns, but may also include more comprehensive tasks such as full road reconstruction or road relocation. Road upgrading also involves a variety of treatments used to make a road more resilient to large storms and flood flows. The most important of these include stream crossing upgrading (especially culvert up sizing and elimination of stream diversion potential), removal of unstable sidecast and fill materials from steep slopes, and the application of drainage techniques to improve dispersion of road surface runoff. A host of potential road upgrading treatments prescribed for forest, ranch, agricultural and residential roads have been well tested, documented and evaluated in similar erosion control and erosion prevention projects on the northcoast. Properly designed and implemented, these measures have been shown to be effective in significantly reducing sediment yield from managed lands.

Road upgrading costs may not differ significantly from those required for road decommissioning. Costs are highly dependent on the frequency and nature of the potential erosion problems along the alignment, the number and size of stream crossings whose drainage structures must be upgraded, the number of bridge installations required, road surface treatments and surfacing requirements, as well as the size (volume) of unstable fills that must be excavated and end-hauled to stable spoil disposal locations. The type and intensity of use can also affect upgrading costs. Thus, where rock surfacing is insufficient to eliminate fine sediment erosion during winter use (for example on heavily used subdivision roads), paving may be required. Over the long term, paving may actually be less expensive than decades of annual surface rocking.

From least intensive to most intensive, road upgrading tasks typically include at least some of the following measures⁵:

1. *Rolling dip installation/construction (critical dip)*, involves dipping the roadbed at stream crossings on maintained roads where the potential for stream diversion is high, thereby assuring that when culverts plug, stream flow will be directed over the road prism and back into the natural stream channel, rather than down the road bed. Rolling dips are also installed along roads to drain the road surface and disperse excess surface runoff.
2. *Rolling dips, waterbars and cross-road drains* are installed at 200 or 400-foot intervals, or as necessary at springs and seeps, to disperse road surface runoff. Waterbars are also installed on season roads that are closed to vehicle traffic during the wet season.
3. *Installing or cleaning culverts*, includes adding new or larger culverts where they are needed, or cleaning the inlets or outlets of partially plugged culverts on maintained roads. Correct installation procedures are described elsewhere (Pacific Watershed Associates, 1994).
4. *In-place outsloping (IPOS)* ("pulling the sidecast") calls for excavation of unstable or potentially unstable sidecast material along the outside edge of a road prism or landing, and replacement of the spoil on the roadbed against the corresponding, adjacent cutbank, or within several hundred feet of the site. Placement of the spoil material against the cutbank usually blocks access to the road and is used in road decommissioning. In road upgrading, the excavated material can be used to build up the road bed and convert an insloped, ditched road to an outsloped road.
5. *Exported outsloping (EOS)* is comparable to in-place outsloping, except spoil material is moved off-site to a permanent, stable storage location. Where the road prism is very narrow, where there are springs along the road cutbank or where continued use of the road is anticipated, spoil material is typically not placed against the cutbank and material is end-hauled to a spoil disposal site. This treatment frequently requires dump trucks to end-haul spoil material. This is typically a decommissioning treatment as part or all of the roadbed is removed.
6. *Road surfacing* is used to stabilize a road for winter use or to minimize the erosion and loss of fine sediments to nearby streams. On wildland roads surfacing typically consists of the addition of 6" to 12" of crushed or quarried rock to a native surface road to allow for wet weather travel or commercial hauling. In some locations, especially for residential roads or public roads, a bituminous surface (chip-seal or asphalt) is used.

Road cutbanks and road ditches are thought to deliver relatively significant volumes of fine sediment to many wildland watersheds with unsurfaced roads, and they have been found to significantly affect watershed hydrology. Relatively simple treatments can be performed to

⁵Many of these and other erosion prevention and erosion control techniques are described in the "Handbook for Forest and Ranch Roads" (PWA, 1994c).

upgrade road drainage systems to significantly reduce or largely eliminate these watershed effects. Fine sediment can usually be prevented from entering culverted stream crossings by installing ditch relief culverts or rolling dips just up-road from stream crossings, or by outslowing roads in the immediate vicinity of stream crossings. Such treatments also reduce the hydrologic impacts of roads (e.g., increased peak flows and timing of peak flows) on watershed function.

Hand labor is typically used for both revegetation and erosion control work at sites disturbed by heavy equipment, at sites where drainage structures need repair or upgrading, and where hand labor is needed to assist in excavation work. Hand labor is also needed on sections of road that are recommended for upgrading. Labor work at drainage structures include such preventive tasks as adding culvert downspouts and trash racks, adding extensions to culverts, cleaning culvert inlets, cleaning debris out of the channel above a culvert inlet, and assisting in culvert installation or replacement.

Maintenance

One goal of implementing road upgrading measures should be to reduce the level of road maintenance required of roads. Ideally, roads should be self-maintaining, but by their nature all drainage structures, cutbanks, fillslopes and road surfaces will need regular inspection and maintenance to catch any potential problems before they become uncontrollable or deliver sediment to a stream. Clearly, roads and their drainage facilities, no matter how well designed and constructed, will require continuing inspection and maintenance. The techniques for regular road inspection and maintenance are covered in a separate LMP.

Effectiveness

Road upgrading is a highly effective technique for reducing and minimizing sediment production and yield from road systems in a watershed. It is one part of the overall strategy for managing and controlling road-related erosion and impacts within an ownership or a watershed. This three pronged strategy for roads consist of the following elements: First, an inventory of all roads is undertaken to identify existing and potential sediment sources that could impact stream channels and downstream aquatic habitat (as well as other beneficial uses). From this a transportation plan is developed for each property and for the watershed as a whole. Second, all abandoned and high risk roads are decommissioned. Third, roads (and drainage structures) which are to be retained in the watershed are upgraded to current standards, including the capability of drainage structures and fillslopes to withstand the 50-year storm without failure and with minimal damage.

Sketches/Drawings

Typical measures are attached.

5. Excavating Unstable Road and Landing Sidecast and Fill Material

Description and Purpose

Many roads (including both abandoned and actively maintained roads) in the Redwood Creek watershed, especially those located on steep hillslopes, exhibit isolated locations of unstable sidecast and/or fill materials. Many of these road-related landslides can be identified and treated through straight forward excavation. In locations where this material could fail and enter a Class I, II or III stream channel it should be excavated and the spoils stored at a stable location. On active roads, this may require end-hauling to an off-site location.

Planning Criteria and Applicability

Fillslope excavations are one of the simplest and most cost-effective erosion prevention treatments that can be applied to a road system. First, potentially unstable fills and sidecast areas along existing roads are identified through the watershed sediment source inventory (see RLMP 6.7.1). The presence of the most obvious indicators (including cracks, small scarps, emergent groundwater, moisture loving vegetation within the fill, leaning trees, etc) suggest which slopes are the most visibly unstable. These are then treated by direct excavation, removing all or most of the potentially unstable material. The excavated earth is either stored locally or hauled off to a stable storage location where it cannot fail or be eroded and delivered into a watercourse.

Methods and Materials

Typically, potentially unstable fill material is removed from the outside edge of the road or along the outside edge of a landing or area of previous spoil disposal. The unstable sidecast or fill is "pulled" back up (to the extent it can be reached) and placed against the adjacent cutbank, or within several hundred feet of the site. This is called "in-place" outsloping in that the spoil is stored locally. Placement of the spoil material against the cutbank usually blocks access to the road and is used in road decommissioning. In road upgrading, the excavated material can be used to build up the road bed and convert an insloped, ditched road to an outsloped road.

Where the road prism is very narrow, where there are springs along the road cutbank or where continued use of the road is anticipated, spoil material is typically not placed against the cutbank and material is end-hauled to a permanent spoil disposal site. This treatment frequently requires dump trucks to end-haul spoil material. This type of treatment is often performed along actively maintained roads as a part of road upgrading and erosion prevention work.

Generally, a hydraulic excavator is used to reach as far down the fillslope as is possible (typically about 25 feet) and to excavate a concave profile into the potentially unstable fill materials. The average thickness of the excavated material is dependent on each particular site and should be spelled out by the inventory specialists during the field assessment. On active roads, enough road prism will have to be left to allow for continued traffic. Likewise, the left and right margins of the excavation should have been flagged in the field by the same crew. The finished grade at the excavation site should be a free draining, concave-up surface. The concave profile (rather than a straight profile) ensures that bulk of unstable fill material will be removed from the outside of the road bench.

Excavated materials should be placed along and against the cutbank, on the inside of a nearby landing or gentle ridge, or be hauled off to a designated, storage location. Spoil material should not be placed on springs or wet areas, or where material could erode or fail and enter a watercourse. All fill sites should be ripped (decompacted) prior to the placement of spoil materials. Fill at the spoil site should be placed onto a road, landing, or skid trail, and against the existing cutbanks, but should not exceed existing cutbank height.

Maintenance

Excavated sidecast or fillslopes should not need maintenance once the potentially unstable material has been removed. If the excavated slope is immediately adjacent a stream channel, and eroded sediment could enter the watercourse, then the bare soil areas should be mulched with straw (4,000 lbs/acre).

Effectiveness

Road fill failures can be categorized as one of two types: 1) those which involve only sidecast materials and 2) those which involve sidecast as well as native ground beneath the sidecast. These later slope failures are usually larger than simple sidecast failures, and they are more difficult to control once movement has been initiated. Usually, the smaller the volume of the potential failure, the greater the likelihood of success in preventing the failure from occurring or delivering sediment to a downslope stream channel. Direct excavation acts in two ways: 1) it removes the unstable material so that there is nothing left to fail or 2) it significantly unloads (unweights) the top part of a larger failure, thereby reducing the mass of the slide (and the volume of material that could enter the stream if it did fail) and potentially stabilizing the remaining material that is not excavated. Adding weight to the upper part of a slide adds to its instability. By the same logic, removing weight from the top of a slide can act to stabilize a slope that might otherwise fail.

Even if it doesn't prevent the failure, direct excavation can be an effective method for minimizing the volume of potential landslide material that fails from roads and enters the stream system.

6. Disconnecting Road Ditches from the Stream System

Description and Purpose

Erosion from road prisms and cutbanks has long been of concern in forested watersheds, since unvegetated roads and cutbanks are an obvious sediment source. Some of this runoff and eroded sediment enters stream channels and adversely affects aquatic habitat. A recently completed study in Oregon indicates nearly 60% of the surveyed road length in several watersheds appear to route water directly to stream channels or into gullies. It was determined that roads might extend the stream network by as much as 40% during storm events, thereby substantially altering flood flows in small watersheds.

In virtually every watershed in the north coast, including Redwood Creek, many road-side ditches also drain directly to stream crossing culverts. At these sites, eroded fine sediment from cutbanks, ditches and the road surface is discharged directly into stream channel (at the culvert inlet) and contributes to downstream impacts in spawning and rearing habitat. Maintained roads are generally less likely than abandoned roads to have culvert failures and related erosion problems. In contrast, roads which are maintained and used regularly are likely to experience substantially greater sediment yield from road surface and ditch erosion processes. On roads which receive substantial traffic, the volume of fine sediment delivered to the stream can be significant. The solution to this problem is straight forward. It involves the installation of rolling dips or ditch relief culverts, or outsloping the road surface, immediately adjacent each crossing in order to divert road and ditch runoff onto well vegetated slopes where the water and sediment can settle out before reaching the stream.

Planning Criteria and Applicability

Surface erosion along roads comes from four main sources: 1) the road surface, 2) the cutbank, 3) the ditch and 4) the fill slope. The nature and intensity of use of roads (especially commercial hauling), as well as the type and quality of surfacing on the road prism, strongly controls subsequent sediment production from the road bed. Similarly, the erodibility of the soil and the degree of vegetative cover largely controls cutbank erosion rates. The grade (slope gradient) of the road and ditch, the drainage area collecting runoff, the erodibility of subsoils, and grading disturbances control erosion rates along the ditch. Fill slope erosion rates are controlled by the gradient and length of the fill slope, soil erodibility, vegetative cover and runoff rates.

There are several ways to limit the amount of fine sediment that is delivered to streams from a road. They all function in one of two ways: 1) they divert road and ditch runoff into buffer areas or catch basins along the road where water can infiltrate and/or sediment can settle out before it has a chance to reach a stream, or 2) they prevent water along the road from ever concentrating and then being delivered to the stream. The first methods is typically accomplished using ditch relief culverts or rolling dips installed immediately adjacent each stream crossing to drain the road and ditch. The second method, dispersing road runoff and never letting it concentrate, is accomplished by eliminating the ditch and outsloping the road so that road and cutbank runoff drains across the road bed and into adjacent vegetated hillslope areas.

Methods and Materials

The first step in preventing road runoff from entering the stream system is to locate and inventory each and every location where runoff and fine sediment is currently being discharged to a stream channel. This inventory should identify two such types of sites: 1) approaches to stream crossings where one or both approaching road segments drain toward a stream channel (either to the culvert inlet or over the outside edge of the fill), and 2) ditch relief culverts or rolling dips that carry sufficient flow to cause an outlet gully to form which then carries runoff and sediment from the discharge point to a stream channel. Once the sites of existing or potential discharge are identified, treatments can be prescribed to eliminate the source of runoff and eroded sediment.

To solve the problem of fine sediment contributions from roads, identified sites need to be treated to minimize the discharge of road runoff and eroded sediment to streams. There are several ways to effectively reduce the contribution of fine sediment from road ditches. In the inventory, one can simply identify and measure the length of roadside ditch which drains directly into each stream crossing in the basin. These are called "contributing" ditches. As a first choice of treatment, roadside ditches near stream channels should then be eliminated by outsloping the road bed and dispersing runoff rather than collecting and concentrating it in ditches.

Alternatively, ditch relief culverts or rolling dips (called "cutoff" structures) could be installed just up-road from each stream crossing so that ditch runoff (and eroded sediment) is diverted and dispersed on the hillslope below the road rather than being discharged through the ditch and into the inlet of the stream crossing culvert. Culverts or dips (which intercept all ditch flow) would need to be installed within approximately 100 feet (or less) up-road of each crossing to achieve maximum effectiveness at reducing sediment contributions to the stream channel. Specific locations for the placement of ditch relief culverts or rolling dips need to be mapped in the field so that sediment and water from ditches can be effectively dispersed onto hillslopes below the road with no threat that it will enter the stream channel. In many instances, the remaining short section of road and ditch between the "cutoff" (rolling dip or ditch relief culvert) and the stream crossing can be outsloped.

Utilizing either solution (outsloping or installation of drainage cutoff structures), it is clear that not all the road ditches in the basin will have to be eliminated, just the ones that drain road and cutbank runoff directly into stream channels. Ditches which drain into ditch-relief culverts that then discharge water and sediment onto vegetated slopes below the road (without producing gullies) are not considered to have a potential for delivery of sediment into the watershed's stream channels. These latter sites are not treated.

Maintenance

Different requirements for maintenance accompany each of the different possible treatments for disconnecting roads and ditches from streams. Ditch relief culverts (a cutoff structure) require the greatest amount of maintenance to keep open and functional. Rolling dips, where they are used as an alternative "cutoff" to ditch relief culverts, require little or no maintenance (other than making sure the grader operator does not eliminate them accidentally). Likewise, road outsloping is a maintenance-free treatment that only requires proper road surface grading (making sure not

outside berms are unintentionally constructed or left behind) to ensure that road and cutbank runoff is dispersed below the road rather than down the road and into the stream crossing.

Effectiveness

Each of the methods used to detach the road and ditch system from the stream channel network is highly effective. Compared to many other erosion control and erosion prevention treatments, the effectiveness is high and the costs are relatively low. Most of the work is conducted utilizing heavy equipment (tractor, excavator and/or backhoe), with some labor needed if ditch relief culverts are installed.

Sketches/Drawings

Typical measures are attached.

7. Eliminating Diversion Potential at Stream Crossings

Description and Purpose

A significant source of fluvial erosion on managed wildlands originates from the diversion of streams at road stream crossings. Diversion of streamflow can occur if the stream crossing itself was constructed with a *diversion potential (DP)*, where the road and ditch system slope away from the crossing in at least one direction. In this case, when the culvert plugs, stream flow diverts down the road and produces gullies on the unprotected road surface and on nearby hillslopes where the water is finally diverted off the road. Large streams can cause severe erosion and sediment yield. However, even small streams can cause large landslides and gully systems when they are diverted out of their channel.

Stream crossings with a diversion potential "loaded guns" waiting for a large storm and flood to cause culvert plugging and stream diversion. The threat is compounded where the culvert is undersized or prone to plugging with sediment or woody debris. In contrast, when the stream crossing is constructed with no diversion potential, the stream backs up behind the road and eventually flows over the roadbed and right back into the natural stream channel; it does not divert down the road. At worst, the stream will only erode the volume of material placed in the fill crossing when the road was constructed.

Planning Criteria and Applicability

Treatments to prevent stream diversions are straight forward and inexpensive. All newly constructed stream crossings should be built with no diversion potential, by dipping the road into and out of the crossing. All existing stream crossings which currently have a diversion potential should be reconstructed or "reshaped" with a low point next to the crossing. In this manner, when the culvert plugs and the stream backs up and flows onto the road surface, the water will drain across the road (not down the road) and back into the natural channel. This reconstruction simply involves constructing a rolling dip (called a "critical dip") immediately adjacent to the crossing, typically on the hinge line (that line which crosses the road at the junction between the stream crossing fill and the natural slope).

Methods and Materials

The first task in this LMP is to: 1) make sure all new roads are planned, designed and constructed with critical dips at each stream crossing, and 2) inventory every existing road reach or road network to locate all stream crossings which currently display a potential for stream diversion. This inventory can be performed by landowners or equipment operators who have been trained to recognize stream crossings which exhibit a diversion potential. Some crossings are obvious and can immediately be classified, while others (on low gradient roads) are more subtle and may require detailed observations and the use of a clinometer or other slope measuring instrument.

On new roads, it is simple and adds little or no additional cost to make sure the road dips (slopes) into and out of each stream crossing during construction. The low point in the crossing should not be built directly over the culvert, which is often the deepest part of the fill. This could result in significant erosion and loss of the culvert if the crossing fill were to be severely eroded.

Instead, the low point (critical dip) should be placed on the "down-road" hinge line which separates the native, intact bedrock materials from the newly placed fill materials of the crossing. This usually occurs within 10 to 30 feet on one side of the center-line of the crossing. When stream flow tops over the fill at this location, it encounters native hillslope materials and the rate and amount of down cutting is likely to be less than if it were centered over the center of the fill.

On existing roads, stream crossings that have been identified as having a diversion potential will require some heavy equipment treatment to reshape the road bed. As with new roads, a critical rolling dip needs to be constructed on the hinge line of the stream crossing fill. The steeper the grade of the road, the more difficult it becomes to build functional rolling dips. On roads steeper than about 10% to 15% rolling dips become abrupt and steep, making commercial traffic difficult.

Critical dips have several important design criteria. The most important consideration is to make sure the dip is constructed on the down-road hinge line of the fill. Secondly, the critical dip must be the low point on the fill, so that stream flow will be captured and find its way through the dip rather than down the road, into the ditch or across the stream crossing fill at some other point. Often, the ditch adjacent the rolling dip will have to be filled (plugged) so that stream flow will not be diverted down the ditch. It generally takes about one hour, using a medium size bulldozer, to construct a critical rolling dip on an existing road. If the road is surfaced, it will need to be resurfaced following the excavation work.

Maintenance

If properly constructed, a critical rolling dip will not require maintenance. Grader operators will have to be trained to maintain the location and function of the critical rolling dips which are built at stream crossings. Poor road surface maintenance practices can quickly obliterate a critical dip, and render the structure non-functional.

Effectiveness

Construction of critical rolling dips to prevent stream diversion is perhaps the most cost-effective techniques that can be employed to reduce road-related erosion in wildland watersheds. Properly located and constructed, critical dips are highly effective in minimizing road-related watershed erosion and damage to roads during heavy winter storms.

Sketches/Drawings

Typical measures are attached.

8. Using Wet and Dry Fords

Description and Purpose

Stream crossing culverts are always prone to plugging and failure during large winter storms. When culverts plug, either the streamflow is diverted down the road (creating large gullies) or the stream crossing fill may wash out. Construction of a ford (instead of a culverted stream crossing) allows winter storm-flow to pass over the drainage "structure" without washing out the fill or diverting the stream. The road is built to dip into and out of the crossing, thereby minimizing the crossing fill volume. The bed of the ford is composed of either rock armor (that will not be eroded by the stream) or another non-erodible base (such as cement). Where needed, the downstream edge of the ford is structurally built up with a non-erodible sill to make a level travel surface over the crossing.

Planning Criteria and Applicability

Not all stream crossings are suitable for the construction of fords. Fords work well on small to medium sized streams where there is a stable stream bottom and vehicle traffic is light. Compared to a culverted fill, they have the advantage of little fill to wash out during flood flows. Unless wet fords are constructed of poured concrete, they are less desirable in high traffic areas because continued disturbance to the streambed can cause persistent downstream turbidity and fine sediment pollution problems. Dry fords on seasonal roads can often be installed and used with minimal impact to the channel system. In certain situations, where flash floods, high seasonal flood peaks or floating debris are problems, fords may be a practical answer for crossing a poorly incised, shallow stream.

Methods and Materials

Fords of live streams, called "wet fords," are typically composed of streambed gravels, fill, or concrete structures built in contact with the streambed so that vehicles can cross the channel. If possible, a stable, rocky (or bedrock) portion of the channel should be selected for the ford. Fords can be made of permeable trench drains of coarse cobbles and boulders. Low summer flows seep through the fill, and high water discharges flow over the top. During extreme events, however, the ford may be completely washed-out. Permeable fords may be a barrier to migrating fish and installation will require approval by the Department of Fish and Game.

Paving fords across live streams may be necessary to maintain water quality if there is to be regular traffic. Paving consists of a concrete, slightly dish-shaped slab across the watercourse, and a discharge apron or energy dissipator on the downstream side to prevent scour during high flows. The structure should be designed to pass both sediment and debris during high flows. Unfortunately, concrete fords are often plagued by scour around their edges, leaving the ford elevated and impassable. Ford structures are sometimes even moved downstream by large flood flows.

A ford crossing is vulnerable to erosion and can create pollution from several sources. High traffic levels and/or high water flows can cause erosion of both natural and artificial streambed materials. Material placed in the stream or moved about by vehicle traffic can create a barrier to

fish migration. Deep water crossings can cause oil products to be released from vehicles as they pass through a wet ford. Streams with high stream banks require the excavation of substantial ramps to get vehicles down to the streambed. These through-cut ramps are often sites of substantial surface erosion and rilling that enters the stream during periods of winter rain.

On small, poorly incised, ephemeral or intermittent streams a ford may be needed if there is insufficient channel depth to install a culvert. In fact, a rock lined rolling dip with a rock apron face is generally desirable to permanent culverts on these swales and small watercourses. Fords have the advantage, over culverted fills, of never plugging. For poorly incised, dry channels, rock-lined dry-fords can be installed as long as they are completely "pulled" or removed at the completion of use, or before the beginning of the winter period (whichever occurs first). Dry fords work well where the approaches to the channel are relatively flat. The road is built to dip across the channel using as little fill as is possible, and any fill along the outside edge of the road can be armored with fabric and appropriately sized rip-rap, or with an over-side drain.

Fords on small streams should be rock armored to prevent erosion of the road surface and fill during periods of runoff. The fill face on the downstream side of the fill can either be protected with rock armor or fitted with a large overside drain (berm drain) to prevent erosion. Unimproved fords, which consist of a stream channel that has been filled with a substantial quantity of soil and left unprotected by armor or surfacing is a hazard to water quality and should not be constructed.

Maintenance

Fords will require periodic maintenance because of damage caused by vehicle traffic or by winter storm flows. Rock armor may need to be replaced when it is washed downstream. The downstream edge of a ford is often subject to erosion if a permanent sill and energy dissipation is not properly installed. Fords made of concrete may become cracked and fall apart if they are not built with steel reinforcing bars. Likewise, it is important to place large, stable energy dissipation at the downstream end of the ford to prevent undercutting and the development of a plunge pool.

Effectiveness

Used in the correct circumstances (weakly incised stream channels with moderate or gentle sideslopes), and with appropriate materials (resistant to erosion and transport), fords have several distinct advantages over culverted stream crossings. The use of fords minimizes the volume of material in the stream crossing fill, and hence the potential volume of fill which could be eroded if the crossing were to wash out. In addition, fords are not subject to plugging and stream diversion as are culverted stream crossings. By their nature, ford crossings do not have a diversion potential. Hardened fords are also highly effective as stream crossings in locations where debris torrents commonly cross the road bed and would otherwise plug the culvert or erode the fill.

9. Installing Culvert Trash Racks and Debris Barriers

Description and Purpose

Floating organic debris is perhaps the most common cause for culvert plugging, and the consequent failure of stream crossings or diversion of streams during winter storms. A debris control structure (trash rack or debris barrier) at the culvert inlet is a key component of stable culvert design. It acts to prevent plugging of the culvert, and the subsequent overtopping of the fill by flood waters. Plugged culverts are the leading cause of stream crossing failures in the north coastal region and are perhaps the most common road maintenance issue along rural and forest road systems. Trash barriers can be used to lower the probability of stream crossing failure, as well as to reduce the frequency and cost of culvert maintenance.

Planning Criteria and Applicability

Culverts are prone to plugging when woody debris is wedged across the pipe inlet. Debris barriers are constructed upstream from culverted stream crossings where limbs and other large woody debris is likely to be transported downstream to the culvert inlet. Debris barriers are not typically installed at bridges or at ford crossings. In these locations debris is allowed to pass through or under the drainage structure.

Methods and Materials

Creativity and experience can be used to develop a successful design of a debris barrier. Drop inlet "trash racks" have proven to be effective in trapping debris without allowing the culvert to plug. If constructed incorrectly, wooden crib boxes built around the culvert inlet can become clogged with debris and plug the culvert, or significantly reduce its capacity to pass flood waters. The most common problem with trash racks placed over the culvert inlet is that small debris is often trapped by the structure rather than being allowed to pass through the culvert. This small debris can clog the trash rack and actually cause the inlet to plug.

The design of protective debris barrier structures has been varied, and there are as many successful designs as there have been failures. Debris control is best obtained by some type of grate or "filtering" structure built of inclined poles built across the channel just *upstream* from the culvert inlet. The size of the barrier, and the strength of the individual components, is a function of the size of the stream and the woody material it is capable of transporting. Large streams will require large and strong barrier structures.

As a general rule, debris barriers (often called "trash racks") which are constructed over the inlet to the stream crossing culvert are to be avoided unless the design has been proven to be locally successful. These designs often cause premature crossing failure when the barrier captures small debris and is itself quickly plugged.

Maintenance

Debris barriers, by definition, require regular inspection and maintenance. Debris must be removed from the barrier as it accumulates so that the barrier will continue to function as a filter. If the barrier is not cleaned, it may fail catastrophically and send a wave of debris into the culvert

inlet, causing it to fail. Debris barriers should be inspected prior to each winter period and during and following each significant winter flood. Some streams will require more frequent inspection and maintenance than others, based on their ability to transport sediment and woody debris. If the barrier is constructed of wood, it will need to be replaced at least every 5 to 10 years.

Effectiveness

The effectiveness of debris barriers is dependent on the design and the maintenance of the structure. If it is improperly designed or poorly maintained, the debris barrier could actually hasten culvert plugging and stream crossing failure. Properly designed, installed and maintained, debris barriers are highly effective in protecting culverted stream crossings from plugging and failure during winter storms.

10. Installing Culvert Downspouts (flumes)

Description and Purpose

Culvert outlet erosion can be a significant source of preventable erosion and sediment yield from rural and wildland roads. In many locations, "shot-gun" culverts cause significant gullying at the culvert outlets and created large gullies in the natural channel downstream from the outlet of the drainage structure. Even many older culverts continue to erode and gully through loose fill materials. Energy dissipation, including half-round downspouts and rock armor, are common methods for controlling outlet erosion. These structures may be needed on both ditch relief culverts and stream crossing culverts to prevent high velocity culvert flows from eroding the channel bed or banks or the road fill at the culvert outlet.

Planning Criteria and Applicability

Culvert outlets (at both stream crossings and ditch relief culverts) should extend past the end of the road fill and discharge into the natural channel. If the outlet exits midslope, a flume or downspout should be attached to the pipe end and extended past the fill before flow is discharged into the channel or onto the natural slope. Rock armor or other energy dissipation should be used at the outlet of culverts and flumes to prevent erosion by the fast moving flow. Outlets that are experiencing erosion should be armored or fitted with a downspout.

Methods and Materials

Culvert downspouts may be either full-round or half-round pipes, and they may be either the same diameter, or one size larger diameter than the pipe which emerges from the fill. All downspouts should be designed to carry flow past the base of the sidecast or stream crossing fill and discharge the concentrated flow onto non-erodible materials. Flow through steep culvert pipes is typically rapid. Some type of energy dissipation may be needed if flow velocities or flow volumes are high and would otherwise erode the discharge area.

Half-round downspouts are simple to install. Full round downspouts require a fabricated elbow at the culvert outlet so the downspout can turn downward to follow the fillslope angle. Half round metal downspouts are fabricated from full round culverts by cutting with a metal torch. They are preferable to wooden flumes and sheet metal troughs because of their longer life and durability. Half-round downspouts are typically bolted to the outlet end of the existing culvert, laid along the fillslope and terminated in the natural channel or hillslope. They come in 20 foot lengths and will have to be bolted together to span longer slope distances. If downspouts are to be longer than 20 feet, they should be secured to the hillslope using metal fence posts, bolts and bailing wire.

Maintenance

Half round downspouts can twist or turn (and spill their water) if they are undercut on the fillslope or hit by falling limbs or trees. Half round downspouts will need periodic inspection and maintenance to make sure water is contained in the flume, and that the separate segments do not become detached. If the slope fails or moves slightly, or a falling tree hits the downspout, the segments can detached. Full round downspouts should need less maintenance.

Effectiveness

Ideally, culverts should be installed at the base of the fill and their outlet should extend all the way past the base of the fill. However, many older culverts were installed high in the fill. Downspouts are an effective means of controlling or preventing culvert outlet erosion in these locations. Culvert downspouts up to 24 inches in diameter can usually be installed by hand labor, but larger diameter downspouts will require the assistance of a backhoe to lower and hold the pipe in place.

11. Road Maintenance Practices

Description and Purpose

Regular road inspection and maintenance is essential to protect roads and to prevent environmental damage. Roads and drainage structures along all roads should be inspected annually, at a minimum, prior to the beginning of the rainy season. Inspections should cover culvert inlets and outlets on stream crossings, ditch relief culverts, and road surface drainage such as waterbars, outslloping, and ditches. In addition to annual, pre-winter road and drainage structure inspections, crews are needed to inspect and perform emergency maintenance during and following peak winter storms.

Maintenance should address the road surface, cutbanks, and fillslopes, as well as drainage structures and erosion control measures. Road maintenance practices include tasks which improve road drainage and tasks which improve road stability. Work may include culvert cleaning, repairing culverts and drainage structures, improving road surface drainage (reshaping, adding rolling dips, adding ditch relief culverts, etc); and repairing road instabilities. Some of the most important winter maintenance can be performed by hand labor, keeping culvert inlets clear and open. Other problems will require the use of backhoes or other heavy equipment to move large amounts of sediment and debris. All roads which are not properly closed or decommissioned require maintenance.

Planning Criteria and Applicability

Road maintenance, by definition, is designed to improve the condition of a road system and to prepare it for winter storm periods. At the same time, many road maintenance practices can directly impact stream resources if they are not carefully undertaken. All roads used for vehicle travel should be regularly inspected and maintained according to an established or written schedule. If personnel and resources cannot be committed to providing regular maintenance, roads should be built (or rebuilt) as temporary, and then properly closed (decommissioned) upon the completion of operations, but before the first winter period. Temporary roads that have been properly closed do not need continued maintenance and pose little threat to downstream resources. Subdivisions and other multi-owner road systems should develop plans for both emergency maintenance and long term inspection and maintenance activities.

Methods and Materials

Specific techniques can be employed to increase the effectiveness of road maintenance practices and improve the protection to stream resources. These observations, not listed in order of importance, include the following general practices:

1. Winter road use: The first rule of maintaining a stable road surface is to minimize hauling and grading during wet weather conditions, especially if the road is unsurfaced.
2. Summer road use: Heavy traffic or hauling on a dry road bed in the summer can churn and pulverize road surface material and create thick, loose layers of soil and rock powder (dust).

Summer hauling should be accompanied by dust control and watering to maintain the road surface condition.

3. Grading roads: Road surfaces should be graded only when needed to maintain a stable, smooth running surface and to retain the original surface drainage. Over grading results in unnecessary erosion and increases road surface rock wear.

4. Unwanted berms: Berms that are created by road surface grading often concentrate runoff during winter rains should not be left along the outside edge of the road. When regrading roads, avoid constructing berms along the outside edge of the road, where it would act to collect and concentrate road surface drainage. Remove berms where they have been inadvertently constructed by years of grading. Where past grading has piled good surfacing materials along the outside edge of the road, it can be retrieved and worked back into the road bed.

5. Ditch grading: Frequent, routine mechanical grading of ditches is usually unnecessary and can cause erosion of the ditch, undermine cutbanks, and expose the toe of the cutslope to erosion. Ditches should be graded only when and where necessary. Routine mechanical ditch grading should be avoided.

6. Maintenance of seasonal roads: Unsurfaced seasonal roads require almost the same maintenance effort as permanent roads, but are much more sensitive to wet weather use. These roads should not be used when wet, and hauling or other intensive vehicle activity should be limited to dry periods when soils retain their maximum natural strength.

7. Seasonal closure of roads: Gates can be used to discourage wet weather use, but the use of gates or other barriers does not eliminate the need for annual and emergency winter maintenance inspection and repairs.

8. Stream crossing maintenance: Summer culvert inspections and maintenance is often performed at the same time as ditch maintenance. The critical component of successful culvert maintenance is to fix problems before complete failure occurs. Culverts inlets, and trash racks located upstream from culverts, need to be regularly inspected cleaned of woody debris to prevent plugging.

9. Cut slope and fill slope maintenance: The key to maintaining cut slopes and fill slopes, including sidecast materials, is to observe and note when and how changes to these features occur. Corrective measures can then be implemented, depending on the problem.

Cut slopes - Typical cutslope problems include excessive raveling, rilling, and slumping which may block the ditch or require frequent ditch cleaning and maintenance. In the long term, it may be necessary to flatten the cutslope, revegetate bare soil areas, widen the ditch (so that it does not plug so easily), install ravel barriers on the slope and at the base, and/or build a retaining structure to contain or prevent slope movement. Often, simply loading the toe of a small cutbank slump with heavy riprap can provide sufficient weight to

stabilize the feature. Stabilizing or controlling the movement of larger unstable areas may require analysis by an engineer or engineering geologist.

Fill slopes - Regular inspection and prevention (including excavation) is the key to maintaining stable fillslopes and sidecast areas. Unstable fillslope materials should be excavated and removed, including organic debris, *before* they fail. If the potential instability is perched above a stream channel immediate treatment is usually required. Larger fill slope landslides, including those that include the hillslope below the road, may be difficult or effectively impossible to stabilize. Stabilizing or controlling the movement of larger unstable areas may require analysis by an engineer or engineering geologist.

10. Winterizing roads: Before winter, all permanent, seasonal and temporary roads should be inspected and prepared for the coming rains. Winterizing consists of maintenance and erosion control work needed to drain the road surface, to ensure free flowing ditches and drains, and to open all culverts to their maximum capacity. On unsurfaced roads, waterbars may be required at spacings dictated by the road gradient and the erodibility of the soil. Trash barriers, culvert inlet basins and pipe inlets should all be cleaned of floatable debris and sediment accumulations. Ditches that are partially or entirely plugged with soil and debris should be cleaned and heavy concentrations of vegetation which impede ditch flow should be trimmed. This is also the best time to excavate all unstable or potentially unstable fills and sidecast which could fail and be delivered to a watercourse during the coming winter. Once seasonal and temporary roads have been winterized, they should be gated and closed to "non-essential" traffic.

11. Spoil disposal: Spoil material should be hauled to a stable site safely distant from streams, contoured to disperse runoff and stabilized with mulch and vegetation. Excess spoil from maintenance activities should never be sidecast near streams. Berms of excess spoil along the road shoulder should be removed or frequently breached prior to the rainy season. Avoid sidecasting on approaches to incised stream crossings which are being rebuilt, replaced or widened. End-haul spoil material, instead of sidecasting, where there is any likelihood of sediment reaching the channel system, especially in rocky slope areas or where soils are composed of highly erodible unstable, sheared schist or decomposed ultramafics.

12. Outsloping roads: Where feasible, convert insloped roads to a gentle outslope and remove the ditch. If the ditch is necessary, the road surface can still be outsloped. Outsloping roads in appropriate locations can reduce both maintenance requirements and soil erosion.

13. Rolling dips: Emphasize the increased construction and use of rolling dips to drain road surfaces. Rolling dips can also be used to drain the ditch at regular intervals. They are used as a low maintenance, low cost alternative to ditch relief culverts and waterbars.

14. Trash barriers at stream crossings: Construct trash barriers on large or active streams which transport debris. They should be placed somewhat upstream from culvert inlets, to protect the inlet against plugging with organic debris. Trash barriers will require periodic inspection and cleaning, but their use can prevent expensive and damaging stream crossing failures. Smaller stream crossing culverts (up to 24 inch diameter) that have a history of plugging with debris can

be protected by installing a fence post about two feet above the culvert inlet. This acts to turn small debris so that it will pass through the culvert and to block large debris that would otherwise plug the inlet.

15. Culvert downspouts: Shot gun culverts create gullies. Downspouts should be installed on existing and newly installed culverts which show any sign of continuing outlet erosion, in order to carry flow to natural ground below the base of erodible fill material.

16. Culvert sizes: Standardize the practice of using 18-inch culverts as the minimum sized pipe utilized in new road construction and culvert replacement projects, and 24-inch culverts as the minimum diameter for stream crossings.

Maintenance

By definition, most of the features of an active road require regular inspection and maintenance. Especially critical components include stream crossing drainage facilities (especially culvert inlets), road surfaces (to ensure proper drainage), and road fill slopes (especially unstable fill slopes on steep slopes near stream channels).

Effectiveness

Regular inspection and maintenance of roads and their drainage facilities is the only way to minimize unnecessary soil erosion and sediment delivery. First, roads need to be upgraded. Poorly designed and constructed roads will yield substantial eroded sediment regardless of the amount of maintenance that occurs. Second, all permanent and seasonal roads must be inspected before each winter and after each major winter storm (or as problems arise) maintained. To be effective, sufficient resources (personnel and equipment) must be available and obligated by the land owner to maintain roads on the property.

12. Grading and Erosion Control Practices for Construction Sites

Description and Purpose

Unit soil erosion and sedimentation from construction sites can be many times greater than that from other agricultural and forest practices because of the extreme degree of soil disturbance. As residential pressures and construction activities increase in the watershed, this source of sediment will become more and more important. However, most of this erosion can be significantly reduced by proper planning and construction, and the application of specific erosion control measures at the construction site.

The general principles for controlling sediment from construction sites include the following: 1) diverting clean water from upslope areas around the site (to minimize the amount of water that must be dealt with), 2) minimizing the size of the construction area and the duration of disturbance, 3) employing temporary erosion control measures during construction, 4) protecting drainage and runoff channels which will carry concentrated runoff from the construction site and 5) maintaining each installation and measure to ensure each continues to function for its needed life. A host of specific techniques are available to meet each of these objectives, depending on site conditions.

Planning Criteria and Applicability

Erosion control at construction sites can be divided into a number of best management practices applied to provide both temporary and permanent control of sediment. This LMP will outline the basic practices needed to be followed to minimize the off-site impacts of construction practices on streams. A complete description of each practice, in its various forms, is beyond the scope of this LMP. However, readily available references can provide additional detail on each of the following elements.

These erosion control practices are divided into the following basic elements:

1. Diverting flow
2. Managing overland flow
3. Trapping sediment in channelized flow
4. Establishing permanent drainage ways
5. Protecting inlets

Generally, temporary measures may not require engineering analysis and design, whereas permanent drainage and earthwork facilities are likely to need more detailed design work performed. County Planning and Building departments, as well as other state agencies, may have additional requirements for residential and commercial construction projects which are expected to create large areas of bare soil which could impact water quality.

Methods and Materials

1. Diverting flow - Flow diversions are created or constructed to collect and divert surface runoff around disturbed areas or construction sites to a location where water can be discharged without scouring stream channels or impacting receiving waters. Channels are constructed upslope of

disturbed areas, upslope of spoil piles or in areas to divert runoff to detention basins. Channels should be designed to accommodate the 25-year, 24-hour discharge. The channel should have a trapezoidal cross section with stable sideslopes. It should be excavated into natural ground and sloped such that flow velocities are non-erosive. The diversion side slopes should be stabilized with straw mulch and seeded for rapid revegetation. If the channel is to carry discharges which are erosive, the channel should be lined with an erosion control fabric, rock armor or other stabilizing material along the bed and banks.

2. Managing overland flow - Overland flow refers to runoff that is flowing over the surface of the land but has not yet collected into channels. Generally, areas subject to overland flow are small in size. BMP treatments are generally placed on the slopes and on the downslope side of such areas to control erosion and to prevent water from concentrating and eroding exposed soils.

Cost-effective BMP treatments for bare soils include:

1. silt fences,
2. straw bale fences,
3. mulching and
4. sodding and mulching (including hydroseeding)

The former two practices (fencing) are used to intercept and detain runoff and eroded sediment. The latter two practices are designed to prevent erosion and sediment transport on the bare soil areas of a construction site or disturbed area.

Silt fences consist of geotextile fabric or woven fabric stretched across and attached to supporting posts (usually metal fence posts) and entrenched six inches into the ground. Straw bale fences consist of a row or entrenched and anchored straw bales. Both types of fences are built on contour across a hillslope. The ends of each fence should be turned upslope to contain runoff and sediment.

Silt fences and straw bale fences are equivalent practices used to contain eroded soils and prevent sediment from leaving a construction site. Straw bale fences are generally used to contain small amounts of sediment. Both types of fences are designed to intercept and detain storm water runoff and to prevent sediment from leaving the construction site. They are placed around spoil piles and on the downslope side of bare soil areas less than about 10 acres in size. If a channel passes through a disturbed area, fences should be placed along the channel edges to prevent eroded soil from entering the watercourse or channel.

General guidelines for the spacing of both types of fencing on disturbed hillslopes is shown in Table 1. Parallel fences may be needed on long slopes or where slopes are steep. The slope behind the fence should be no greater than 50%. Silt fences and straw bale fences are not designed for use in streams, swales or ditches where concentrated flow is expected. Sediment retention fences will be more useful and effective if runoff from above the construction site is diverted around the disturbed area. Finally, they should be installed prior to disturbing the upslope area.

Mulching and seeding are techniques used to minimize or prevent soil erosion from occurring on bare areas. They are usually used in conjunction with sediment fences. Mulching acts to protect

Table 1. Suggested maximum slope length between parallel erosion control fences for a given slope gradient.	
Slope (%)	Maximum slope length (ft)
<2%	100 feet
2% - 5%	75 feet
5% - 10%	50 feet
10% - 20%	25 feet
> 20%	15 feet

the soil surface from raindrop erosion and minor rilling, and it creates a favorable microclimate for seedling establishment. Mulching can include simple materials such as straw or wood chips, or more specialized nets and mats of various compositions. Mulch should be applied at a rate of 3,000 to 4,000 lbs/acre (70 - 90 lbs/1000ft² (1 bale = 80 lbs)). A good application should conceal most of the bare soil beneath. In windy areas or where slopes are steeper than about 40%, straw will need to be secured to the soil surface either by punching, by the use of a covering net or a tackifier. The application procedures for mats or nets are provided by the manufacturer of the erosion control materials and should be closely followed. They typically involve overlapping guidelines and stapling instructions.

To be effective, seeding should be performed prior to significant rainfall so that a well established ground cover has been established when serious rainfall occurs. Seeding usually employs a mixture of grass and legumes, but can also include native brush and tree species for a more permanent vegetative cover. Seeded areas should be mulched after the seed has been applied so that both immediate and long term protection will be afforded. Depending on soil conditions, fertilization may be needed to develop a continuous cover. Preferred rates for seeding and fertilization are area-specific and are usually available from local highway departments or from seed distributors.

3. Trapping sediment in channelized flow - Channelized flow refers to concentrated runoff flowing through depressions, swales or channels. This BMP describes how to trap sediment carried by channelized flow. The specific practices to be employed vary with the drainage area of the project site (Table 2). Each of the available practices cause flow velocities to slow sufficiently to allow sediment to settle out. It then accumulated behind the barriers or traps.

For small drainage areas, where channels are to carry low discharges and low velocity flows, diversions and barriers can be employed to trap sediment. Filter fabric and straw bale barriers (as

shown in the attached diagrams) are constructed perpendicular to and across the channel and entrenched into the channel and sideslopes. The spacing between barriers is determined by both drainage area and channel slope. Each fence should have contributing drainage area not exceeding 1 to 2 acres. Secondly, the difference in elevation between fences should not exceed

Table 2. Sediment trapping techniques for various drainage areas.	
Drainage area of project site (acres)	Typical sediment trapping technique
Less than 2 acres	filter fabric barriers straw bale barriers temporary diversions
Less than 5 acres	sediment traps
Less than 150 acres ¹	sediment retention basins
¹ Regardless of the project area, disturbed sites greater than about 10 acres of bare soil will require the construction and use of at least one sediment retention basin.	

two-thirds the height of the barrier. Straw bale barriers are often employed in areas of lower discharge and slower velocity, and are never used in intermittent or perennial streams. They are typically less effective than filter fabric barriers.

Sediment traps are small temporary basins designed and constructed to trap sediment in channelized flow courses. They are useful for drainage areas less than about 5 acres and have an efficiency of 70% to 80% (clay-sized particles will not settle out in these small basins). The trap should have a length:width ratio of not less than 2:1, a minimum depth of 2 feet and embankment sideslopes of 2:1, or less. The outlet of the basin should be sized for the 25-year flow and should have energy dissipation to prevent erosion. The maximum height of the sediment trap embankment (crest) should be 5 feet, with a top width of four feet and an outlet elevation at least one foot below the embankment crest.

Sediment basins are the largest of the sediment trapping devices described here. They are used where drainage areas are less than 150 acres where other sediment retention devices are not adequate to prevent off-site sedimentation. These large structures may come under the definition of "dams" and may be subject to other local, state or federal codes. Sediment basins and embankments should be designed by an engineer or erosion control specialist.

Typically, the basin should include a principal spillway, a dewatering outlet and an emergency overflow spillway. The length/width ratio of the basin should be between 2:1 to 5:1, the latter being preferable. The sediment storage volume should be sufficiently large to contain the estimated annual sediment volume from the drainage area. The principal spillway (typically a horizontal culvert with an anchored vertical riser in the retention basin) should have a 10-year, 24-hr peak flow capacity. It should also have dewatering holes to allow for dewatering of the basin

in no less than three days following a runoff event. The inlet should have a trash barrier to prevent plugging. The embankment should have a minimum top width of four feet and sideslopes of 2:1, or less. The native soil beneath the embankment should be stripped of organic debris prior to construction. An emergency overflow spillway shall be constructed to have sufficient design capacity for the 25-year, 24-hr flood. It should have a minimum elevation of at least one foot higher than the principal spillway. Its outlet should be protected with energy dissipation and it should discharge to a stable drainage way. For safety, sediment basins are surrounded by fences.

4. Establishing permanent drainageways - Some construction sites will create locations for permanent channels or waterways. These channels will require permanent stabilization practices to protect them from erosive flows. The three main types of permanent channels include grassed waterways, geotextile-lined grassed waterways and rock or concrete lined waterways.

Stabilization of newly constructed channels will occur through the use of vegetation in combination with physical structure (armoring). The types of channels where this practice is suitable includes active swales, ditches and diversions. In general, channels can be lined with vegetation to control erosion if velocities do not exceed 3 to 4 ft/sec. Generally, channels less than about 3% gradient may remain unlined. If flow will intermittently exceed these velocities, if flow is to be continuous, or if the channel is steeper than 3%, the channel should be lined with geotextile fabric or rock rip-rap. In all cases, channels should have sufficient capacity to conduct the 25-year, 24-hour peak storm discharge, with no steeper than 2:1 sideslopes.

Grassed waterways is the least protective method for channel stabilization. It consists of a constructed channel that is shaped or graded to required dimensions and established with vegetation that is suitably dense that channel remain stable during flow events. It is employed to protect the soil surface of ditches and small channels from erosion and to slow the velocity of flowing water. Grassed waterways need to be constructed and completely vegetated prior to receiving expected runoff.

Where flow velocities are expected to be high, geotextile fabrics can be used to anchor and reinforce the vegetation. Manufacturers provide specific design criteria and installation instructions for a variety of channel applications and one or more products. These instructions should be closely followed to assure project success and channel stability, especially in regards to the burial of fabric edges and fabric overlap procedures. Fabric linings serve as temporary channel protection until vegetation can become suitably established. A variety of natural fabrics (such as jute netting) and synthetic materials and grids can be employed to protect the channel under moderate and high velocity settings.

Gravel and rock is the simplest and most traditional type of channel lining. Depending on the availability of rock, it may also be relatively expensive. Rock linings can be made to withstand most stream velocities if the proper size rock is chosen. The construction procedure is to: 1) construct channel, 2. place a filter layer of finer material (or filter fabric) on the soil, and 3. Place the layer of rock on the filter layer. It is important the rock is placed not only on the channel bed but also up both channel banks to an elevation above the design flood level. Engineering tables exist for selecting proper rock diameter based on the channel bottom slope and channel

dimensions, and for determining proper rock size based on a calculation of expected flow velocities in the channel.

5. Protecting inlets - The above listed measures are not 100% effective in preventing erosion. For this reason, it is important to provide filtering of storm water at all conveyance structure inlets to prevent sediments from reaching lakes, streams and other water bodies. Thus, all temporary storm drain, catch basin and culvert inlets at construction sites should be protected with straw bale barriers, filter fabric barriers or equivalent filtering mechanisms. The design of the filtering mechanism or barrier is similar to that for sediment traps where flow velocities are slowed and sediment is allowed to drop out before water is conducted through the pipe and discharged into the receiving waters.

Maintenance

Maintenance of each practice will be necessary to ensure proper functioning. Above all, the entire site needs to be thoroughly inspected following each rain to ensure that all possible sediment sources have been identified and properly treated. Any untreated sources will need immediate treatment. Most specifically, all structures need to be inspected after the first storm flow, and on a regular and frequent basis for at least the first year after that, to ensure they continue to function as designed and constructed. Any problems that develop need to be repaired immediately. In addition, sediment retention and sediment filtering structures need to be emptied of deposited sediment on a regular basis prior to reaching 50% of their storage capacity.

Diversion channels and grass-lined waterways need to be inspected and maintained until at least such time as the vegetative cover is completely established. Silt fences need to be inspected within 24 hours of each rainfall or daily during prolonged rainfall. Repairs need to be made immediately. Straw bale barriers need regular inspection for undercutting and flow between bales. Mulching that has moved or become ineffective should be immediately supplemented with additional mulch until vegetation is suitably established. Seeding may need to be watered immediately after planting to develop a continuous cover. Seeded areas will need to be reseeded if the ground cover is not complete.

Effectiveness

Structural erosion control and erosion prevention measures require proper construction to function effectively. Poorly or improperly constructed measures will not function, and can sometimes cause erosion that would not otherwise have occurred. Most sediment retention measures have a design efficiency of about 70% to 80%; with the fine sediments (clay) passing through the system and into receiving waters. Most erosion control measures (mulching and seeding) can be highly effective at controlling fine sediment loss and movement from bare soil areas. Channel erosion control measures can be effective if properly designed and installed, but improper construction can result in serious erosion and downstream sedimentation. Finally, frequent inspection and maintenance is key to having a highly effective erosion and sediment control program at construction sites.

Sketches/Drawings

Typical measures are attached.

13. Inner Gorge Road Building and Timber Harvesting Practices

Description and Purpose

Road building and certain types of timber harvesting conducted on steep, unstable inner gorge hillslopes can result in increased rates of landsliding and sediment delivery to stream channels. In many coastal watersheds this is one of the leading sources of management-related sediment production and yield. Road construction on these slopes can result in relatively high rates of road failure, sidecast failures, persistent maintenance problems and high maintenance costs.

Modification of harvesting and roading practices in these and other sensitive geomorphic locations (such as steep headwater swales) can be employed to reduce future management-related slope failure and sediment delivery. Prior to developing site-specific land management practices for such areas, potentially susceptible inner gorge slopes must first be delineated through the use of aerial photographic analysis, field inspections and modeling.

Planning Criteria and Applicability

A variety of measures can be employed to reduce disturbances to potentially unstable inner gorge slopes. In these areas, landowners may choose to utilize uncut buffers, light selection cuts or other methods which retain understory vegetation and a significant portion of the existing overstory vegetation with specified re-entry intervals aimed at maintaining substantial forest cover. Except in unusual cases, road construction should be avoided on steep, potentially unstable inner gorge slopes along Redwood Creek and its tributaries. Other possible preventive treatments in these identified sensitive areas might include strictly limiting timber harvesting on *visibly unstable inner gorge slopes*, on all *steep and potentially unstable inner gorge slopes* and on *steep (>65%) stream-side slopes* adjacent Class I and Class II streams, depending on site specific field reviews at the time of the pre-harvest inspection. Road construction on the latter stream side slopes should be limited to designated stream crossings and should employ full bench end-haul construction techniques.

Methods and Materials

Steep inner gorge areas contain some of the most unstable slopes of the watershed. Inner gorge slopes are characterized by steep slopes which commonly exceed 70% and locally exceed 90% in steepness. In addition, emergent groundwater, hydrophillic vegetation, sheared and incompetent bedrock and zones of deep colluvial deposits often characterize much of the inner gorge. Many of the existing slides are typically found on concave (convergent) hillslope morphologies where subsurface water tends to accumulate and concentrate. These factors are all suggestive of the inherent instability of many inner gorge locations, and slope movement is a recent occurrence at many sites. Other areas show slope failures, independent of road building, that have occurred since the slopes were harvested.

Three common locations where land use activities are especially prone to causing landsliding (debris torrents) and the direct delivery of large volumes of sediment to Redwood Creek and its tributaries include: 1) steep inner gorge slopes, 2) lower hillslope positions along deeply incised tributary streams and 3) steep headwater swales. Harvesting, tractor yarding and, especially, road

construction in these areas can substantially increase the likelihood of large scale slope failure and sediment delivery during large storms.

Roads and harvesting on steep inner gorge slopes: Roads constructed on the steep inner gorge slopes along the main channel of Redwood Creek and its major tributaries have locally been associated with large slope failures which delivered substantial sediment to stream channels. Thus, suggestions for harvesting and road location include avoiding and/or modifying practices on selected, steep, potentially unstable inner gorge locations; steep, wet headwater swale areas and steep stream-side slopes of high order, incised tributary streams.

Clearcut harvesting and road construction (or reconstruction) are likely to trigger failure of some inner gorge slopes which are currently marginally stable or showing signs of instability (including leaning trees, abundant emergent water, convergent topography, steep slopes and/or recent scarp development). In these potentially unstable areas, harvesting may have to be deferred or harvesting techniques may have to be modified to successfully prevent widespread slope failures from occurring during the next major storm event.

It is recommended that each inner gorge site receive detailed geological evaluation prior to developing specific harvesting or road building plans to determine which (if any) units or areas should be deferred and what specific harvesting and yarding techniques would have the least adverse impact on slope stability and be most protective of fishery resources.

Roading and harvesting on steep tributary sideslopes: Although more geographically confined, the inner gorge slopes along deeply incised tributaries to Redwood Creek represent another likely site for fillslope failures, native hillslope failures and stream crossing failures, with resultant sediment delivery to the channel system. These channel sideslopes often display widespread zones of emerging groundwater, as well as either mottled, deeply weathered, highly unstable soils, or deep colluvium. Roads built across these lower hillslopes typically fail shortly after construction and are abandoned or remain as extremely high maintenance areas. Failures of stream crossings and fillslopes built on the approaching hillslopes deliver large quantities of sediment to the tributaries.

Road construction in steep headwater swales: As typical forest roads cross a hillslope, the fill/cut ratio is usually the greatest in swales (topographic depressions). These relatively deep, wide fill wedges appear to impede subsurface groundwater flows. This results in elevated pore pressures and leads to hillslope failure in areas of steep, wet slopes.

According to the aerial photo analysis, headwater torrents often originate where landings or roads have been built across these steep, wet swale areas. Improved road and skid-trail location and design can prevent many potential headwater debris torrents that would otherwise be associated with road construction.

General recommendations: It is far more effective and cost-effective to avoid sites of potential instability when the units are logged or roads are constructed. Once roads have been built on

unstable hillslopes, there is little that can be done to retroactively stabilize the hillside and control landsliding. Individual sites of potential debris slides (such as those in steep, headwater swales) and stream crossings can be treated through excavation, but larger scale features cannot effectively or economically be treated once instabilities have begun.

When possible, the following sites or practices should be generally avoided in order to minimize the potential for land use-caused hillslope failure and sediment delivery to Redwood Creek and its tributaries.

1. Avoid constructing roads on steep inner gorge slopes along Redwood Creek and its major tributaries. Instead, build roads above the slope-break and cable yard logs up to gentler, more stable ground. For inner gorge slopes steeper than 60%, there should be detailed geotechnical planning and design of any proposed road.
2. Where possible, employ cable yarding (or helicopter yarding), rather than tractor yarding, on inner gorge slope areas that are to be logged in the future.
3. When soils and slopes exhibit unstable characteristics, consider eliminating clearcutting in favor of retention or the use of less intensive harvesting. For example, employ techniques such as light selection, using thin corridors during three or four separate entries over a 50 to 60 year period so that a stand of mature trees is always retained on such slopes.
4. Consider leaving substantial, mature buffer strips of 100 feet or more along fish-bearing stream channels, both to enhance slope stability and for organic recruitment to the channel.
5. Known unstable areas, areas of abundant emergent groundwater and zones of unstable or sheared, mottled soil materials (especially in inner gorge areas) should be considered for exclusion from logging plans.
6. Where it is necessary for roads to cross steep, wet, headwater swales, two road design practices could lessen the incidence or magnitude of failures: 1) minimize the amount of fill placed in swale areas by reducing the width of the road and following the hillslope contours more closely, and 2) provide adequate drainage through and/or under road prisms, using french drains, gravel blankets, or synthetic drainage blankets. Ideally, such potentially unstable sites should be identified during the planning process and avoided during the construction phase.
7. Where it is necessary to construct road across incised or deeply incised stream channels, the approaches to these crossings should be constructed as full bench roads with the spoil materials end-hauled to a stable storage location. Sidecast construction should be avoided.
8. Where roads must be constructed across unstable or potentially unstable inner gorge slopes or other high risk areas, the alignments should be considered temporary. Stream crossings should be excavated, landings should be kept to the minimum size possible, and uncompacted fills should be physically removed before the first winter following operations.

Maintenance

A variety of techniques aimed at reducing slope failures on steep and potentially unstable inner gorge and stream side slopes have been discussed. Harvest-related recommendations are preventive measures designed to maintain slope stability in sensitive hillslope locations. These measures require no special maintenance other than the maintenance of substantial, mature vegetative cover. Mitigation measures related to road construction techniques, such as full bench construction, end-hauling, minimizing landing size and other techniques require periodic inspection to determine if slope stability problems are developing, and then removal or stabilization of any unstable road or hillslope materials if conditions warrant.

Effectiveness

Prevention is the most effective and cost-effective technique for reducing sediment delivery from harvesting and road-related mass movement processes on steep inner gorge slopes. One harvesting has occurred, there is little that can then be done to mitigate any resulting in-unit or stream side slope failures. Similarly, if roads trigger mass movement processes involving original ground, they often occur quickly and cannot be mitigated. Prevention is the best tool to make sure land use practices in sensitive slope locations do not adversely affect slope stability and sediment yield.

Sketches/Drawings

Typical measures are attached.

14. Gully Prevention and Control Practices

Description and Purpose

Gully erosion on forested lands, agricultural properties and ranch lands is a significant source of fluvial erosion and sediment delivery to stream channels in the Redwood Creek watershed. Strategies for preventing new gullies and controlling erosion within existing gullies and gully systems are needed to reduce sediment delivery to local streams and to conserve soil on managed lands. Recognizing the causes of increased hillslope erosion provides the only sound mechanism for preventing similar sediment production and yield from occurring in the future. A variety of prevention methods are discussed in this LMP and, as a last resort, structural and non-structural techniques for controlling gully erosion are described.

Planning Criteria and Applicability

Gullies are much more effectively treated by prevention than by employing expensive control measures after erosion has already been initiated. Where gullying has already occurred, cost-effective erosion control treatments can best be designed for existing gullies by first determining the cause of the on-going erosion. Thus, gullies should not be routinely treated with expensive control structures and other measures if the cause (the unnatural source of increased runoff) can be identified and the flow redirected back into the natural watercourse where it belongs. As a first measure, gully prevention treatments will include measures to prevent the concentration and diversion of water from managed lands, especially along road systems but also within agricultural areas. With existing gullies, control measures first concentrate on dewatering active gullies, recontouring and revegetation. Only then are other, less cost-effective secondary erosion control measures considered, including the use of check dams and rock armor.

Methods and Materials

Gullies are defined as newly eroded channels with a cross section larger than 1 ft² (1' by 1'). Some gullies are natural, but often gullies form because of some human action that causes runoff to collect and concentrate on an area that did not previously carry such volumes of flow. Gullies often form on or downslope from construction sites, in sloping agricultural areas (both crop lands and range lands) where large expanses of soil have been exposed, or in areas where roads (or skid trails) collect, divert and discharge concentrated runoff.

Gully control can be one of the most important restoration methods employed in watershed management. Three gully prevention and control measures should be applied in order.

1. Catchment improvement to reduce and regulate runoff (a gully prevention method),
2. Diversion of surface runoff (both a prevention and control measure) and
3. Structural stabilization and revegetation of gullies (a control method).

Gully prevention is almost always easier, more effective and less costly than controlling a gully after it has formed. The best strategy is to prevent gullies from forming in the first place rather than trying to control them after they have developed. Prevention treats the source and cause of the erosion. Preventive treatments are generally permanent and require little or no maintenance.

Prevention is accomplished by *reducing runoff* from managed areas, by *dispersing runoff* and by *directing and retaining runoff* to stable sites where gulying will not occur.

1. *Gully prevention through catchment improvements* - Many land management practices cause soil disturbance, disturb natural drainage patterns and increase runoff from hillslope areas. These effects can cause gully erosion. Runoff reduction is perhaps the single greatest tool for preventing gully erosion from managed areas. On-the-ground techniques for reducing runoff include:

- a. forest fire prevention (vegetation management to reduce forest fire intensity),
- b. grazing control to maintain an effective ground cover and reduce soil compaction,
- c. prevention of large grass fires,
- d. revegetation of open areas, disturbed areas and burned areas,
- e. maintenance of soil fertility on land which is under forestry or agriculture,
- f. use of agricultural cover crops during fallow periods and between commercial plantings,
- g. control of road construction and mining (dispersing runoff),
- h. minimizing exposed soil during construction activities, and
- i. the immediate stabilization and control of moderate sheet and rill erosion and incipient gullies in forest, rangeland and cultivated areas.

In addition to proper land management practices aimed at *reducing or minimizing runoff*, runoff from managed areas and sites, runoff may be retained, dispersed and/or diverted to stable areas. Each of these practices can prevent gully erosion. *Retention* measures can include such practices as the construction of infiltration ditches, basins and ponds which temporarily hold water, reduce storm-period runoff and result in increased infiltration of water which would otherwise have runoff.

b. *Gully prevention and control through runoff dispersion and diversions* - Gully prevention is also dependent on *dispersing runoff* from managed areas, by making sure runoff does not collect and concentrate in unprotected areas. This type of prevention practice is most appropriate along roads where ditches and berms commonly concentrate surface runoff and cause gully erosion. Road runoff can be dispersed by employing rolling dips and ditch relief culverts, or by outsloping the road bench so that runoff is uniformly dispersed along the alignment. This type of flow dispersion can nearly eliminate road-related gulying.

Finally, gully erosion can be prevented by *diverting* concentrated runoff away from erodible slopes and onto stable or non-erodible areas. Examples of the use of diversions to prevent gully erosion include ditching above construction sites (to reduce runoff within the disturbed construction area), the construction of waterbars on roads and skid trails to divert runoff onto stable areas (this is also a dispersion technique) and the construction of critical rolling dips at stream crossings on roads to direct stream flow back over the road when the culvert plugs. Diversion ditches or channels, regardless of where they are constructed, should always be built with a low gradient and designed to carry the volume of water which can be expected to flow through the channel during periods of maximum runoff.

c. Gully control through structural stabilization and revegetation - Gullies can form on hillslopes either from general increases in surface runoff (caused by over grazing, forest fire, grading, etc) or from diversion or concentration of a runoff source (stream diversion, culvert outfall, etc). Once a gully has formed, treatment to control continued erosion and gully enlargement can be both expensive and potentially ineffective. The best possible treatment for a developing gully is to divert the runoff from the head of the gully to a stable location where it will no longer cause erosion. Once this is performed, the former gully can often be refilled, recontoured and revegetated, or it can be left without additional treatment (because it no longer carries significant flow it should stabilize and naturally revegetate).

On certain slopes, engineered or vegetated waterways can be constructed by filling and recontouring gullies which have formed. This technique is usually limited to small first order channels where gullying has developed due to land disturbance, such as grazing, or to diversions which have since been corrected. A broad new channel is created in a different location (adjacent the filled gully) that is lower gradient and wider (5:1 sideslopes) than the gully. It is then quickly revegetated and may be stabilized with erosion control fabric to provide for immediate protection. This new channel will be stable if it is well vegetated, if disturbance is controlled (e.g., fencing to eliminate riparian grazing) and if runoff volumes are not excessive for the site. This technique is preferable to the installation of check dams or other structural controls because it is permanent and requires little or no maintenance.

As a last resort, if flow cannot be diverted out of a gully, or the gully cannot be stabilized by recontouring, a structural measure may be needed to control continued gully erosion. Controlling gully erosion using structural erosion control measures is not a simple task, and it is not always successful. Construction techniques must be thoughtfully designed and accurately implemented for the measure to work as intended. In addition, most structural measures require substantial and continued maintenance for continued success.

Gully control structures should usually be viewed as a temporary aid in long term vegetative recovery of the gully. Structures provide immediate protection when nothing else will work. Properly installed, they are designed to stabilize the bed of the gully, allow the channel bottom to revegetate and thereby promote revegetation of the banks. Vegetation perpetuates itself and represents the long-term, permanent control in most situations.

A variety of structural measures are available to temporarily stabilize an enlarging gully. These most commonly include check dams (made of a variety of materials) as well as channel armor. To be effective, each of these techniques must follow certain rules and accomplish certain tasks. Incorrect design, construction or maintenance will most certainly result in failure of one or all the structures at a site. Design criteria include the following elements:

1. For rock armor, the armoring material must continuously cover the bed of the gully and extend up the banks sufficiently to contain the maximum expected discharge.

2. Where rock armor is used, it must be sufficiently large to prevent transport downstream, yet small enough to ensure that flow is not deflected by the armor against unprotected gully banks. A variety of rock sizes should be used.
3. For check dams:
 - a. Each dam must be excavated sufficiently into the bed and banks to prevent undercutting or lateral piping,
 - b. Each dam must be made of materials which will last as long as is required for permanent vegetative stabilization to develop on the gully bed and banks,
 - c. Each dam's spillway must be designed to pass the design (peak) discharge expected for that channel over the center of the dam,
 - d. Each dam must be spaced such that the ponded sediment behind one extends upstream to the base of the next dam (the structures must protect the bed of the gully from flowing water - water is no longer allowed to flow directly on the eroding stream bed),
 - e. Each dam must have energy dissipation below its spillway such that the energy of the cascading water falls entirely on the dissipator,
 - f. Wing walls and other measures may be needed to protect the dams from lateral cutting and failure.
4. Each dam site, including the banks and bed of the gully, must be planted with rapid growing woody species (such as alder, willow, baccharis, etc.).
5. Each dam must be inspected and repaired, as necessary, after each flow event.

The main function of check dams is NOT to store sediment behind the structures. Rather, check dams are designed to prevent continued channel down cutting by creating a new, artificial stream bed on top of the gully bottom. Water only flows on the ponded sediment behind each dam and over each hard structure, but never on the erodible stream bed. Similarly, channel armor protects the entire gully from continued flow, thereby preventing continued gully enlargement. As might be expected, channel armor typically requires less maintenance than check dams and is less likely to fail. Both types of structural treatment need to be followed with a variety of plantings to provide for permanent channel stabilization.

Maintenance

All gully prevention and gully control measures will require some at least some inspection and maintenance; some measures will require extensive maintenance. Of the three mechanisms of prevention or control described above, watershed improvements to reduce or minimize runoff or to retain water for infiltration is the most permanent type of treatment. These prevention measures will typically require the least maintenance. Depending on site conditions, treated watershed areas may need replanting and some hand labor may be needed to prevent rilling and gullying of exposed areas until vegetation has become re-established. Grazing and exclusions will need to be monitored and repaired until vegetation has become self sufficient.

Gully prevention and control measures which act by dispersing or diverting surface runoff will also need periodic inspection and maintenance. Road outcropping, rolling dips and newly installed ditch relief culverts along roads will need to be checked after each storm during their first year and periodically thereafter. Repairs may be required to ensure their proper functioning. Ditches, waterbars and other diversion structures, likewise, need regular inspection and maintenance.

Structural stabilization measures, including check dams, typically require substantial and frequent maintenance to be successful. Check dams will need to be inspected after every storm to check for evidence of existing or potential problems. Piping of water under or around check dams needs to be stopped (plugged) immediately. Plunge-pool erosion below a check dam spillway needs to be stopped by installing better energy dissipation. Any problems which are resulting in continued gully erosion, or any problems which are being caused by the erosion control structures need to be repaired quickly. Once a single dam fails by undercutting or lateral erosion, adjacent dams are likely to fail very soon.

Effectiveness

Gully prevention and control measures can be highly effective if they are well designed, properly constructed and religiously maintained. Watershed improvement practices, such as grazing restrictions in riparian areas and along gullied channels, can be a very effective technique for controlling erosion provided cattle continue to be excluded or managed to maintain effective vegetative cover. Failure to maintain such measures can quickly result in deteriorated conditions. The effectiveness of structural gully control measures, such as check dams, is directly dependent on proper construction and continued maintenance. Because of their high maintenance requirements, structural measures should be employed as a last resort.

Sketches/Drawings

Typical measures are attached.

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