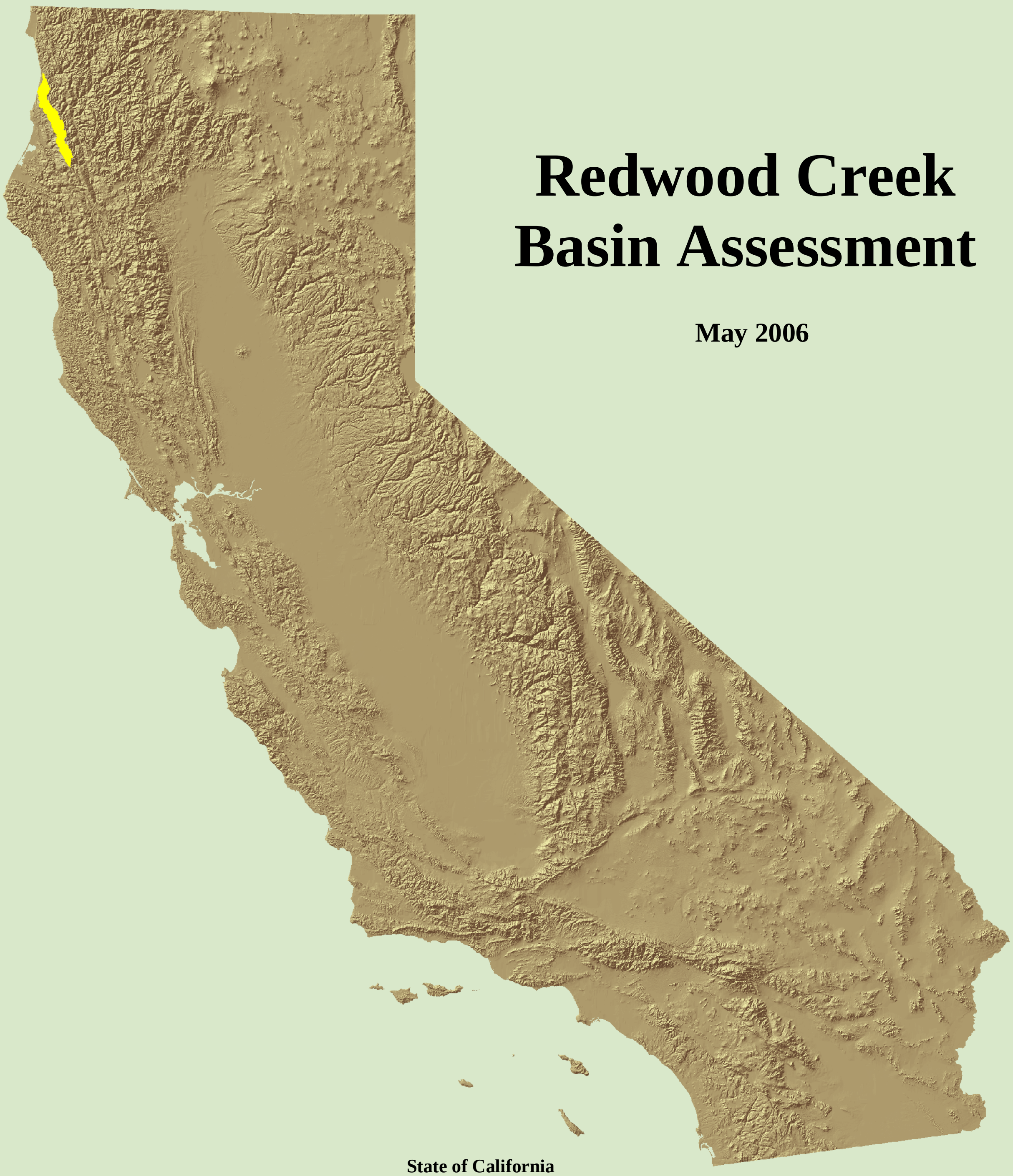
Coastal Watershed Planning and Assessment Program
and
North Coast Watershed Assessment Program



Redwood Creek Basin Assessment

May 2006

State of California

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California Resources Agency

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Redwood Creek Assessment Report

Executive Summary

The North Coast Watershed Assessment Program (NCWAP) was an interagency effort between the California Resources Agency and the California Environmental Protection Agency (CalEPA) established to provide a consistent body of information on North Coast watersheds for use by landowners, stakeholders, collaborative watershed groups, and agencies. The NCWAP was initiated in response to specific requests from landowners and watershed groups that the State take a leadership role in conducting scientifically credible, interdisciplinary assessments that could be used for multiple purposes. The need for comprehensive watershed information grew in importance with listings of salmonids as threatened or endangered species, the Total Maximum Daily Load (TMDL) consent decree, and the increased availability of assistance grants for protecting and restoring watersheds.

NCWAP participating State agency departments include:

- Forestry and Fire Protection (CDF);
- Fish and Game (CDFG);
- Conservation/California Geologic Survey (CGS);
- Water Resources (DWR), in conjunction with the North Coast Regional Water Quality Control Board (RWQCB);
- State Water Resources Control Board (SWRCB).

Due to California's General Fund reductions in 2003, the NCWAP program was cut from the state budget before the Redwood Creek Basin assessment report was complete. This report was completed by the CDFGs Coastal Watershed Planning and Assessment Program (CWPA) with inputs from other Resources Agency Departments as budgets and time constraints allowed. This assessment was guided by the following assessment questions at the basin and subbasin scales:

Assessment Guiding Questions

- What are the history and trends of the size, distribution, and relative health and diversity of salmonid populations?
- What are the current salmonid habitat conditions; how do these conditions compare to desired conditions?
- What are the relationships of geologic, vegetative, fluvial, and other natural processes on watershed and stream conditions?
- How has land use affected these natural processes and stream conditions?
- Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?
- What watershed management and habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

Strategic Goals

The assessment program's products are designed to meet these strategic goals:

- Organize and provide existing information and develop baseline data to help evaluate the effectiveness of various resource protection programs over time;
- Provide assessment information to help focus watershed improvement programs, and to assist landowners, local watershed groups, and individuals in developing successful projects. This information will help

guide support programs, such as the CDFG Fishery Restoration Grants Program, toward those watersheds and project types that can efficiently and effectively improve freshwater habitat and lead to improved salmonid populations;

- Provide assessment information to help focus cooperative interagency, nonprofit, and private sector approaches to protect watersheds and streams through watershed stewardship, conservation easements, and other incentive programs;
- Provide assessment information to help landowners and agencies better implement laws that require specific assessments such as the State Forest Practice Act, Clean Water Act, and State Lake and Streambed Alteration Agreements.

General Assessment Approach

Each of the program's participating departments developed data collection and analysis methods used in their basin assessments. The departments also jointly developed a number of tools for interdisciplinary synthesis of information. These tools included models, maps, and matrices for integrating information on basin, subbasin, and stream reach scales to explore linkages among watershed processes, current conditions, and land use. The tools provided a framework for identifying refugia areas and factors limiting salmonid productivity, as well as providing a basis for understanding the potential for cumulative impacts from natural and man caused impacts. The NCWAP team identified relationships or root causes contributing to the habitat deficiencies and made recommendations to improve habitat conditions. This information is useful for developing restoration, management, and conservation recommendations.

The general steps in our large-scale assessments include:

- Form a multi-disciplinary team;
- Conduct scoping and outreach workshops;
- Determine logical assessment scales;
- Discover and organize existing data and information according to discipline;
- Identify data gaps needed to develop the assessment;
- Collect field data;
- Amass and analyze information;
- Conduct Integrated Analysis (IA);
- Conduct Limiting Factors Analysis (LFA);
- Conduct refugia rating analysis;
- Develop conclusions and recommendations;
- Facilitate implementation of improvements and monitoring of conditions.

The roles of the five original participating NCWAP agencies in these efforts included these activities:

- DOC/CGS compiled, developed, and analyzed data related to the production and transport of sediment;
- CDF compiled, developed, and analyzed data related to vegetation and land use in the watersheds;
- RWQCB compiled, developed, and analyzed water quality data for the assessment;
- DWR installed and maintained stream monitoring gages where needed to develop and analyze stream flow information;
- CDFG collected and analyzed data related to anadromous salmonid populations and their habitat.

Results of assessments conducted by various agency personnel on the Redwood Creek team were brought together in an integrated synthesis process. This process recognizes the dynamic spatial and temporal relationships between watershed and stream conditions and watershed processes. To assist in this process, the team used Geographic Information System (GIS) based watershed data coverage and the Ecosystem Management Decision Support (EMDS) model to help evaluate watershed and stream conditions.

Assessment Products

Assessment products include:

- A basin level geologic evaluation that includes:
  - Map of landslides and geomorphic features related to landsliding with accompanying text;
  - Relative landslide potential map with accompanying text.
- A basin level Synthesis Report that includes:
  - Collection of Redwood Creek historical and sociological information;
  - Description of historic and current vegetation cover and change, land use, geology and fluvial geomorphology, water quality, aquatic habitat conditions, and distribution and status of anadromous salmonids;
  - Evaluation of watershed conditions and land use affecting stream habitat;
  - An interdisciplinary analysis to detect relationships between watershed conditions, watershed processes and stream habitat conditions, salmonid distribution, and refugia areas;
  - Tributary and watershed recommendations for management, refugia protection, and restoration activities to address limiting factors and improve conditions for salmonid production;
  - Monitoring recommendations to improve the adaptive management efforts;
  - Compilation of reference materials.
- Web based access to the Program's products: http://ncwatershed.ca.gov/, and http://imaps.dfg.ca.gov/.

Redwood Creek Assessment Subbasins

The Redwood Creek assessment team used the California Watershed Map (CalWater version 2.2a) to delineate the Redwood Creek Basin into five subbasins for assessment and analysis purposes. These study areas were the Estuary, Prairie Creek, Lower, Middle, and Upper subbasins (Figure ES-1). In general, the CalWater 2.2a Planning Watersheds (PWs) contained within each of these assessment subbasins have common physical, biological, and/or cultural attributes. Delineation in this manner provides a large, yet common scale for conducting assessments. It also allows for reporting of findings and making recommendations for watershed improvement activities that are generally applicable across a large, relatively homogeneous area. The Subbasins are:

Estuary Subbasin: The Estuary Subbasin includes the drainage of Redwood Creek below the confluence with Prairie Creek, including Strawberry Creek, Sand Cache Creek, and Dorrance Creek.

Prairie Creek Subbasin: The Prairie Creek Subbasin contains all of Prairie Creek watershed except for a small portion of Skunk Cabbage Creek that is in the Estuary Subbasin.

Lower Subbasin: The Lower Redwood Creek Subbasin includes the area above the confluence of Redwood and Prairie Creeks to the confluence of Redwood and Devil's Creeks including Devil's Creek.

Middle Subbasin: Middle Redwood Creek Subbasin includes the area above the confluence of Redwood and Devil's Creeks and extends just upstream of State Highway 299 crossing to the confluence of Redwood and Lupton Creeks, including Lupton Creek.

Upper Subbasin: The Upper Redwood Creek Subbasin includes the area above Lupton Creek and covers the same area as the CalWater 2.2 Lake Prairie Hydrologic Area.

Table ES1. Redwood Creek subbasin attribute summary.

	Estuary Subbasin	Prairie Creek Subbasin	Lower Subbasin	Middle Subbasin	Upper Subbasin	Total
Square Miles	5.4	39.6	69.5	100.1	67.7	282
Total Acres	3,429	25,339	44,488	64,088	43,344	180,690
Private Acres	2,007	463	275	58,040	40,970	101,280
Federal Acres	1,422	18,247	44,213	6,048	2,375	71,960
State Acres	0	6,629	0	0	0	6,630
Principal Communities	Orick			Redwood Valley		
Predominant Land Use	Livestock Grazing	Park Land	Park Land	Timber Production	Timber Production	
Predominant Vegetation Type	Pasture Land	Redwood Forest	Redwood Forest	Douglas-fir Forest	Hardwood Douglas-fir Forest	
Anadromous Fish Stream Miles	5	24	28	42	23	122
Lowest Elevation	0	26	26	325	866	
Highest Elevation	1,243	2,270	1,286	4,091	5,322	

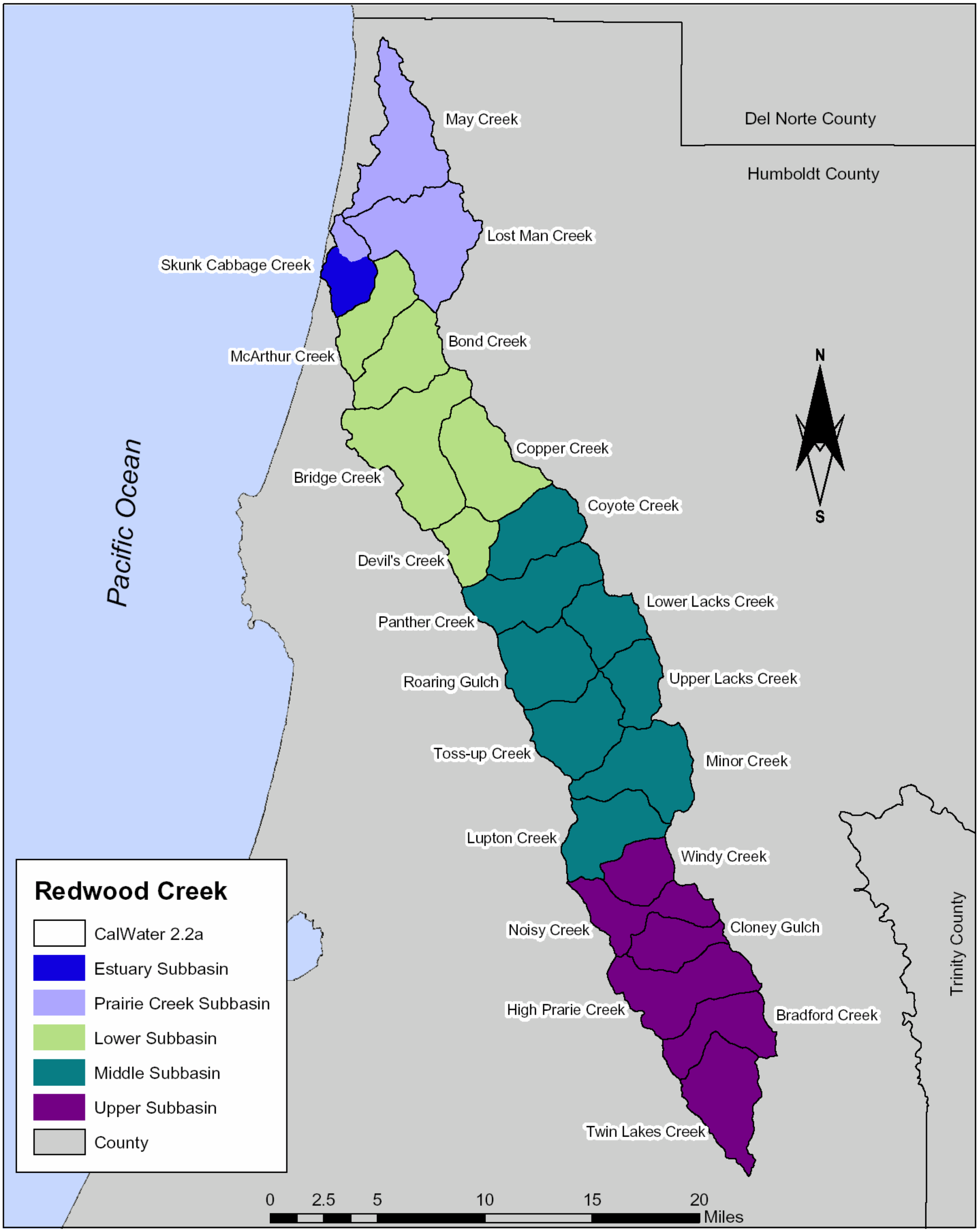

Figure ES- 1. Redwood Creek Subbasins and CalWater2.2a Planning Watersheds.

Redwood Creek Basin Profile

Redwood Creek flows into the Pacific Ocean near the town of Orick, approximately 35 miles north of Eureka, in northern Humboldt County, California. The basin contains approximately 285 square miles (about 180,000 acres) of mostly forested and mountainous terrain. The elongate shaped basin extends in a NE/SW direction for approximately 65 miles and averages only about 6 miles wide (Figure ES-2). Elevation ranges from sea level near the town of Orick up to 5,200 feet at headwaters near Board Camp Mountain, located at the south-east end of the basin.

Geology

The Redwood Creek basin has large areas with highly unstable terrain. The basin is situated in a tectonically active and geologically complex area, with some of the highest rates of uplift, and seismic activity in North America (Cashman et al. 1995; Merritts 1996). The basin's elongate shape is largely controlled by the Grogan Fault which the Redwood Creek channel follows for most of its length. Distinct bedrock units meet at the Grogan Fault, predominantly, Redwood Creek schist to the west and coherent sandstone and incoherent sandstone-mudstone units to the east. These bedrock units are relatively weak, easily weathered, and when saturated by heavy rainfall, become susceptible to landsliding. Inner gorge areas appear to be particularly unstable because the steep slopes combine with emergent groundwater (Fetter 1980; Freeze and Cherry 1979) to reduce overall slope stability within the hillsides (Bell 1998; Rahn 1996; Griggs and Gilchrist 1977; Duncan 1996; Sowers and Royster 1978). As a result of geologic instability, approximately 72% of the basin shows signs of very high and high landslide potential and the basin is vulnerable to ground disturbance. Any land use that weakens the structural integrity of hillslopes can significantly add to erosion rates.

The Upper and Middle subbasins have the greatest percent of area covered (80 and 73% respectively) by active and dormant landslides, disrupted ground, and debris slides. The Prairie Creek Subbasin has the smallest area (56%) in these features that are sources of sediment delivery to streams. Recent findings indicate that the Upper Subbasin is contributing the most sediment to streams and the Prairie Creek Subbasin contributes the least sediment.

Climate

The climate of the Redwood Creek Basin varies from moderate seasons along the coastal area to the more extreme seasons inland. The majority of precipitation occurs November through March and ranges from 32 inches at lower elevations to 98 inches at the headwaters with frequent snow above 2,000 feet. Winter storms often bring heavy rainfall.

Fog and moist marine air are climatic features near the coast. Fog often occurs daily in the summer and frequently throughout the year. Higher elevations and the inland region tend to be relatively fog free. Air temperatures range from below freezing in winter to above 100°F in summer months.

Recent flood events (1955, 1965, 1972, 1975, and 1997) played important role in shaping the stream channel and aquatic habitat conditions of the Redwood Creek Basin. The flood of December 1964 had the most significant and long-lasting adverse impacts to salmonid habitat in Redwood Creek. Although peak discharge was not much different than the flood of 1955 and earlier events, the amount of disturbance to channel features from the 1964 flood was much greater. A difference between the two storms was that intensive logging activity occurred between 1955 and 1964, which left the basin's terrain in a disturbed condition and extremely vulnerable to erosion from the heavy rain on snow event. Less drastic, but significant erosion occurred during a moderate storm in 1997 (Madej 2001).

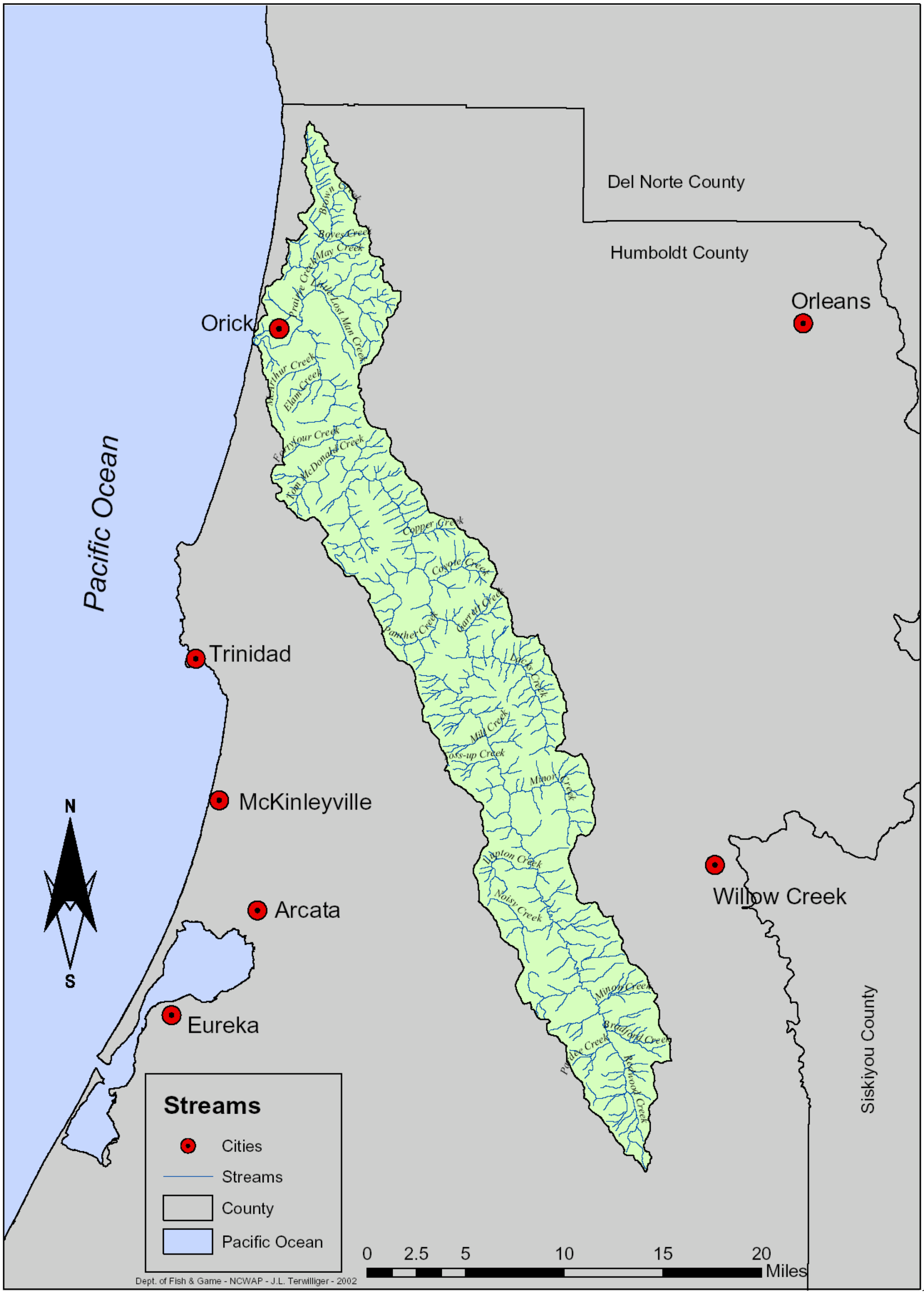

Figure ES-

Figure ES- 2. Redwood Creek Basin and tributaries.

Vegetation

Five vegetation types account for 90% of the vegetation in Redwood Creek. Redwood and redwood-Douglas-fir vegetation types cover about 61,000 acres, accounting for 34% of the watershed area. Most of the Redwoods grow in the Estuary, Prairie Creek and Lower subbasins. Douglas fir stands cover 71,652 acres, or 40% of the watershed mostly within the Middle and Upper subbasins. Most of this old growth forest is in publicly owned lands in Redwood National and State Parks (RNSP). The other major vegetation types are annual grass/forbs, Oregon white oak, tanoak, and red alder. Areas of grasslands are found along the main ridge tops and south facing slopes of the watershed. Stands of ponderosa and Jeffery pine are found at the upper elevations.

The Redwood Creek Basin in 2004 had about 24,000 acres, 13% of the basin area in old growth coniferous forests. Most of this is in park lands where ancient redwood groves are famous and include some of the world's tallest trees. Prior to the harvesting of timber, 82% (150,000 acres) of the basin supported mature coniferous forests.

Land Use

Land use across the basin includes the town of Orick, pasturelands, livestock grazing, and timber harvests in the Estuary Subbasin; public parklands (RNSP) are located in the Estuary, Prairie Creek and Lower Subbasins; and private forestland, managed for timber harvesting are in the Middle and Upper subbasins. Eight large land owners own approximately 90% of the private lands in the Middle and Upper subbasins. Small private developments are a found in the Estuary, Middle, and Upper subbasins.

Approximately 65,000 acres in the Prairie Creek and Lower subbasins are managed by RNSP. RNSP also manages 1,400 acres in the Estuary Subbasin. The RNSP land management strategies include: 1) perpetuation of the redwood forest and associated ecosystems as prime resources; 2) perpetuate ongoing natural influences on the basis of natural values and visitor use; and 3) protect threatened and endangered species and species of special concern (USDOI 1999).

Large scale timber harvesting began in the basin during the early 1950s, although harvests and land clearing occurred in the late 1800s and early 1900's in the Estuary and Prairie Creek subbasins. Over the last century, timber operations provided jobs and produced large quantities of timber products. By 1966, 55% of the basin's coniferous timber was cut and by 1992, over 80% (123,000 acres) of the basin's timber lands were harvested at least once. Even age silviculture prescriptions (clear cuts) and tractor yarding are the most commonly used timber harvest methods. Most of the basins timberlands are restocked, and should continue to be a productive source of future lumber products.

The vast majority of road construction occurred during the initial timber harvest period of the 1950s-1970s. These roads were built without the present knowledge of road construction methods to minimize erosion.

Beginning in 1978, road improvement projects within the RNSP (mostly in the Lower Subbasin) have removed or treated 215 miles of roads. Road assessment for the entire Redwood Creek Basin is nearing completion (Bundros et al. 2004). With the funding of the road assessment program, roughly 90% of the private lands in the Redwood Creek Basin will be inventoried and prioritized for road treatments. At present, road assessments and implementation projects are a focus of RNSP and private landowners of the basin.

Water Quality

Thirty years of water chemistry data collected 1958-1988 by USGS and USEPA characterizes Redwood Creek as a moderately hard water, moderately oligotrophic stream. Most water chemistry parameters were within optimal ranges for human consumption. However, due to excessive sediment inputs to stream channels and a reduction in shade canopy, the basin's streams are listed as sediment and temperature impaired under Section 303(d) of the federal Clean Water Act, and hence falls under jurisdiction of the state and federal TMDL programs. High water temperature and excessive sediment loads have adversely altered the stream habitat creating undesirable conditions for anadromous salmonids in portions of the basin, especially in the mainstem of Redwood Creek. In addition, high turbidity levels in Redwood Creek are believed to occur more frequently and persist longer than in the past.

The coolest water temperatures are found in the Prairie Creek Subbasin, the headwaters area of Redwood Creek, and in tributary streams. At present, tributary contributions are unable to reduce the high temperature along the mainstem. However, localized patches of cool water refugia may form at the confluences of tributaries along the mainstem Redwood Creek. Temperature refuge sites in the mainstem are also located in thermally stratified pools, near springs, or sites where cool intergravel flows accumulate to maintain cool bottom water (Ozaki 1988).

Salmonid Fishery Resources

The Redwood Creek Basin supports populations of Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead trout (*O. mykiss*), coastal cutthroat trout (*O. clarki clarki*), and other valuable fisheries resources. Due to declining populations in California's northern coastal streams, Chinook, coho and steelhead are listed as threatened under the endangered species act. Coastal cutthroat trout are a California Special Concern Species. Redwood Creek's anadromous salmonid stocks are critically valuable natural resources and increasing the abundance, diversity, and distribution of these stocks are vital steps towards the restoration of viable salmonid populations to California.

A review of the past fisheries studies, anecdotal information and data collected for this assessment indicates that the present anadromous salmonid populations are less abundant and less widely distributed compared to their historic presence in the Redwood Creek Basin. Impairments to freshwater and estuarine habitat have been identified as a leading factor in the decline. Summer steelhead, sea run coastal cutthroat, coho, and Chinook salmon have likely suffered widespread declines due to their sensitivity to degradation of specific habitat factors necessary to complete the freshwater and/or estuarine phase of their life cycle. Winter run steelhead tolerate a wider range of habitat conditions than the other anadromous species, and they are still widely distributed in the basin, but their abundance is likely below historic numbers. Steelhead have persisted in streams where other species have declined or are now rarely observed.

There are several habitat factors necessary for the successful completion of an anadromous salmonid's life history. Good estuarine conditions, good instream habitat, and benefits from nearstream forests and riparian vegetation are essential for healthy populations. Good stream condition includes several factors: clean and adequate stream flow, appropriate water temperature, clean gravels, and channel diversity. Adequate instream flow and free passage is essential to provide salmonids access to spawning grounds, free forage range, cover from predation, and utilization of localized temperature refugia. Instream shelter provided by LWD, vegetation, boulders and undercut banks are also essential. A bottleneck to salmonid production or limiting factor may emerge when any of these habitat factors are missing or deficient in function.

Redwood Creek Basin Key Issues and Summary Findings

Salmonid populations have declined from historic levels, prompting listings under the state and federal ESAs:

- Redwood Creek's anadromous salmonid stocks are critically valuable natural resources;
- Present anadromous salmonid populations are less abundant and less widely distributed compared to their historic presence in the Redwood Creek Basin;
- Increasing the abundance, diversity and distribution of Redwood Creek's salmonid stocks are vital steps towards the restoration of viable salmonid populations to California;
- The capacity for salmonids to increase in abundance and distribution is in part limited by the reproductive potential of existing stocks;
- Sport and commercial fish harvests have likely played a role in the reduction of numbers of Redwood Creek's salmonid populations;
- The presence of salmonid stocks does not mean that efforts to protect habitat conditions should be relaxed;

- Given improving aquatic habitat conditions, it will likely take several generations before salmonid populations rebound to viable levels.

<u>Impairments to freshwater and estuarine habitat needed to complete salmonid freshwater life cycles have been identified as a leading factors in the decline of Redwood Creek's anadromous salmonids:</u>

- Warm water temperature in mainstem Redwood Creek limits salmonid production in most of the Upper Subbasin and all of the Middle and Lower subbasins;
- Many tributaries across the basin have cool water temperatures but often lack the combination of structural components that create the habitat diversity and complexity needed to support viable salmonids populations;
- A significant factor affecting salmonid production is the large reduction in area and habitat quality of the estuary/lagoon;
- The present habitat problems observed in most streams of the basin are often related to excessive sediment in stream channels and/or the lack of a large conifer contributions from riparian and nearstream forests;
- Excessive sediments inputs can result in several adverse and long lasting impacts to salmonid habitat including impaired spawning habitat, a decrease in channel diversity, a reduction in the numbers and depths of pools, stream bank erosion, widened channels, and loss of shade;
- The negative impacts from excessive sediments are in some cases exacerbated by the general lack of instream large wood debris (LWD);
- More LWD is needed in many stream channels to help with channel maintenance processes including formation of pools and sediment routing, providing shelter for fish, and to provide nutrient inputs;
- As a result of timber harvests and stream bank erosion, there is a loss of shade provided by large conifers and a low potential for near term LWD input to several anadromous reaches in the basin.

<u>Natural geologic instability contributes to sediment inputs to the basin's stream network:</u>

- The Redwood Creek Basin is situated in a tectonically active and geologically complex area. Most of the bedrock is relatively weak, easily weathered and naturally susceptible to erosion;
- The region experiences a high level of seismic activity and major earthquakes have occurred along the Cascadia subduction zone as well as within the individual tectonic plates and along well-defined faults;
- The inner gorge of the Redwood Creek channel is particularly prone to yielding sediment from stream side landslides;
- High rates of regional uplift provide a continual source of sediment to the basin.

<u>Much of the naturally occurring erosion resulting from slope instability has been compounded by human activities:</u>

- The combination of naturally unstable terrain, intensive land use and severe storms (such as the one that occurred in December 1964) can trigger major episodes of erosion;
- Much of the erosion in the basin is linked to legacy impacts from past land uses;
- There are high road densities in much of the basin and large amounts of sediment is generated from road related failures, especially from roads located on steep, unstable slopes;
- Large scale removal of timber accelerates storm runoff and contributes to an increase in erosion;
- Fine sediment accumulations in stream channels are typically more abundant where land use activities such as roads or land clearing expose soil to erosional processes;
- High turbidity levels in Redwood Creek are believed to occur more frequently and persist longer than observed in the past;

- Many of the effects from land use activities on upland sediment sources are spatially and temporally displaced from response reaches;
- Past fluvial erosion was accelerated by land use and this erosion could have been minimized with better erosion-control and road-maintenance measures.

Riparian and near stream forests functions have been altered by timber harvests and bank erosion:

- Timber harvests in riparian and nearstream forest areas contribute to a reduction in both overstory shade canopy and LWD input potential;
- Shade over the water from willow and alder riparian vegetation alone is not enough to keep water cold;
- Micro-climate benefits provided by near stream forests and overstory shade are important to help provide cool air near streams that helps maintain cool water temperature;
- Retention and recruitment of large trees is needed along streams, especially along mainstem Redwood Creek;
- As trees grow and become subject to harvest, how will management protect valuable aquatic and fishery resources from similar impacts as occurred in past years?

The Redwood Creek basin is an excellent candidate for a successful long-term, programmatic watershed improvement effort:

- Management strategies should take a basin-wide perspective;
- It is important to note that without management strategies that promote restoring integrity to watershed ecosystem process by addressing root causes of problems, instream improvement projects will likely be short-lived patches on the environment;
- Stream condition improvement and increasing anadromous salmonid populations largely depends on achieving a balance between the socio-economic needs for timber resources and management needed to maintain or improve basin conditions that sustain viable fish populations;
- Most of the basin has a high potential to improve fish habitat conditions. Reaching that goal is dependent upon the formation of a well organized and thoughtful improvement program founded on broad based community support for the effort.

Basin Scale Recommendations

Barriers to Fish Passage

- Fish barriers were found at culverts, perched sediment deltas, or boulder and/or debris accumulations.
- Facilitate fish passage at sites that may impede upstream fish passage into tributary streams for spawning or downstream movements.

Flow and Water Quality Improvement Activities:

- Water flow does not appear to be and issue at this time over most of the basin. However, fish habitat requirements and channel maintenance flows should be considered prior to any water development projects including riparian diversions and small domestic water use;
- In order to help reduce water temperature in tributaries and the mainstem, ensure that near stream forest management encourages growth and retention of conifers sufficient for providing shade and cool micro climate benefits to stream and riparian zones;
- Consider using willow baffles, tree planting or other applicable methods to promote effective shading from riparian trees and to reduce the channel width along reaches of Redwood Creek;
- Timber harvests or other land use should be conducted in a manner that does not increase peak flows, accelerate runoff rates, or deliver excessive sediment to stream channels;

Erosion and Sediment Delivery Reduction Activities:

- Existing sediment production problem sites that have potential to deliver sediments to streams should be evaluated and mitigated;
- Since timber harvesting and other land use can cause disturbances that may contribute to slope instability, management on slopes with high landslide potential and/or on lands adjacent to streams should first involve a risk assessment or be avoided. Determination of appropriate practices should be made through the use of the CGS landslide and landslide potential maps, in conjunction with site-based geological examinations by licensed and appropriately trained geologists;
- For timber management on steep and/or potentially unstable slopes (in many cases, slopes greater than 35%) we recommend use of lower impact silvicultural prescriptions to maintain vegetative cover and the use of cable or helicopter yarding to reduce the potential for erosion and sediment production, which can result in sediment accumulation in Redwood Creek;
- Landowners should continue road erosion hazard surveys throughout the basin and use this information to set priorities for road removals and upgrades, and implement these improvements as rapidly as private and public funding allow. Roads located on unstable slopes and roads near streams should receive high priority for survey and upgrades and decommissioning projects;
- Consider avoidance or mitigation for risks of excessive erosion when planning, building or removing roads in or near deep-seated landslides and earthflows;
- Reduce road density across the basin especially in the Middle and Upper subbasins;
- If new roads need to be constructed, they should be designed to prevent erosion and not be located near the valley bottom where they may pose a high risk of generating sediment delivery to streams. Consider locating roads along ridge tops where feasible;
- The use of fire for site preparation purposes should be minimized on schist soils during warm, dry periods (late summer and fall).

Riparian and Stream Habitat Improvement Activities:

- To increase shade canopy, promote growth and retention of large conifers in the riparian corridor along mainstem Redwood Creek;
- Where current near stream forest canopy is strongly dominated by hardwoods and site conditions are appropriate, land managers should consider cautious thinning of hardwoods from below to hasten the development of denser and more extensive coniferous canopy component;
- To address the lack of large woody debris in many tributary channels and along the Redwood Creek mainstem, management should promote growth of near stream conifers and allow natural recruitment of trees to stream channels;
- Where near stream conifers are not large enough to function as naturally occurring scour elements, consider importing LWD from nearby hillslopes for placement in locations and orientations where it will provide beneficial habitat elements and will not accelerate adverse bank erosion;
- Add combinations of boulders and LWD to increase shelter complexity to cool water patches located in Redwood Creek. The cool patches may be located in temperature stratified pools or adjacent cool water inputs from springs, seeps and tributary flows;
- For timber harvest plans in the Upper and Middle subbasins, consider additional measures to increase function of watercourse protection zones when justified by lack of large conifers to provide shade and microclimate, lack of instream LWD, and low LWD loading potential;
- Consider the use of conservation easements or other management strategies to maximize potential benefits to aquatic habitats from near stream forest protection along the middle and upper reaches of Redwood Creek;

- Consider limiting cattle access in streams where their presence has caused significant bank erosion and impaired growth of vegetation;
- Prescribed fire use within the Redwood Creek basin could reduce adverse impacts to watercourses and wet areas. Regular use of prescribed fire could reduce fuels so that catastrophic fires are less likely to occur.

Monitoring, Education and Research Activities:

- Utilize CalVeg GIS layers to locate areas where coniferous trees are too small to provide beneficial functions of LWD loading. These areas should be considered for LWD addition to stream channels if needed to retain and promote desirable pool characteristics, sediment routing and other channel maintenance processes;
- Temperature monitoring by land owners and responsible agencies should continue at current and additional sites to extend trend lines and track changes that may impact salmonids or that may indicate a status change. The establishment of trend lines from these data will aid in future studies, validate improvements from forest and stream recovery and will be helpful for habitat improvement project effectiveness monitoring;
- Monitoring suspended and in-channel stored sediments by sampling sediment size distribution, turbidity, V*, photo points, etc. should be continued, and tracking of streambed levels with stream channel cross sections should be continued by responsible agencies and landowners;
- A long-term, concerted monitoring effort among the land owners, interested parties and responsible agencies is needed to determine the status and trends of anadromous fish populations of Redwood Creek. Efforts should include annual spawner surveys, weir counts, summer steelhead dive counts and monitoring juvenile populations;
- Biological monitoring, particularly for aquatic insects and aquatic food web dynamics, will be an important addition to monitoring efforts in the Redwood Creek basin;
- Ensure that CEQA-compliant environmental assessment is conducted prior to issuance of the Fish and Game Code 1600 series streambed alteration permits and Corps of Engineers or NOAA Fisheries permitting requirements are complete for significant projects on streams of Redwood Creek;
- It is unclear whether modern timberland management practices will allow full restoration and recovery of desirable watershed ecosystem function. Conservation easements that provide wider buffers along water courses or additional management measures may be needed to provide the protection needed to promote watershed and aquatic ecosystem recovery;
- CDFG stream habitat surveys provide information only for reaches accessible to anadromous salmonids. Additional surveys above the limits to anadromy are necessary to identify upstream conditions that affect anadromous reaches such as riparian canopy status or additional sediment delivery sites that may benefit from erosion control treatments.

The Subbasins

Estuary Subbasin

The Redwood Creek estuary/lagoon plays a vital role as habitat for juvenile and adult anadromous salmonids. The estuary/lagoon once had all of the characteristics of excellent anadromous salmonid habitat, but its present value as fisheries habitat is greatly reduced compared to the historic condition. Over the past 125 years, the estuary area was altered by conversion of forest, riparian and wetland areas to pasture land, and by channel modifications and levee construction. These changes combined with sediment accumulations have impaired the physical and biologic function and capacity of the estuary/lagoon to support salmonids. The present estuary condition limits salmonid production.

The Redwood Creek estuary is an excellent candidate area for channel and riparian improvement projects that benefit for anadromous salmonids. RNSP and others have developed management alternatives to improve the estuarine habitat while offering flood control protection to the town of Orick and pasturelands surround the estuary. The recent project alternatives involve levee removal, relocation, and re-configuration. A restoration project should benefit fish production by increasing the depth and area of the lower embayment while increasing depth, shelter, connectivity, and circulation between the main channel and slough channels. Projects that increase the estuary/lagoon's juvenile salmonid carrying capacity and survival rate during the summer months should receive high priority. Restoration efforts that move conditions and processes towards historic status also will benefit other fish and wildlife resources of Redwood Creek.

Estuary Subbasin Issues and Summary Findings

Key salmonid fishery issues of concern identified for the Redwood Creek estuary include:

Juvenile salmonid rearing success is impaired by estuarine habitat conditions;

- The fish rearing area of the Redwood Creek estuary/lagoon has been reduced by 50 to 75%;
- Survivorship is very low (estimates of 7-15%) for juvenile Chinook and steelhead that rear in the lagoon through the summer;
- The estuary/lagoon once supported an abundant, year round population of coastal cutthroat trout. At present, only a few coastal cutthroat are found during fish surveys;
- The estuarine channels are shallower compared to historic conditions;
- Habitat shelter complexity is low due to a lack of riparian vegetation and LWD;
- Dissolved oxygen levels can be at stressful or lethal levels in the slough channels;

Channel modifications from the flood control levee system have likely had the most impacts to the physical form and alterations of natural processes that drive the estuarine ecosystem:

- The affects of levees exacerbate sediment accumulations and a contribute to the loss of tidal connectivity to slough channels and a reduction in tidal prism;
- Removal of riparian trees for pasture development and levee construction caused the loss of benefits from the riparian forests;
- Riparian vegetation is periodically removed from the estuary channel as part of a levee maintenance procedure.

The estuary is particularly susceptible to watershed cumulative effects:

- The low gradient, depositional reach of Redwood Creek in the Estuary Subbasin accumulates watershed products delivered from upstream reaches;

- Juvenile salmonids that reside and pass through the estuary during spring and early summer during seaward migrations find favorable water quality conditions for rearing and may acclimate to changes in salinity and temperature;
- Much of the water quality and sediment characteristics of the estuary are related to upstream watershed conditions;
- These include relatively warm water inputs and high levels of sediment delivery.

Estuary habitat improvement projects have been proposed:

- A large amount of work has been done by RNSP, private landowners, public agencies, and interested parties to develop alternatives to improve habitat conditions in the estuary/lagoon, while protecting Highway 101 and the Town of Orick. These include various levee setback alternatives and shortening the extent of the levees to exclude the lowermost channel reach;
- A properly functioning riparian zone is needed to improve the estuarine ecosystem and increase the estuary's value as salmonid habitat.

Estuary Subbasin Recommendations

A great amount of work has been done by RNSP, private landowners, public agencies, and interested parties to develop alternatives to improve habitat conditions in the estuary/lagoon, while protecting Highway 101 and the Town of Orick. These include:

- widening the levees and shortening the extent of the levees to exclude the lowermost channel reach;

Flow and Water Quality Improvement Activities:

- Increase tidal prism by restoring tidal and riverine flow and connectivity between the main channel and slough channels;
- Increase depth and tidal exchange at the confluence of North Slough channel;
- Increase circulation between the lagoon, Strawberry Creek and sloughs to help mix water and increase dissolved oxygen levels;
- Prevent or reduce cattle waste from entering stream and slough channels;
- Develop a shade corridor of riparian trees along main channel to help cool water;
- Land managers should work to maintain and/or establish adequate overstory shade canopy along Redwood Creek and its tributaries throughout basin to reduce water warming from solar radiation and high air temperatures;
- The goal of any controlled breech project must be to maintain the volume in the lagoon to best support the anadromous fisheries;
- Digging of any artificial channel through the beach sand berm that would result in an uncontrolled breech should be discouraged;
- Any controlled breech should be performed as an option and in coordination with the expert judgment of RNSP staff and CDFG to preserve natural resources.

Erosion and Sediment Delivery Reduction Activities:

- Reduce inputs of sands by tidal currents to the embayment and North Slough by modifying levee configuration or removing levees altogether;
- Use levee set back, reconfiguration or removal strategies to achieve more natural flood plain characteristics;

- Land managers should continue their efforts such as road improvements, good maintenance, and decommissioning and other erosion control practices associated with all land use activities throughout the basin to reduce sediment delivery to the estuary.

Riparian and Instream Habitat Improvement Activities:

- A properly functioning riparian zone is needed to improve the estuarine ecosystem and increase the estuary's value as salmonid habitat;
- Where feasible, develop or improve riparian vegetation function along the banks of Redwood Creek, Strawberry Creek, and slough channels;
- Use levee set backs, reconfiguration, or levee removal strategies to develop a wider flood plain to restore natural sinuosity, improve connectivity with sloughs and adjacent wetlands, and promote the development of an effective zone of riparian vegetation;
- Work to restore natural drainage patterns within adjacent wetlands and the subbasin;
- Increase off-channel and rearing habitat by improving conditions of sloughs and tributaries (Strawberry, Dorrance and Sand Cache creeks);
- Increase depth and complexity in the main channel and slough channels;
- Where feasible add LWD to increase salmonid shelter complexity;
- Leave large wood in estuarine channels, on the beach, and on stream banks for potential recruitment as complex shelter elements;
- Relocate drift logs that block tidal connectivity between the embayment and the North Slough channels;
- Re-establish a corridor of riparian vegetation to lower Strawberry Creek and restore riparian function in areas where vegetation removal or significant cattle impacts have been noted. This may require temporary fencing the riparian zone to prevent cattle and deer from grazing on seedlings and trampling growing trees.

Education, Research, and Monitoring Activities:

- Work should continue by Redwood National and State Parks (RNSP), private landowners, agencies, and interested parties to improve habitat conditions of the estuary by modifying the levees system while protecting Highway 101 and the town of Orick;
- RNSP, DFG, RWQCB should continue existing monitoring of anadromous salmonid populations and expand to include some winter and early spring sampling;
- Water temperature and dissolved oxygen monitoring in the lagoon and sloughs should continue. Some dissolved oxygen measurements should be collected just before sunrise to capture lowest diurnal levels;
- Monitoring water quality in the lagoon should be expanded to include nutrient levels (ammonia, nitrates, nitrates) that may be elevated from runoff from cattle pastures;
- Work with USACE, Redwood National and State Parks, and Humboldt County Department of Public Works to modify levees and levee maintenance manuals to be consistent with habitat requirements of salmonids and a properly functioning estuarine ecosystem.

Prairie Creek Subbasin

The Prairie Creek Subbasin supports self sustaining populations of Chinook and coho salmon, steelhead and coastal cutthroat trout. It is believed that the Prairie Creek Subbasin supports more coho than all other subbasins in Redwood Creek. Under RNSP management, protection is given to natural resources and refugia habitat that are important to the recovery and expansion of anadromous salmonid populations of the Redwood Creek Basin. Based on integrated analysis, it is apparent that timber harvest activities, road and highway construction, and road density have long lasting adverse impacts to anadromous salmonid stream habitat in the subbasin. Physical factors including debris jams that impede fish passage and sediment inputs that impair anadromous salmonid habitats are linked to these past land use activities. In contrast, undisturbed areas of the subbasin generally maintain desirable conditions for anadromous salmonids. Overall, the best stream habitat of the subbasin was found in areas that received the least amount of land disturbance.

The Prairie Creek Subbasin provides an excellent opportunity to maintain and improve stream habitat conditions and to strengthen anadromous stocks of Redwood Creek. Road removal and road improvement projects in the Lost Man Creek Planning Watershed should help alleviate sediment sources to Lost Man Creek. The Prairie Creek Subbasin offers opportunities for implementing projects, conducting effectiveness monitoring of stream and riparian habitat improvement activities, and further research into watershed dynamics that may be applied to similar north coast streams. In addition, the Prairie Creek Subbasin is an excellent location to study watershed science and to observe responses of fish populations in disturbed versus undisturbed watersheds. These streams offer the opportunity to compare and contrast natural stream recovery with habitat improvement projects aimed at increasing aquatic habitat quality and fish abundance and diversity.

Prairie Creek Subbasin Issues and Summary Findings

The Prairie Creek Subbasin is predominantly managed by RNSP:

- RNSP management goals include the protection of natural resource values including anadromous salmonids and their habitat;
- The Prairie Creek subbasin supports self sustaining populations of Chinook, coho, steelhead, and coastal cutthroat trout;
- The Prairie Creek Subbasin likely supports the largest coho salmon population of the Redwood Creek basin;
- The RNSP is a World Heritage Site and is part of the California Coast Range Biosphere Reserve, designations that reflect worldwide recognition of the parks' natural resources as irreplaceable.
- The RNSP has done a significant amount of work to survey road systems, identify problems, and implement road removals and upgrades that should result in reducing erosion and sediment inputs into stream channels;
- Much of the upper watershed of Prairie Creek and Little Lost Man Creek watersheds are relatively undisturbed areas. These areas retain old growth forest characteristics and provide some of the highest quality fisheries habitat within the Redwood Creek basin.

Before RNSP was expanded, approximately half of the subbasin was logged using timber harvest practices that resulted in disturbance to salmonid habitat:

- Impacts from past timber harvest still effect some riparian and stream habitat;
- Debris accumulations on Lost Man Creek may impede anadromous fish passage to upstream spawning grounds;
- Lost Man Creek watershed still has a relatively high density road network;
- It appears that land use has exacerbated landsliding in the Lost Man Creek Planning Watershed and the landscape has not fully recovered from past disturbances.

Impacts from Prairie Creek Hatchery operations:

- Steelhead/rainbow trout from other basins were introduced through the hatchery.

Sediment impacts from the Highway 101 bypass are a concern:

- Surface and drainage alterations associated with the construction of the Highway 101 bypass resulted in the generation and delivery of large quantities of fine sediments into headwaters of tributary streams. Salmonid spawning and rearing habitat of Prairie, Brown, Boyes, and May Creeks were affected by the event.

Prairie Creek Subbasin Recommendations

Barriers

- Modify large debris accumulation on Lost Man Creek to improve passage of spawning adults.

Flow and Water Quality Improvement Activities:

- Ensure that adequate streamside protection measures are used to maintain shade canopy in order to reduce moderate inputs to the lower reach of Prairie Creek and to maintain good water temperature in Lost Man Creek and other tributary streams;
- Water flow or water quality does not appear to be and issue at this time, but fish habitat requirements and channel maintenance flows should be considered prior to any water development projects.

Erosion and Sediment Delivery Reduction Activities:

- Continue road assessments and upgrades or removal of roads, especially in the Lost Man Creek planning watershed;
- Work with CalTrans to reduce sediment input potential to streams from HWY 101 activities;
- Consider bank stabilization projects in the Lost Man Creek watershed.

Riparian and Instream Habitat Improvement Activities:

- Restore riparian function in areas where vegetation removal or significant cattle impacts have been noted in lower Prairie Creek;
- Consider modifying debris accumulations in Lost Man Creek to facilitate fish passage;
- Consider adding pool enhancement structures to increase the number of pools or deepen existing pools in Lost Man Creek, May Creek, and Boyes Creek.

Supplemental Fish Rescue and Rearing Activities:

- The use of Prairie Creek hatchery can be considered to supplement fishery resources of Redwood Creek if populations fail to respond to current management strategies.

Education, Research, and Monitoring Activities:

- The wide range of habitat conditions within the watershed provides an opportunity to monitor channel and salmonid habitat recovery rates under various habitat improvement treatments within a variety of channel types and conditions;
- Humboldt State University and RNSP should continue and expand their salmonid population and continuous temperature monitoring tasks in the Prairie Creek subbasin. This includes the use of fish counting weirs, spawner and redd surveys and juvenile population studies;
- A long term, concerted monitoring effort between the land owners, interested parties and responsible agencies is needed to determine the status and trends of anadromous fish populations in the Prairie Creek Subbasin;
- Water temperature monitoring should occur at the confluence of Prairie Creek and the mainstem to determine the effects of colder Prairie Creek water on the mainstem and estuary;
- Nutrients contributed to streams from eggs and decaying carcasses has declined. Studies should be conducted to discern relationships between nutrient contributions from carcasses, stream productivity, and salmonid production;
- Ensure that any land management activities include protection and preservation of stream and riparian habitats;
- CalTrans should continue to monitor and reduce sediment delivery from the Highway 101 bypass.

Lower Subbasin

The Lower Subbasin supports populations of all anadromous salmonid species of Redwood Creek. The lower mainstem of Redwood Creek is an important migratory route for all species and provides spawning area for Chinook salmon. Lower Subbasin tributary streams provide important salmonid spawning and year round rearing habitat for all salmonid species.

Elevated summer water temperature and lack of channel complexity are factors most limiting juvenile anadromous salmonid production in lower mainstem Redwood Creek. These limiting factors are products of channel aggradation and associated impacts such as a widened channel, lack of shade over the water, and lack of LWD. Watershed erosion, excessive sediment inputs to streams and loss of large conifers from nearstream areas in the Upper, Middle and Lower subbasins are root causes for limiting factors.

Water temperature is generally suitable in the tributaries year round. However, in the tributary streams fish habitat lacks sufficient area in deep, complex pools. Spawning gravels were moderately to highly embedded in fine sediments, which is considered unfavorable for successful incubation salmonid eggs.

Based on the survey sample sites, stream habitat improvement activities for Lower Subbasin streams include reducing sediment inputs by stabilizing stream bank and hillslope erosion, increasing depth and complexity to existing pool habitats, promoting nearstream conifer growth, and adding shelter complexity to cool water refuge sites. Further surveys are needed to assess conditions of other Lower Subbasin tributaries.

The Lower Subbasin offers opportunities for implementing projects, conducting effectiveness monitoring of stream and riparian habitat improvement activities, and further research into watershed dynamics that may be applied to similar north coast streams. In addition, the Lower Subbasin is an excellent location to study watershed science and to observe responses of fish populations in disturbed versus undisturbed watersheds. These streams offer the opportunity to compare and contrast natural stream recovery with habitat improvement projects aimed at increasing aquatic habitat quality and fish abundance and diversity.

Lower Subbasin Issues and Summary Findings

Impairments to freshwater habitat needed to complete salmonid freshwater life cycles have been identified as a leading factors in the decline of Lower Subbasin anadromous salmonids:

- Mainstem Redwood Creek summer water temperatures generally exceed favorable limits for salmonid production;
- Anecdotal accounts by long time residents and CDFG reports indicate that water temperature was once much colder in Redwood Creek;
- Lower Subbasin tributaries provide water temperature that supports salmonids;
- A lack of instream large woody debris (LWD) contributes to poor aquatic habitat structure including a low number of deep, complex pools;
- LWD recruitment potential to Lower Subbasin appears low at most locations;
- Stream habitat conditions in the Lower Subbasin can be improved.

Lands within the Lower Subbasin are managed by RNSP:

- RNSP management goals include the protection of natural resource values including anadromous salmonids and their habitat;
- The Lower Subbasin was made part of the Redwood National and State Park system in 1978.
- Prior to 1978, approximately 68% of the landscape was harvested for timber resources.
- Adverse impacts from legacy timber harvests are still affecting mainstem and tributary stream habitat.

<u>The lower reach of Redwood Creek is a low gradient, depositional reach which accumulates excessive sediments derived from upstream sources:</u>

- The aggraded channel condition contributes to elevated water temperatures, a widened channel, and an overall lack of channel diversity and complexity in Redwood Creek;
- During the summer months of recent low rain years (2001 and 2002) the lowermost reach of Redwood Creek became intermittent or dry from the Highway 101 bridge up to the confluence with Hayes Creek, loosing connection with the estuary. In a recent newspaper article in the McKinleyville Press (2002), it was noted by a local resident since 1945 that Redwood Creek has never been so low.

Lower Subbasin Recommendations

Barriers to Fish Passage

- Modify or remove potential barriers such as deltas or boulder and/or debris accumulations that may impede upstream fish passage into tributary streams for spawning.

Flow and Water Quality Improvement Activities:

- Promote near stream conifer growth to reduce solar radiation and to moderate air temperatures along stream corridors. This will reduce heat inputs to Redwood Creek and its tributaries and help to keep water cool.

Erosion and Sediment Delivery Reduction Activities:

- Any reduction of sediment from upstream sources will benefit the lower mainstem Redwood Creek;
- In order to reduce sediment delivery to Redwood Creek and its tributaries RNSP should continue efforts such as road improvements (e.g., upgrading crossings, rocking native surface roads, outsloping, ensuring surface drainage does not flow directly into watercourses, etc.) and decommissioning (e.g., removing unstable fills, removing drainage structures and fills, restoring natural contours, blocking vehicle access, etc.) throughout the Redwood Creek Basin;
- To address accumulations of fine sediments observed in Elam, Bridge, and Forty-four creeks, Sediment sources from eroding stream banks and adjacent hillslopes should be identified and treated.

Riparian and Stream Habitat Improvement Activities:

- Where appropriate, land managers should use tree planting, thinning from below, and other vegetation management techniques to promote the development of large near stream conifers along mainstem Redwood Creek, Bridge Creek or other steam reaches with a low coniferous component in the riparian zone. Thinning to encourage conifer growth should be done with consideration of maintaining adequate shade canopy over stream channels;
- Instream LWD is needed for channel maintenance and shelter complexity;
- Strategically add wood into pools and flatwater units to increase pool depth and overall shelter complexity in Bridge, and Elam, Forty-four creeks and other streams within the subbasin that lack deep complex pools;
- Consider adding shelter complexity with wood to existing cool temperature refuge sites on Redwood Creek, and lower reaches of tributary sites. This could be done even on a temporary basis using small woody debris to provide escape cover for juvenile salmonids during summer season. The cool patches may be located in temperature stratified pools or adjacent to cool water inputs from tributary flows at Bridge Creek or near springs, and seeps.

Education, Research, and Monitoring Activities:

- The range of habitat conditions within the Lower Subbasin provides an opportunity to monitor channel and salmonid habitat recovery rates using habitat improvement treatments within a variety of channel types and conditions;

- Perform stream habitat surveys in tributaries throughout the Lower Subbasin to identify excessive erosion areas, assess salmonid stream habitat, identify deltas or boulder and/or debris accumulations that may impede passage for spawning, and to identify potential sites for improving habitat with restoration techniques;
- Monitoring in-channel sediment by measuring sediment size distribution, turbidity, V*, photo points should be increased; tracking of streambed levels with stream channel cross sections should be continued along the mainstem reach of lower Redwood Creek;
- A long term, concerted monitoring effort between the land owners, interested parties and responsible agencies is needed to determine the status and trends of anadromous fish populations in Lower Subbasin streams;
- Land managers and responsible agencies should increase continuous temperature monitoring efforts along the mainstem and at additional tributary locations to determine the impact of cold-water inputs from tributary and ground water sources;
- Although there were no formal stream reach surveys for LWD; observations of crews and findings regarding pool complexity indicate that there is limited instream LWD. Formal surveys for LWD loadings could be done to verify these observations.

Middle Subbasin

Streams of the Middle Subbasin play important roles as anadromous salmonid habitat. Coho salmon, once noted as abundant in some streams were not detected in 2001 surveys. Potential access problems and lack of sheltered pools may be limiting coho in these streams.

Elevated summer water temperature, lack of channel complexity, and low amounts of instream shelter elements are factors most limiting juvenile anadromous salmonid production in mainstem Redwood Creek. These limiting factors are products of channel aggradation and associated impacts such as a widened channel, lack of shade over the water, and lack of LWD. Watershed erosion, excessive sediment inputs to streams and loss of large conifers from nearstream areas in the Upper, Middle subbasins are root causes for limiting factors.

Water temperature is generally suitable in the tributaries year round. However, the tributary streams lack sufficient habitat area in deep, well sheltered pools and most tributaries have less than a desirable amount of good spawning habitat.

After 30 years of relatively moderate winters and droughts, the mainstem has self-adjusted from a near featureless channel, overwhelmed by sediment, to a channel providing structural diversity and formation of regularly spaced pools, runs, and riffles. Except for a setback in 1997 due to a 12 year flood event that initiated several landslides, associated sediment delivery and a rise in bed elevations, the channel remains on a recovery trajectory (M. Madej RNSP, Personnel Communication). The problem of deficient amounts of instream shelter still persists.

The Middle Subbasin offers opportunities for developing and implementing watershed, stream, and riparian habitat improvement activities. Watershed management strategies aimed at reducing erosion and developing functional near stream forests will help address landscape issues affecting stream habitat. The near stream forest corridor should be managed to encourage growth and retention of large coniferous trees. Stream habitat improvement activities should focus on increasing depth and complexity to existing pool habitats, and adding shelter complexity to cool water refuge sites. This will help to reduce water temperature, increase bank stability, provide a source of LWD and reduce sediment inputs to stream channels.

Middle Subbasin Issues and Summary Findings

Salmonid populations have declined from historic levels, prompting listings under the state and federal ESAs:

- There is a decline in abundance and distribution of coho salmon and coastal cutthroat trout in the Middle Subbasin;

- Coho salmon were not observed in 2001 fish surveys;
- The summer steelhead population has declined to critically low levels of abundance;
- Chinook salmon show variable spawning success among years.

Impairments to freshwater habitat needed to complete salmonid freshwater life cycles have been identified as a leading factors in the decline of Redwood Creek's anadromous salmonids:

- Mixed conditions for salmonid spawning and rearing success exist in the subbasin;
- There is a lack of shade canopy along mainstem Redwood Creek;
- High summer water temperature along the mainstem Redwood Creek and lower reaches of Lacks and Minor creek impairs juvenile rearing habitat and adult holding habitat for summer steelhead;
- There is a lack of deep and complex pools in tributary streams and mainstem Redwood Creek;
- A lack of instream LWD impairs fish habitat;
- Stream habitat conditions in the Middle Subbasin can be improved.

The Middle Subbasin terrain is highly susceptible to erosion:

- High potential exists for large sediment inputs from disturbed and unstable hillslopes;
- High levels of sediment are stored in mainstem and some tributary channels;
- Historically active landslide features cover 4,200 acres (6.5%) of the subbasin. These features are critical sources of sediment inputs to stream channels.

Land uses can increase erosion rates:

- Land use has made the Middle Subbasin's terrain more susceptible to erosion;
- High road density of both abandoned and useable roads adds to sediment delivery potential;
- Debris slides and debris flows are often initiated by management activities (such as road construction) that take place on existing earthflows or rockslides.

Riparian and near stream forests have been altered by timber harvests and bank erosion:

- Timber harvests have caused significant levels of disturbance to riparian and near stream forest areas causing a reduction in both overstory shade canopy and LWD input potential;
- In response to aggraded channels, stream banks erode, channels widen, and riparian vegetation becomes less affective to provide shade over the water.

What are the impacts from Chezem dam on Redwood Creek and salmonids?

- Dam construction increases suspended sediment levels to downstream reaches;
- Mutes changes in diurnal water temperatures to downstream reaches;
- Inundates approximately one mile of stream habitat.

Middle Subbasin Recommendations

Barriers to fish passage

- Investigate improving fish passage through 500 foot long culvert under HWY 299 on Lupton Creek;
- Modify sediment deltas or boulder accumulations that impede upstream migration into tributaries. A sediment delta formed by boulder accumulations is located within the lowermost reach of Panther Creek and possibly other tributaries;
- Modify large debris accumulations that may impede fish passage on Panther Creek and other tributaries (completed by Green Diamond and the California Conservation Corps in 2004).

Flow and Water Quality Improvement Activities:

- Reducing water temperature is essential to improve anadromous salmonid habitat in the Middle Subbasin. A long term goal should be to reduce water temperature in the middle reach of Redwood Creek and the lower reaches of tributary streams including Panther, Coyote, Minor and Lacks creeks;
- A reduction in temperature will likely occur as the result of increasing pool frequency and depth, controlling erosion, increasing the coniferous component of the riparian zone and allowing near stream conifers to obtain large size for development of microclimate benefits;
- Functional nearstream conifer forests need to be developed and/or maintained along Redwood Creek in the Middle Subbasin. Large near stream conifers are needed to help increase shade canopy, moderate air temperatures, and to promote LWD loading. This may require more than the minimum protection provided by present Forest Practice Rules;
- Increase shelter complexity in existing cool water refuge sites;
- Managers should explore methods to develop cool water refuge sites on Redwood Creek and the lower reaches of Panther, Lacks, and Minor and other creeks. Methods should include using pool scour elements, and increasing connectivity to cool ground water sources.

Erosion and Sediment Delivery Reduction Activities:

- In streams where the majority of pool tail spawning substrate is highly embedded with fine sediment, sediment sources should be located, rated according to their potential sediment yields, and treated;
- Upgrade or decommission roads in accordance with existing or future road assessment surveys. This work should be done especially on older roads built below current standards on unstable slopes and roads near streams in Upper and Lower Lacks, Minor, Lupton, Panther, and Coyote and Roaring Gulch planning watersheds;
- For timber management in Lacks, Minor, Coyote and other planning watersheds, with active landslides or on steep and/or potentially unstable slopes (slopes $\geq$ 35%) we recommend the use of lower impact silvicultural prescriptions to maintain vegetative cover, root strength, and the use of cable systems or helicopter yarding to reduce the potential for mass wasting and sediment production;
- Land management activities adjacent to all streams, particularly in the inner gorge, head walls, and on slopes 35% (19 degrees) or greater, must be carefully evaluated and designed to avoid generation and delivery of sediment to stream systems;
- Timberland managers should decrease the use of tractor or ground lead yarding on all slopes steeper than 35% (19 degrees); and use fully suspended (skyline) cable or helicopter yarding on steep and unstable slopes;
- RNSP and private landowners should continue efforts such as road improvements (e.g., upgrading crossings, rocking native surface roads, outsloping, ensuring surface drainage does not flow directly into watercourses, etc.) and decommissioning (e.g., removing unstable fills, removing drainage structures and fills, restoring natural contours, blocking vehicle access, etc.) throughout the Redwood Creek basin to reduce sediment delivery to Redwood Creek and its tributaries;
- A qualified, licensed geologist or engineer should be consulted before initiating any project that involves road construction, timber harvest, or building. The NCWAP Landslide Potential maps should be reviewed before modifying hillslopes to avoid creating, or contributing to, hillslope instability and excessive, human-induced erosion through mass wasting or creation of gullies.

Riparian and Stream Habitat Improvement Activities:

- To increase overstory shade and to promote input of large woody debris, encourage near stream conifers to grow to large sizes and retain them along Redwood Creek and all tributary streams in the subbasin;

- Where there is adequate shade canopy along Lacks, Minor, Molasses, and Coyote Creeks, land managers should consider thinning hardwoods from below in riparian areas to hasten the development of large near stream conifers;
- Trees large enough to function as LWD need to be allowed to grow and recruit to stream channels from riparian and near stream forest areas;
- Consider adding pool forming structures to increase the number of pools in Redwood, Lacks, Minor, Lupton, Molasses, Panther, Mill, and Beaver creeks;
- Deepen and increase the size of existing pools in Dolly Varden, Toss Up, Garret, Lupton creeks and in lower reach of Coyote Creek;
- Add wood into pools and flatwater units to increase shelter complexity especially where the average size of near stream conifers is less than 2 feet DBH in Redwood, Lacks, Minor, Lupton, Panther, Coyote and Molasses creeks;
- Consider adding shelter complexity to existing temperature refuge sites on Redwood Creek.

Education, Research, and Monitoring Activities:

- Water temperature monitoring should continue at the current locations to observe changes in temperature as effects from aggradation, degradation, channel widening, and riparian condition adjust over time;
- Identify potential perched sediment deltas and/or debris accumulations that may impede passage for spawning into Panther Creek and other Middle Subbasin tributaries;
- A long term, concerted monitoring effort between land owners, interested parties and responsible agencies is needed to determine the status, abundance and trends of anadromous fish populations of the Middle Subbasin streams;
- Investigate impacts from fine sediments on salmonid spawning success and aquatic insect community structure;
- Formal stream reach surveys were not done for LWD; however observations of crews and findings regarding pool complexity indicate that there is limited instream LWD. Formal survey for LWD loadings could be done to verify these observations;
- Monitoring in-channel sediment routing and storage(e.g., sediment size distribution, turbidity, V*, photo points, etc.) should be increased and tracking of streambed levels (i.e., stream channel cross sections) should be continued;
- Summer steelhead dive counts should be conducted on an annual basis on the middle reach of mainstem Redwood Creek and in the lower reach of Lacks and Minor creeks;
- Continue monitoring juvenile fish population trends such as downstream migrant trapping operations on mainstem Redwood Creek;
- Investigate possible improvements to cool water refugia and potential to increase such areas;
- Further study of the effects of Chezem summer dam on fish and fish habitat is warranted;
- Ensure that CEQA-compliant environmental assessment is conducted prior to issuance of the Fish and Game Code 1603 streambed alteration permits and Corps of Engineers or NOAA Fisheries permitting requirements are complete for any summer dams on Redwood Creek.

Upper Subbasin

The Upper Subbasin streams provide important habitat for anadromous salmonids. The mainstem of Redwood Creek is an important migratory route for all species and provides spawning area for Chinook salmon. Tributary streams provide important salmonid spawning and year round rearing habitat for steelhead.

Streams of the Upper Subbasin were severely affected by the combination of unstable geology, intensive land use, the flood of 1964, and other recent flood events. Land use activities, combined with natural geologic slope instability of the subbasin, and high precipitation regimes continue to generate large quantities of sediment inputs into streams. Watershed management strategies aimed at reducing sediment inputs by reducing erosion will help address landscape issues that contribute to impairment of aquatic habitat.

Stream habitat improvement projects should also focus on preserving cool water flowing from the headwaters reach of Redwood Creek by re-establishing riparian shade and reducing the channel width along mainstem Redwood Creek. Restoration projects such as tree planting and adding LWD and shelter complexity to stream channels may increase the rate of stream recovery. Adding shelter complexity to cool water refuge sites will provide summer steelhead protective cover needed during their summer holding stage. In tributary watersheds, stream habitat improvement activities should focus on increasing frequency, depth and complexity to pool habitats, adding instream shelter complexity, and promoting nearstream coniferous forest growth retention.

Upper Subbasin Issues and Summary Findings

Impairments to freshwater habitat needed to complete salmonid freshwater life cycles have been identified as a leading factors in the decline of the Upper Subbasin's anadromous salmonids:

- Mixed conditions for salmonid spawning and rearing success exist in the subbasin;
- There is a lack of shade canopy along mainstem Redwood Creek;
- High summer water temperature along the mainstem Redwood Creek impairs juvenile rearing habitat and adult holding habitat for summer steelhead;
- The water temperatures increase quickly to above desirable levels in the upper mainstem Redwood Creek due to the widened stream channel and lack of riparian shade canopy;
- There is a lack of deep and complex pools in tributary streams and mainstem Redwood Creek;
- A lack of instream LWD impairs fish habitat;
- Stream habitat conditions in the Upper Subbasin can be improved.

The Upper Subbasin is highly susceptible to erosion:

- Seventy-two percent of the subbasin has high or very high land slide potential;
- Land use such as timber harvest activities exacerbate erosion potential;
- Recently the Upper Subbasin has produced more sediment than the Middle and Lower Subbasins combined;
- The Upper Subbasin generates and exports sediments that contribute to aggradation and persistent impairment of salmonid habitat in the Lower and Estuary subbasins.

Land management can influence watershed processes:

- Land uses, such as timber harvest activities, increase erosion potential over much of the Upper Subbasin;
- High road density of both abandoned and useable roads adds to instream sediment delivery potential;
- Debris slides and debris flows are often initiated by management activities (such as road construction) that take place on existing earthflows or rockslides.

Riparian and near stream forests have been altered by timber harvests and bank erosion:

- Timber harvests have caused significant levels of disturbance to riparian and near stream forest areas causing a reduction in both overstory shade canopy and LWD input potential;
- In response to aggraded channels, stream banks erode, channels widen, and riparian vegetation becomes less affective to provide shade over the water.

Upper Subbasin Recommendations

Barriers to Fish Passage

- Modify sediment deltas or boulder and/or debris accumulations that impede upstream migration into tributaries. A barrier is located at the confluence of Lake Prairie Creek. Consider modifying debris accumulation and building step pools in the lower reaches where sediment accumulations may restrict or delay access to migrating salmonids.

Flow and Water Quality Improvement Activities:

- Maintaining and improving good water temperatures in tributaries and in the upper reach of Redwood Creek is essential to improve of salmonid habitat condition in the Upper Subbasin and also will provide benefits to downstream reaches;
- A high priority should be placed on re-establishing riparian shade and reducing the channel width along portions of the upper reach of Redwood Creek. This will help extend the benefits of cool water flowing from the headwaters reach.

Riparian and Instream Improvement Activities:

- In appropriate locations along the upper reach of mainstem Redwood Creek, consider installing live willow baffles or other habitat structure to help establish shade over water and to encourage channel width reduction;
- The riparian corridor and near stream forest along the upper reach of Redwood Creek should be managed to encourage growth and retention of coniferous trees. The shade provided by large trees will help maintain cool water temperatures, their stems will provide large woody debris and provide nutrient inputs to the stream, and roots will add stability to banks and buffer against sediment delivery. This may require more than the minimum protection provided by Forest Practice Rules;
- In tributaries with an abundance of shade, consider cautious thinning from below in riparian areas to hasten the development of large near stream conifers;
- Design and engineer pool enhancement structures to increase the number of pools or increase the size, deepen, or add shelter complexity to existing pools in Redwood Creek and Fern Prairie Creek and Minon Creek and other tributaries;
- Consider adding shelter complexity with wood and large boulders to existing cool temperature refuge sites on upper Redwood Creek. This could be done on a seasonal basis using small woody debris to provide escape cover for adult summer steelhead and juvenile salmonids during summer season. The cool patches may be located in temperature stratified pools or adjacent cool water inputs from tributary flows, springs, and seeps;
- To address the lack of complex pools add, large woody debris in Redwood and Minon and Fern Prairie creeks, consider direct placement of large woody debris in existing pool habitat, especially where the average size of near stream conifers is less than 2 feet DBH;
- Consider the use of conservation easements along the upper reach of Redwood Creek to protect valuable riparian and near stream forest from development or timber harvests.

Erosion and Sediment Delivery Reduction Activities:

- In streams where the majority of pool tail spawning substrate is highly embedded with fine sediment, sediment sources should be located, rated according to their potential sediment yields, and treated;
- Upgrade or decommission roads in accordance with existing or future road assessment surveys, especially roads located on unstable slopes and roads near streams. These are found throughout the subbasin but are most frequent in Windy Creek, Twin Lakes Creek, Bradford Creek, and High Prairie Creek Planning Watersheds;
- Consider bank stabilization projects in tributary streams throughout the Upper Subbasin;

- Throughout the Upper Subbasin, timberland managers should avoid the use of tractor yarding on slopes steeper than 35% (19 degrees) and instead use full suspension cable or helicopter yarding on steep and/or highly unstable slopes.

Education, Research, and Monitoring Activities:

- Conduct stream surveys in tributaries and mainstem reaches not addressed in this report;
- Continue temperature monitoring at the current locations to observe changes in temperature as effects from mainstem fluvial conditions, such as aggradation, degradation, channel widening, and riparian function adjust through time;
- Monitoring for in-channel sediment (e.g., sediment size distribution, turbidity, V*, photo points, etc.) should be continued and tracking of streambed levels (i.e., stream channel cross sections) should be continued at upper Redwood Creek study sites;
- A long term, concerted monitoring effort between the land owners, interested parties and responsible agencies is needed to determine the abundance and trends of anadromous fish populations of Upper Subbasin streams;
- Summer steelhead dive counts should be conducted on an annual basis along the upper reach of mainstem Redwood Creek.

Improvement in the Redwood Creek Basin

Advantages

Redwood Creek Basin has several advantages for planning and implementing successful salmonid habitat improvement activities that include:

- Approximately one third of the basin in managed by RNSP to persevere natural resource values;
- An interdisciplinary team of watershed scientists from the Redwood Creek Land Owners Association are working together to solve watershed problems;
- A basin wide effort is underway to perform road assessment and road implementation projects;
- Several in basin studies have shown relationships between land use, geology, climate, and stream conditions.

Challenges

The Redwood Creek Basin also has some challenges confronting efforts to improve watershed and fish habitat conditions, and increase anadromous fish populations:

- Land use on the basin’s unstable geology will require careful planning and mitigation to prevent large scale sediment generating floods like seen in the past;
- A watershed wide cooperative land-base needs to be maintained, so treatment options can be implemented at a basin scale. Without basin wide participation, some key areas may be removed from consideration of project development;
- The present reduced levels of coho salmon and summer steelhead populations limit re-colonization potential into improved or expanded habitat conditions.

Program Introduction and Overview

Assessment Needs for Salmon Recovery & Watershed Protection

The Redwood Creek Basin Assessment began as project of the North Coast Watershed Assessment Program (NCWAP). The NCWAP was an interagency effort between the California Resources Agency and the California Environmental Protection Agency (CalEPA) established in 2000 to provide a consistent scientific foundation for collaborative watershed restoration efforts and to better meet California's needs for protecting and restoring salmon species and their habitats under state and federal laws. The program was developed by a team of managers and technical staff from the following departments with watershed responsibilities for the North Coast:

- California Resources Agency;
- California Department of Fish and Game (CDFG);
- California Department of Forestry and Fire Protection (CDF);
- California Department of Conservation/California Geological Survey (DOC/CGS);
- California Department of Water Resources (DWR);
- North Coast Regional Water Quality Control Board (NCRWQCB) of the State Water Resources Control Board.

The California Resources Agency in coordination with CalEPA, initiated the program in part in response to specific requests from landowners and watershed groups that the State take a leadership role in conducting scientifically credible, interdisciplinary assessments that could be used for multiple purposes. The need for comprehensive watershed information grew in importance with listings of salmonids as threatened species, the Total Maximum Daily Load (TMDL) consent decree, and the increased availability of assistance grants for protecting and restoring watersheds.

Funding for the NCWAP was cut from the State budget before the Redwood Creek assessment project was complete. This assessment report was completed largely by the CDFGs Coastal Watershed Planning and Assessment Program (CWPAP) with inputs from other Resources Agency Departments as budgets, personnel, and time constraints allowed.

Listings under the federal Endangered Species Act for areas within the North Coast region (the North Coast Hydrologic Unit) began with coho salmon in 1997, followed by Chinook salmon in 1999, and steelhead in 2000. In 2001, coho was proposed for listing under the California Endangered Species Act. Concerns about the potential impacts of salmonid listings and TMDLs on the economy are particularly strong on the North Coast where natural resource-dependent industries predominate. Cumulative impacts related to human activities including landslides, flooding, timber harvest, mining, roads, ranching, agricultural uses, and development along with natural processes can adversely affect watershed conditions and fish habitat. In order to recover California's salmonid fisheries, it is necessary to first assess and understand the interactions among management activities, dominant ecological processes and functions, and factors limiting populations and their habitat.

The program integrates and augments existing watershed assessment programs to utilize methodologies and manuals available from each participating department. The program also responds to recommendations from a Scientific Review Panel (SRP) which was created under the auspices of the State's Watershed Protection and Restoration Council as required by the March, 1998 Memorandum of Understanding (MOU) between the National Marine Fisheries Service (NMFS) and the California Resources Agency. The MOU required a comprehensive review of the California Forest Practice Rules (FPRs) with regard to their adequacy for the protection of salmonid species. In addition, the promise of significant new state and federal salmonid restoration funds highlighted the need for watershed assessments to ensure those dollars are well spent.

Program Assessment Region and Agency Roles

Originally, the program was to provide baseline environmental and biological information for approximately 6.5 million acres of public and private lands over a several-year period. This area was to include all coastal drainages from Sonoma County north to Oregon, corresponding with the NCRWQCBs region (Figure I- 1). The Redwood Creek assessment is one of five watershed assessments completed under this program: Gualala, Mattole, Redwood, Albion, and Big Basins.

Figure I- 1. NCWAP assessment area.

The roles of the five participating agencies in these efforts are as follows:

- CDFG collected, developed, and analyzed data related to anadromous fisheries habitat and populations. It also led an interagency evaluation of factors affecting anadromous fisheries production at the watershed level, provided recommendations for restoration and monitoring in the final synthesis report.
- CDF collected, developed, and analyzed data related to vegetation, fire hazard and land use.
- DOC/CGS included a baseline mapping of landslide potential, and discussions of geologic and fluvial processes that effect watershed conditions.
- NCRWQCB compiled, collected, and analyzed water quality data for the assessments. The assessment included comparison of recently collected and past available information comprised of water temperature, sediment, and water chemistry data sets.
- DWR provided discussion of hydrology, stream flows and precipitation patterns.

Program Guiding Questions

The program's work intends to provide answers to the following assessment questions at the basin and subbasin scales in California's North Coast watersheds:

- What are the history and trends of the size, distribution, and relative health and diversity of salmonid populations?
- What are the current salmonid habitat conditions? How do these conditions compare to desired conditions?

- What are the impacts of geologic, vegetative, fluvial, and other natural processes on watershed and stream conditions?
- How has land use affected these natural processes?
- Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?
- What watershed and habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

Program Goals

The program was developed to improve decision-making by landowners, watershed groups, agencies, and other stakeholders with respect to restoration projects and management practices to protect and improve salmonid habitat. It was therefore essential that the program took steps to ensure its assessment methods and products would be understandable, relevant, and scientifically credible. As a result, the interagency team developed the following goals:

- Organize and provide existing information and develop limited baseline data to help evaluate the effectiveness of various resource protection programs over time;
- Provide assessment information to help focus watershed improvement programs, and assist landowners, local watershed groups, and individuals to develop successful projects. This will help guide programs, like the CDFG Fishery Restoration Grants Program, toward those watersheds and project types that can efficiently and effectively improve freshwater habitat and support recovery of salmonid populations;
- Provide assessment information to help focus cooperative interagency, nonprofit and private sector approaches to protect the best watersheds and streams through watershed stewardship, conservation easements, and other incentive programs; and
- Provide assessment information to help landowners and agencies better implement laws that require specific assessments such as the State Forest Practice Act, Clean Water Act, and State Lake and Streambed Alteration Agreements.

North Coast Salmon, Stream, and Watershed Issues

Pacific coast anadromous salmonids are dependent upon a high quality freshwater environment at the beginning and end of their life cycles. They thrive or perish during their freshwater phases depending upon the availability of cool, clean water, free access to migrate up and down their natal streams, clean gravel suitable for successful spawning, adequate food supply, and protective cover to escape predators and ambush prey. These life requirements must be provided by diverse and complex instream habitats as the fish move through their life cycles. If any life requirements are missing or in poor condition at the time a fish or stock requires it, fish survival can be impacted. These life requirement conditions can be identified and evaluated on a spatial and temporal basis at the stream reach and watershed levels. They comprise the factors that support or limit salmonid stock production.

The specific combination of these factors in each stream sets the carrying capacity for salmonids of that stream. The carrying capacity can be changed if one or more of the factors are altered. The importance of individual factors in setting the carrying capacity differs with the life stage of the fish and time of year. All of the important factors for salmonid health must be present in a suitable, though not always optimal, range in streams where fish live and reproduce (Bjorrn and Reiser 1991).

Two important watershed goals are the protection and maintenance of high quality fish habitats. In addition to preservation of high quality habitat, restoration of streams damaged by poor resource management practices of the past is important for anadromous salmonids. Science-based management has progressed significantly and “enough is now known about the habitat requirements of salmonids and about good management practices that further habitat degradation can be prevented, and habitat rehabilitation and enhancement programs can go forward successfully" (Meehan 1991).

Through the course of natural climatic events, hydrologic responses and erosion processes interact to shape freshwater salmonid habitats. The condition of near stream forests throughout a watershed strongly influences habitat structure, water temperature, and food resources of anadromous fish bearing streams. Stream channels interact with their parent watershed geology, morphology, and vegetation to form aquatic habitat in which the anadromous salmonids live.

These processes influence the kind and extent of a watershed's vegetative cover as well, and act to supply nutrients to the stream system. When there are no large disturbances, these natural processes continuously make small changes in a watershed. Managers must constantly judge these small natural changes as well as changes made by human activity. Habitat conditions can be drastically altered when major disruptions of these small interactions occur (Swanston 1991).

Major watershed disruptions can be caused by catastrophic events or created over time by multiple small natural or human disturbances. These disruptions can drastically alter instream habitat conditions and the aquatic communities that depend upon them for days, years, decades or longer. Thus, it is important to understand the critical, interdependent relationships of salmon and steelhead with their natal streams during their freshwater life phases, and their streams' dependency upon the watersheds within which they are nested, and the energy of the watershed processes that binds them together.

In general, natural disturbance regimes like landslides and wildfires do not impact larger basins like the Redwood Creek in their entirety at any given time. Rather, they normally rotate episodically across the entire basin as a mosaic composed of the smaller subbasin, watershed, or sub-watershed units over long periods. This creates a dynamic variety of habitat conditions and quality over the larger basin (Reice 1994).

The rotating nature of these relatively large, isolated events at the regional or basin scale assures streams in the area will be in suitable condition for salmonid stocks. A dramatic, large-scale example occurred in May 1980 in the Toutle River, Washington, which was inundated in slurry when Mt. St. Helens erupted. The river rapidly became unsuitable for fish. In response, returning salmon runs avoided the river that year and used other nearby suitable streams on an opportunistic basis, but returned to the Toutle two years later as conditions improved. This return occurred much sooner than had been initially expected (Quinn et al. 1991; Leider 1989).

Human disturbance sites, although they may be individually small in comparison to natural disturbance events, usually are spatially distributed widely across basin level watersheds (Reeves et al. 1995). For example, a rural road or building site is an extremely small land disturbance compared to a forty-acre landslide or wildfire covering several square miles. However, when all roads in a basin the size of Redwood Creek are looked at collectively, their disturbance effects are much more widely distributed than a single large, isolated landslide that has a high, but relatively localized impact to a single sub-watershed.

Human disturbance regimes collectively extend across basins and even regional scales and have lingering effects. Examples include water diversions, conversion of near stream areas to urban usage, removal of large mature vegetation, widespread soil disturbance leading to increased erosion rates, construction of levees or armored banks that can disconnect the stream from its floodplain, and the installation of dams and reservoirs that disrupt normal flow regimes and prevent free movement of salmonids and other fish. These disruptions often develop in concert and in an extremely short period on the natural, geologic time scale.

Human disturbances are often concentrated in time because of newly developed technology or market forces such as the California Gold Rush or the post-WWII logging boom in Northern California. The intense human land use of the last century, combined with the transport energy of two mid-century record floods on the North Coast, created stream habitat impacts at the basin and regional scales. The result of these recent combined disruptions has overlain the pre-European disturbance regime process and conditions.

Consequently, stream habitat quality and quantity are generally depressed across most of the North Coast region. It is within this widely impacted environment that both human and natural disturbances continue to occur, but with vastly fewer habitat refugia lifeboats than were historically available to salmon and steelhead.

Thus, a general reduction in salmonid stocks can at least partially be attributed to this impacted freshwater environment.

Although no historic fish counts exist for Redwood Creek, Department of Fish and Game fish ladder counts at Benbow Dam and Cape Horn Dam, in the Eel River system, reflect an over 80% decline in coho salmon, Chinook salmon, and steelhead trout populations over the span of the last century (Figure I- 2). The Eel River, especially the South Fork Eel River, which is the location of Benbow Dam, although larger than Redwood Creek, has similar basin conditions and land use history. Anecdotal evidence from anglers and longtime local residents supports the likelihood of a similar decline in Redwood Creek's anadromous fishery resources.

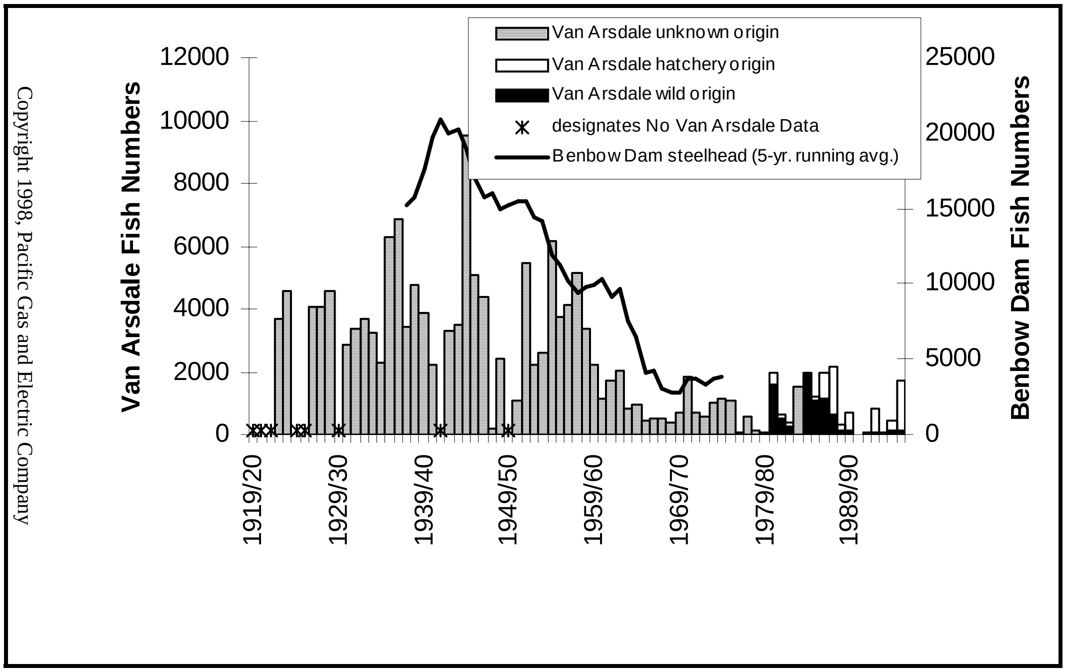

Figure I- 2. Five-year running average of salmonids at Benbow Dam, South Fork Eel River, and mainstem Eel River above Cape Horn Dam and historical steelhead trout ladder counts at Van Arsdale Fisheries Station, mainstem Eel River, and Benbow Dam, South Fork Eel River.

Free passage describes the absence of barriers to the free instream movement of adult and juvenile salmonids. Free movement in streams allows salmonids to find food, escape from high water temperatures, escape from predation, and migrate to and from their stream of origin as juveniles and adults. Temporary or permanent dams, poorly constructed road crossings, landslides, debris jams, or other natural and/or human-caused channel disturbances can disrupt or impede up or downstream fish passage.

Stream condition includes several factors: adequate stream flow, suitable water quality, suitable stream temperature, and diverse and complex habitat. For successful salmonid production, stream flows should follow the natural hydrologic regime of the basin. A natural regime minimizes the frequency and magnitude of storm flows and promotes better flows during dry periods of the water year. Salmonids evolved with the natural hydrograph of coastal watersheds, and changes to the timing, magnitude, and duration of low flows and storm flows can disrupt the ability of fish to follow life history cues.

Habitat diversity for salmonids is created by a combination of deep pools, riffles, and flatwater habitat types. Each of these stream habitats is used by anadromous salmonids during their freshwater residency. Often habitats are partitioned by a particular life stage or species. Pools, and to some degree flatwater habitats, provide escape cover from high velocity flows, hiding areas from predators, and ambush sites for taking prey. Pools and flatwaters are also important juvenile rearing areas, particularly for young coho salmon. They are also necessary for adult resting areas. Excessive levels of sediments fill pools and aggrades flatwater habitats. This reduces depths and can bury complex niches created by large substrate and woody debris. Riffles provide clean spawning gravels and oxygenate water as it tumbles across them. Salmonid fry use riffles and edge waters during rearing. Flatwater areas often provide spatially divided pocket water units that separate individual juveniles which helps promote reduced competition and successful foraging (Flosi et al. 1998).

Important aspects of water quality for anadromous salmonids are water temperature, turbidity, water chemistry, and sediment load. In general, suitable water temperatures for salmonids are between 48-56°F for successful spawning and incubation, and between 50-52°F and 60-64°F, depending on species, for growth and rearing. Additionally, cool water holds more oxygen, and salmonids require high levels of dissolved oxygen in all stages of their life cycle.

A second important aspect of water quality is turbidity. Fine suspended sediments (turbidity) affect nutrient levels in streams that in turn affect primary productivity of aquatic vegetation and insect life. This eventually reverberates through the food chain and affects salmonid food availability. Additionally, high levels of turbidity interfere with a juvenile salmonids' ability to feed and can lead to reduced growth rates and survival.

A third important aspect of water quality is stream sediment load. Salmonids cannot successfully reproduce when forced to spawn in streambeds with excessive silt, clays, and other fine sediment. Eggs and embryos suffocate under excessive fine sediment conditions because oxygenated water is prevented from passing through the egg nest, or redd. Additionally, high sediment loads can cap the redd and prevent emergent fry from escaping the gravel into the stream at the end of incubation. High sediment loads can also cause abrasions on fish gills, which may increase susceptibility to infection. At extreme levels, sediment can clog the gills causing death. Additionally, materials toxic to salmonids can cling to sediment and be transported through downstream areas.

A functional riparian zone helps to control the amount of sunlight reaching the stream, provides vegetative litter, and contributes invertebrates to the local salmonid diet. These contribute to the production of food for the aquatic community, including salmonids. Tree roots and other vegetative cover provide stream bank cohesion and buffer impacts from adjacent uplands. Near-stream vegetation eventually provides large woody debris and complexity to the stream (Flosi et al. 1998).

Riparian zone functions are important to anadromous salmonids for numerous reasons. Riparian vegetation helps keep stream temperatures in the range that is suitable for salmonids by maintaining cool stream temperatures in the summer and insulating streams from heat loss in the winter. Larval and adult macro-invertebrates are important to the salmonid diet and they are in turn dependent upon nutrient contributions from the riparian zone. Additionally, stream bank cohesion and maintenance of undercut banks provided by riparian zones in good condition maintains diverse salmonid habitat, and helps reduce bank failure and fine sediment yield to the stream. Lastly, the large woody debris provided by riparian zones shapes channel morphology, helps retain organic matter and provides essential cover for salmonids (Murphy and Meehan 1991).

Therefore, excessive natural or man-caused disturbances to the riparian zone, as well as directly to the stream and/or the basin itself can have serious impacts to the aquatic community, including anadromous salmonids. Generally, this seems to be the case in streams and watersheds in the North Coast of California. This is borne out by the recent decision to include many North Coast Chinook and coho salmon, and steelhead trout stocks on the Endangered Species Act list.

Disturbance and Recovery of Stream and Watershed Conditions

Natural and Human Disturbances

Intrinsic processes that shape streams and watersheds of the Redwood Creek Basin are numerous and complex. Streams and watersheds change through dynamic processes of disturbance and recovery (Madej 1999). In general, disturbance events alter a streams equilibrium or average conditions, while recovery occurs as stream conditions return towards equilibrium after disturbance events. Given the program's focus on anadromous salmonids, an important goal is to determine the degree to which current stream and watershed conditions in the region are providing salmonid habitat capable of supporting sustainable populations of anadromous salmonids. To do this, we must consider the habitat requirements for all life stages of salmonids. We must look at the disturbance history and recovery of stream systems, including riparian and upslope areas, which affect the streams through multiple biophysical processes.

Disturbance and recovery processes can be influenced by both natural and human events. A disturbance event such as sediment from a natural landslide can fill instream pools providing salmon habitat just as readily as sediment from a road failure. On the recovery side, natural processes (such as small stream-side landslides) that replace instream large woody debris washed out by a flood flow help to restore salmonid habitat, as does large woody debris placed in a stream by a landowner as a part of a restoration project.

Natural disturbance and recovery processes, at scales from small to very large, have been at work on North Coast watersheds since their formation millions of years ago. Recent major natural disturbance events have included large flood events such as occurred in 1955 and 1964 (Lisle 1981a) and 1974 (U.S. EPA 2001) ground shaking and related tectonic uplift associated with the 1992 Cape Mendocino earthquake (Carver et al. 1994).

Major human disturbances (e.g., post-European development, dam construction, agricultural and residential conversions, and the methods of timber harvesting practices used particularly before the implementation of the 1973 Z'Berg-Nejedly Forest Practice Act) have occurred over the past 150 years (Ice 2000). Salmonid habitat also was degraded during parts of the last century by well-intentioned but misguided restoration actions such as removing large woody debris from streams (Ice 1990). More recently, efforts at watershed restoration have been made, generally at the local level. For example, in California and the Pacific Northwest, minor dams from some streams have been removed to clear barriers to spawning and juvenile anadromous fish. For a thorough treatment of stream and watershed recovery processes, see the publication by the Federal Interagency Stream Restoration Working Group (FISRWG 1998).

Defining Recovery

There is general agreement that improvements in a condition or set of conditions constitute recovery. In that context, recovery is a process. One can determine a simple rate of recovery by the degree of improvement over some time period, and from only two points in time. And one can discuss recovery and rates of recovery in a general sense. However, a simple rate of recovery is not very useful until put into the context of its position on a scale to the endpoint of recovered.

In general, recovered fish habitat supports a stable fish population. Recovery not only implies, but necessitates, knowledge of an endpoint. In the case of a recovered watershed, the endpoint is a set of conditions deemed appropriate for a watershed with its processes in balance and able to withstand perturbations without large fluctuations in those processes and conditions. However, the endpoint of recovered for one condition or function may be on a different time and geographic scale than for another condition or function.

Some types and locations of stream recovery for salmonids can occur more readily than others or in succession stages. For example, in headwater areas where steeper source reaches predominate, suspended sediment such as that generated by a streamside landslide or a road fill failure may start clearing immediately, while coarser sediments carried as bedload tend to flush after a few years (Lisle 1981a; Madej and Ozaki 1996). On the other hand, excessive sediments inputs from the same source reaches may continue for decades adding to chronic turbidity and channel aggradation problems. Broadleaf riparian vegetation can return to create shading, stabilize banks, and improve fish habitat within a decade or so, but re-establishment of overstory canopy, LWD sources, and microclimate benefits provided by large conifers takes much longer. In areas lower in the watershed, where lower-gradient response reaches predominate, it can take several decades for deposited sediment to be transported out (Madej 1982; Koehler et al. 2001), for widened stream channels to narrow, for aggraded streambeds to return to pre-disturbance level, and for streambanks to fully revegetate and stabilize (Lisle 1981b). Lower reach streams will require a similar period for the near-stream trees to attain the girth needed for recruitment into the stream as large woody debris to help create adequate habitat complexity and shelter for fish, or for deep pools to be re-scoured in the larger mainstems (Lisle and Napolitano 1998).

Factors and Rates of Recovery

Over the past quarter-century, several changes have allowed the streams and aquatic ecosystems to move generally towards recovery. The rate of timber harvest on California's north coast has slowed during this period, with declining submissions of timber harvesting plans in many watersheds (THPs) and smaller average THPs (T. Spittler, personal communications). However, in some watersheds, the amount of acreage harvested has increased sharply since 1990 as timber stands mature into merchantable second-growth or third-growth timber.

Timber-harvesting practices have greatly improved over those of the post-war era, due to increased knowledge of forest ecosystem functions, changing public values, advances in road building and yarding techniques, and regulation changes such as mandated streamside buffers that limit equipment operations and removal of timber. Cafferata and Spittler (1998) found that almost all recent landslides occurring in an area logged in the early 1970s were related to legacy logging roads. In contrast, in a neighboring watershed logged in the late 1980s to early 1990s, landslides to date have occurred with about equal frequency in the logged areas as in unlogged areas. However a study of 358 landslides that occurred in the Redwood Creek basin during the 1997 storm season found the volume of sediment generated from landslides in logged areas has been much greater than from unlogged areas (Madej, U.S Geological Survey 2001, written communication.).

Further, most north coast streams have not recently experienced another large event on the scale of the 1964 flood. Therefore, we would expect most north coast streams to show signs of recovery (i.e., passive restoration [FISRWG 1998]). However, the rates and degrees of stream and watershed recovery will likely vary across a given watershed and among different north coast drainages.

In addition to the contributions made to recovery through better land management practices and natural recovery processes, increasing levels of stream and watershed restoration efforts are also contributing to recovery. Examples of these efforts include road upgrades and decommissioning, removal of road-related fish passage barriers, installation of instream fish habitat structures, etc. While little formal evaluation or quantification of the contributions of these efforts to recovery has been made, there is a general consensus that many of these efforts have made important contributions.

Continuing Challenges to Recovery

Given improvements in timber harvesting practices in the last 30 years, the time elapsed since the last major flood event, and the implementation of stream and watershed restoration projects, it is not surprising that many north coast streams show indications of trends towards recovery. Ongoing challenges associated with past activities that are slowing this trend include:

- Chronic sediment delivery from legacy (pre-1975) roads due to inadequate crossing design, construction and maintenance (California State Board of Forestry, Monitoring Study Group 1999) skid trails and landings (Cafferata and Spittler 1998);
- A lack of improvements in stream habitat diversity and complexity, largely from a dearth of large woody debris needed for channel maintenance and development, and successful fish rearing;
- The continuing aggradation of sediments in low-gradient reaches that first deposited as the result of activities and flooding in past decades (Koehler et al. 2001).

Increasing subdivision on several north coast watersheds raises concerns about new stream and watershed disturbances. Private road systems associated with rural development have historically been built and maintained in a fashion that does little to mitigate risks of chronic and catastrophic sediment inputs to streams. While more north coast counties are adopting grading ordinances that will help with this problem, there is a significant legacy of older residential roads that pose an ongoing risk for sediment inputs to streams. Other issues appropriate to north coast streams include potential failures of roads during catastrophic events, erosion from house pads and impermeable surfaces, removal of water from streams for domestic uses, effluent leakages, and the potential for deliberate dumping of toxic chemicals used in illicit drug labs.

Some areas of the North Coast have seen rapidly increasing agricultural activity, particularly conversion of grasslands or woodlands to grapes. Such agricultural activities have typically been subject to little agency review or regulation and can pose significant risk of chronic sediment, chemical, and nutrient inputs to streams.

Associated with development and increased agriculture, some north coast river systems are seeing increasing withdrawal of water, both directly from stream and groundwater sources connected to streams, for human uses. Water withdrawals pose a chronic disturbance to streams and aquatic habitat. Such withdrawals can result in lowered summer stream flows that impede the movement of salmonids and reduce important habitat elements such as pools. Further, the withdrawals can contribute to elevated stream water temperatures that are harmful to salmonids.

Key questions for landowners, agencies, and other stakeholders revolve around whether the trends toward stream recovery will continue at their current rates, and whether those rates will be adequate to allow salmonids to recover their populations in an acceptable time frame. Clearly, the potential exists for new impacts from both human activities and natural disturbance processes to compromise recovery rates to a degree that threatens future salmonid recovery. To predict those cumulative effects will likely require additional site-specific information on sediment generation and delivery rates and additional risk analyses of other major disturbances. Also, our discussion here does not address marine influences on anadromous salmonid populations. While these important influences are outside of the scope of this program, we recognize their importance for sustainable salmonid populations and acknowledge that good quality freshwater habitat alone is not adequate to ensure sustainability.

Policies, Acts, and Listings

Several federal and state statutes have significant implications for watersheds, streams, fisheries, and their management. Here, we present only a brief listing and description of some of the laws.

Federal Statutes

One of the most fundamental of federal environmental statutes is the **National Environmental Policy Act (NEPA)**. NEPA is essentially an environmental impact assessment and disclosure law. Projects contemplated or plans prepared by federal agencies or funded by them must have an environmental assessment completed and released for public review and comment, including the consideration of more than one alternative. The law does not require that the least impacting alternative be chosen, only that the impacts be disclosed.

The federal **Clean Water Act** has a number of sections relevant for watersheds and water quality. Section 208 deals with non-point source pollutants arising from silvicultural activities, including cumulative impacts. Section 303 deals with water bodies that are impaired to the extent that their water quality is not suitable for the beneficial uses identified for those waters. For water bodies identified as impaired, the US Environmental Protection Agency (US EPA) or its state counterpart (locally, the North Coast Regional Water Quality Control Board and the State Water Resources Control Board) must set targets for Total Maximum Daily Loads (TMDLs) of the pollutants that are causing the impairment. Section 404 deals with the alterations of wetlands and streams through filling or other modifications, and requires the issuance of federal permits for most such activities.

The federal **Endangered Species Act (ESA)** addresses the protection of animal species whose populations have declined to critically low levels. Two levels of species risk are defined. A threatened species is any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. An endangered species is any species that is in danger of extinction throughout all or a significant portion of its range. In general, the law forbids the take of listed species. Taking is defined as harassing, harming, pursuing, hunting, shooting, wounding, killing, trapping, capturing, or collecting a species or attempting to engage in any such conduct. A take of a species listed as threatened may be allowed where specially permitted through the completion and approval of a Habitat Conservation Plan (HCP). An HCP is a document that describes how an agency or landowner will manage their activities to reduce effects on vulnerable species. An HCP discusses the applicant's proposed activities and describes the steps that will be taken to avoid, minimize, or mitigate the take of species that are covered by the plan. Many of California’s salmon runs are listed under the ESA, including the Chinook and coho salmon and steelhead found in the Redwood Creek Basin.

State Statutes

The state analogue of NEPA is the **California Environmental Quality Act (CEQA)**. CEQA goes beyond NEPA in that it requires the project or plan proponent to select for implementation the least environmentally impacting alternative considered. When the least impacting alternative would still cause significant adverse environmental impacts, a statement of overriding considerations must be prepared.

The **Porter-Cologne Water Quality Control Act** establishes state water quality law and defines how the state will implement the federal authorities that have been delegated to it by the US EPA under the federal Clean Water Act. For example, the US EPA has delegated to the state certain authorities and responsibilities to implement TMDLs for impaired water bodies and NPDES (national pollution discharge elimination system) permits to point-source dischargers to water bodies.

Sections 1600 et seq. of the Fish and Game Code are implemented by the Department of Fish and Game. These agreements are required for any activities that alter the beds or banks of streams or lakes. A 1600 agreement typically would be involved in a road project where a stream crossing was constructed. While treated as ministerial in the past, the courts have more recently indicated that these agreements constitute discretionary permits and thus must be accompanied by an environmental impact review per CEQA.

The **California Endangered Species Act (CESA)**. The California Endangered Species Act (Fish & Game Code §§ 2050, et seq.) generally parallels the main provisions of the Federal Endangered Species Act and is administered by the California Department of Fish and Game (CDFG). Coho salmon in the Redwood Creek Basin are listed as threatened under CESA.

The **Z'Berg-Nejedly Forest Practice Act (FPA)** and associated **Forest Practice Rules** establish extensive permitting, review, and management practice requirements for commercial timber harvesting. Evolving in part in response to water quality protection requirements established by the 1972 amendments to the federal Clean Water Act, the FPA and Rules provide for significant measures to protect watersheds, watershed function, water quality, and fishery habitat.

Assessment Strategy and General Methods

In 2003, the NCWAP released a Methods Manual that identified a general approach to conducting a watershed assessment, described or referenced methods for collecting and developing new watershed data, and provided a preliminary explanation of analytical methods for integrating interdisciplinary data to assess watershed conditions.

This chapter provides brief descriptions of data collection and analysis methods used by each of the program's participating departments, and an introduction to methods for analyzing data across departments and disciplines. While the information contained in the report is extensive, more detail is included in a set of appendices to this report from the following disciplines:

- California Department of Forestry
- Ecological Management Decision Support
- North Coast Regional Water Quality Control Board
- California Department of Fish and Game
- California Geologic Survey

The reader is referred to these appendices for more detail on methods, data analysis, and interpretation.

Basin Assessment Approach

The steps in the large-scale assessment included:

Form multi-disciplinary team. In order to assess watershed conditions and processes, several specialists were needed and included: geologists, fluvial geomorphologists, foresters, water quality biologists, fisheries biologists, watershed habitat specialists, and planners;

Conduct scoping and outreach workshops. Landowner involvement was an important component in the assessment process. The Redwood Creek Assessment Team conducted two public meetings, starting with initial scoping and continuing through the public review of a draft report. These meetings included landowners, local agencies, local environmental groups, industry groups, watershed councils, and other interested parties;

During report preparation, the NCWAP team met and discussed issues with local experts from the Redwood Creek Land Owners Association (RNSP and Simpson, Barnum, and Sierra Pacific timber companies, and others). The public meetings and discussions were helpful to address the public's concerns, collecting data, and to gain insight into local watershed processes;

Determine logical assessment scales. The Redwood Creek assessment team used the California Watershed Map (CalWater version 2.2a) to delineate the Redwood Creek Basin into five subbasins (Estuary, Prairie Creek, Lower Redwood Creek, Middle Redwood Creek, and Upper Redwood Creek subbasins) for assessment and analyses purposes;

Collect and organize existing data and information according to discipline. The Redwood Creek basin is one of the most studied coastal watershed ecosystems in California. Numerous journal articles, technical reports and field studies of the basin's geology, fluvial geomorphology, hydrology, water quality and fishery resources have been produced by the U.S Geologic Survey, RNSP scientists, state resource agencies, private consultants, timber companies and HSU students. The NCWAP team performed an intensive search through the existing literature sources for information that would help describe past and present conditions throughout the basin. The vast amount of information provided by the literature reviews was both a virtue and overwhelming at times. Therefore two bibliographic lists are provided, a literature cited list and an additional reference literature list;

Identify data gaps needed to develop the assessment. Working with limited time and resources constrained the amount of fieldwork that was performed;

<u>Collect field data.</u> Over 50 miles of new stream data and numerous fishery surveys were performed for the assessment of the Redwood Creek basin. Water Quality data were analyzed from several locations in the basin that were provided for this assessment by private and agency cooperators;

<u>Amass and analyze information.</u> Each agency assembled, interpreted, and summarized data to create various specific reports for inclusion into the Assessment Report. Each agency's reports were also included in the Redwood Creek Basin appendices;

<u>Construct Integrated Analysis Tables (IA).</u> Through the synthesis of multidisciplinary studies and the use of IA Tables, the information from the various disciplines were integrated to help identify cumulative effects to watershed conditions and root causes to adverse changes to stream habitats.

<u>Conduct limiting factors analysis (LFA).</u> The Ecological Management Decision Support system (EMDS) was used, along with expert analysis and local input, to evaluate environmental factors at the tributary scale. These factors were rated to be either beneficial or restrictive to the well being of fisheries. The CDFG Restoration Manual (Flosi et al. 1998), and other literature, provided habitat condition values to help set EMDS reference curves;

<u>Conduct refugia rating analysis.</u> The assessment team created worksheets for rating refugia at the tributary scale. The worksheets have multiple condition factors rated on a sliding scale from high to low quality. Tributary ratings were determined by combining the results of air photo analyses, EMDS, Water Quality data, data in the CDFG tributary reports, and by a multi-disciplinary team of expert analysts. Ratings of various factors were combined to determine an overall refugia ratings on a scale from high to low quality. The tributary ratings were subsequently aggregated at the subbasin scale and expressed as a general estimate of subbasin refugia conditions. Factors with limited or missing data are noted and discussed in the comments section as needed. In most cases, there are data limitations on one to three factors. A discussion of the rating system is located at the end of this summary;

<u>Develop conclusions and recommendations.</u> Recommendation tables for watershed and stream improvement activities were developed at the tributary scale based upon stream inventory information, air photo analysis, field verification samples, workshop inputs, and other information. The recommendation tables are presented at the end of each Profile chapter as answers to the sixth assessment guiding question;

<u>Facilitate monitoring of conditions.</u> CDFG is developing a monitoring program and will facilitate it in the Redwood Creek and other assessed watersheds.

Guiding Assessment Questions and Responses

The NCWAP assessment team developed lists of questions that they considered important to understanding and implementing watershed assessments. From those lists, a short list of guiding assessment questions evolved and was adopted to provide focus for the assessments and subsequent analyses, conclusions, and recommendations.

- What are the history and trends of the sizes, distribution, and relative health and diversity of salmonid populations within this?
- What are the current salmonid habitat conditions in this subbasin? How do these conditions compare to desired conditions?
- What are the impacts of geologic, vegetative, fluvial, and other natural processes on watershed and stream conditions?
- How has land use affected these natural processes?
- Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?
- What habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

These six questions focus the assessment procedures and data gathering within the individual disciplines and also provide direction for those areas of analyses that require more interagency, interdisciplinary syntheses, including the analysis of factors limiting anadromous salmonid production. The questions systematically progress from the relative status of the salmon and steelhead resource, to the focus of the assessment effort, and lastly to the watershed components encountered directly by the fish—flow, water quality, nutrients, and instream habitat elements, including free passage at all life stages. The products delivered to streams by watershed processes and the influence of human activities on those processes shape these habitat elements. The watershed processes and human influences determine what factors might be limiting fishery production and what can be done to make improvements for the streams and fish.

The first two assessment questions point out the importance of salmonid population information for validating the assessment and predicting habitat conditions. In many watersheds, robust population data may not be available, implying a need for future monitoring efforts. In some watersheds, a need for additional physical habitat sampling may be indicated.

The third and fourth assessment questions consider the past and present conditions of the watersheds and their natural and man-caused watershed processes. The answers to these questions provide us with insights into the future of assessed watersheds and streams, and the feasibility of different management techniques for salmon and steelhead in each watershed.

The last two assessment questions consider factors directly encountered by fish that could be limiting salmonid production. These questions seek to identify opportunities and locations for prudent management practices and pro-active salmonid habitat improvement activities.

These six guiding assessment questions are presented and answered in the overall basin section and in each of the subbasin sections of the assessment report. They are also considered in the CDFG Refugia Rating process at the subbasin and tributary scales. The responses become more specific as the assessment focuses from the course to the finer scales.

Report Utility and Usage

This report is intended to be useful to landowners, watershed groups, agencies, and individuals to help guide restoration, land use, and management decisions. As noted above, the assessment operates on multiple scales ranging from the detailed and specific stream reach level to the very general basin level. Therefore, findings and recommendations also vary in specificity from being particular at the finer scales, and general at the basin scale.

A goal of this program is to help guide, and therefore accelerate the recovery process, by focusing stewardship and improvement activities where they will be most effective. Scaling down through finer levels guided by the recommendations should help accomplish this focus.

To do so, the report is constructed to help provide guidance for that focus of effort. A user can scale down from the general basin finding and recommendation concerning high sediment levels, for example, to the subbasin sections, to the stream reach level information to determine which streams in the subbasin may be most affected by sediment.

There is a list of surveyed streams in each subbasin section. In the general recommendation section, a tributary finding and recommendation summary table indicates the findings and recommendations for the surveyed streams within the subbasin. If indicated, field investigations at the stream reach or project site level can be conducted to make an informed decision on a land use project, or to design improvement activities.

Program Products

The program will produce and make available to the public a set of products for each basin assessed.

These products include:

- A basin level Synthesis Report that includes:
    - Collection of Redwood Creek Basin historical information;

- Description of historic and current vegetation cover and change, land use, geology and, water quality, stream flow, water use, and instream habitat conditions;
- List of issues developed by agency team members and constituents;
- An interdisciplinary analysis of the suitability of stream reaches and the watershed for salmonid production and refugia areas;
- Tributary and watershed recommendations for management, refugia protection, and restoration activities to address limiting factors and improve conditions for salmonid productivity;
- Monitoring recommendations to improve the adaptive management efforts.

- Ecological Management Decision Support system (EMDS) models to help analyze data;
- Databases of information used and collected;
- A data catalogue and bibliography;
- Web based access to the Program's products: http://ncwatershed.ca.gov/, and http://imaps.CDFG.ca.gov/, and ArcIMS site.

Assessment Report Conventions

Subbasin Scale

The complexity of large basins makes it difficult to speak about them concerning watershed assessment and recommendation issues in other than very general terms. In order to be more specific and useful to planners, managers, and landowners, it is useful to subdivide the larger basin into smaller subbasin units whose size is determined by the commonality of many of the distinguishing traits. Variation in subbasins is a product of natural and human factors. Variables that can distinguish subbasins include differences in elevation, geology, soil types, aspect orientation, climate, vegetation, fauna, human population, land use, and other social-economic considerations.

For the purpose of the NCWAP study of Redwood Creek, the basin is divided into five subbasins (Figure II- 1). The five subbasins in Redwood Creek were designated based on geography, historical classification by Redwood National and State Park (RNSP), geology, climate patterns, and land use. They conform to CalWater 2.2 Planning Watershed boundaries when possible and 22 planning watersheds as defined by the CalWater 2.2 system. The Estuary Subbasin contains the area downstream of the confluence of Redwood and Prairie Creeks. Predominant features of the subbasin include the estuary, pasture lands, and the town of Orick.

CalWater 2.2a Planning Watersheds

The California Watershed Map (CalWater Version 2.2a) is used to delineate planning watershed units (Figure II-1). This hierarchy of watershed designations consists of six levels of increasing specificity: Hydrologic Region, Hydrologic Unit, Hydrologic Area, Hydrologic Sub-Area, Super Planning Watershed, and Planning Watershed (PW). CalWater version 2.2a is the third version of CalWater (after versions 1.2 and 2.0) and is a descendent of the 1:500,000-scale State Water Resources Control Board Basin Plan Maps drawn in the late 1970s.

The PW level of specificity is used in many analyses. PWs generally range from 3,000-10,000 acres in size and each PW consists of a specific watershed polygon, which is assigned a single unique code. The program used PWs for mapping, reporting, EMDS, and statistical analysis of geology, vegetation, land use, and fluvial geomorphology.

An important aspect of CalWater 2.2a PWs is that individual PWs often do not represent true watersheds. In other words, PWs often cut across streams and ridgelines and do not cover the true catchment of a stream or stream system. Streams, such as the mainstem Redwood Creek can flow through multiple PWs. In addition, a stream may serve as a border between two CalWater 2.2a PWs. This disconnect with hydrologic stream drainage systems is an artifact of the creation of CalWater 2.2a as a tool for managing forest lands in fairly consistent sized units.

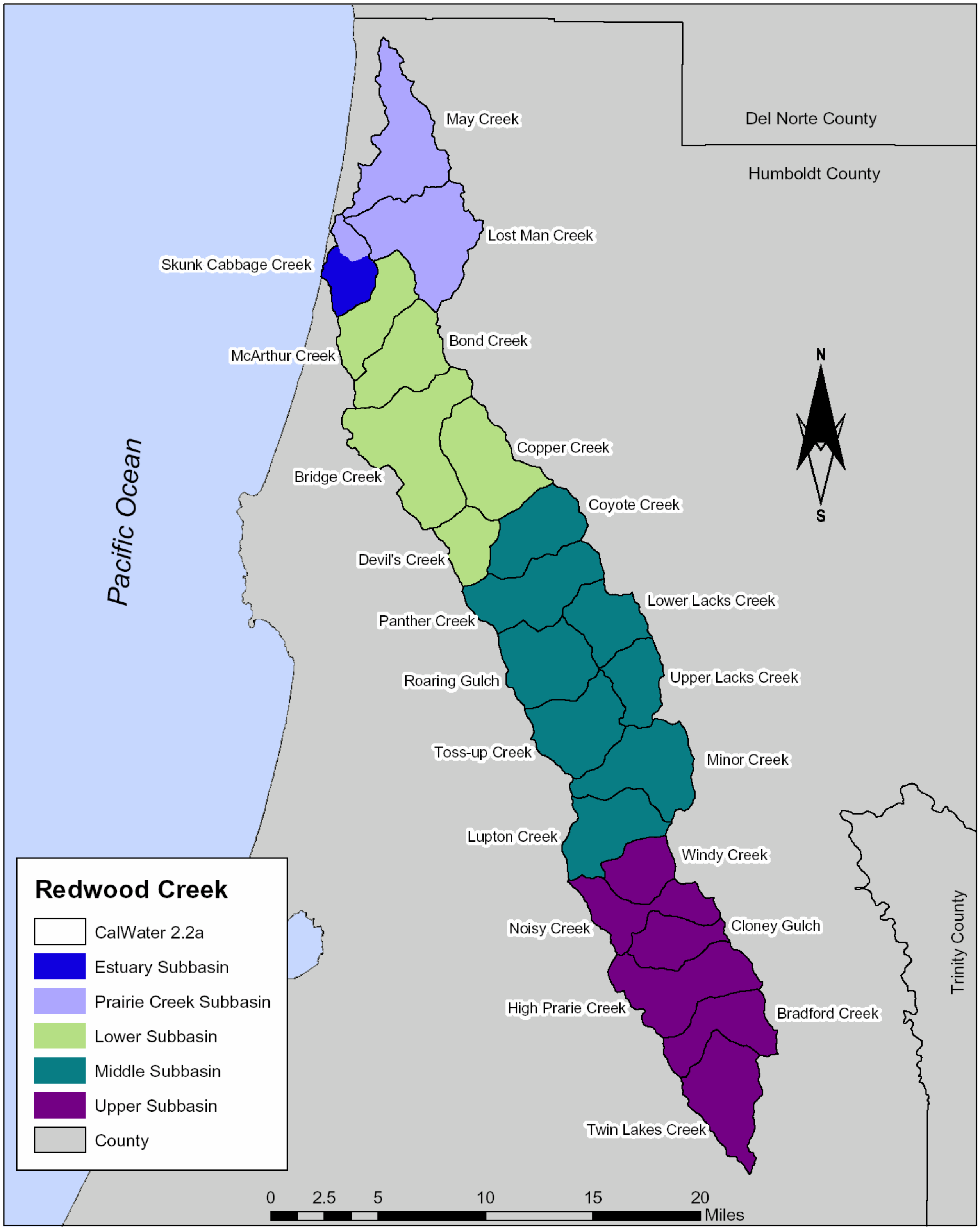

Figure II- 1. Redwood Creek Subbasins and Planning Watersheds.

Hydrology Hierarchy

Watershed terminology often becomes confusing when discussing different scales of watersheds involved in planning and assessment activities. The conventions used in the Redwood Creek Basin assessment follow guidelines established by the Pacific Rivers Council. The descending order of scale is from *basin* level (e.g., Redwood Creek Basin)—*subbasin* level (e.g., Lower Subbasin)—*watershed* level (e.g., Prairie Creek—*sub-watershed* level (e.g., Lost Man Creek).

The subbasin is the assessment and planning scale used in this report as a summary framework; subbasin findings and recommendations are based upon the more specific watershed and sub-watershed level findings. Therefore, there are usually exceptions at the finer scales to subbasin findings and recommendations. Thus, findings and recommendations at the subbasin level are somewhat more generalized than at the watershed and sub-watershed scales. In like manner, subbasin findings and recommendations are somewhat more specific than the even more generalized, larger scale basin level findings and recommendations that are based upon a group of subbasins.

The term watershed is used in both the generic sense, as to describe watershed conditions at any scale and as a particular term to describe the watershed scale introduced above, which contains, and is made up from multiple, smaller sub-watersheds. The watershed scale is often approximately 20-40 square miles in area; its sub-watersheds can be much smaller in area, but for our purposes contain at least one perennial, un-branched stream. Please be aware of this multiple usage of the term watershed, and consider the context of the term's usage to reduce confusion.

Another important watershed term is river mile (RM). River mile refers to a point that is a specific number of miles upstream from the mouth of a river. In this report, RM is used to locate points along Redwood Creek or tributary streams.

Electronic Data Conventions

The program collected or created hundreds of data records for synthesis and analysis purposes and most of these data were either created in a spatial context or converted to a spatial format. Effective use of these data between the four remaining partner departments required establishing standards for data format, storage, management and dissemination. Early in the assessment process, we held a series of meetings designed to gain consensus on a common format for the often widely disparate data systems within each department. Our objective was to establish standards which could be used easily by each department, that were most useful and powerful for selected analysis, and would be most compatible with standards used by potential private and public sector stakeholders.

As a result, we agreed that spatial data used in the program and base information disseminated to the public through the program would be in the following format (see the data catalog at the end of this report for a complete description of data sources and scale):

Data form: standard database format usually associated with a Geographic Information System (GIS) shapefile or coverage (Environmental System Research Institute, Inc.© [ESRI]). Data were organized by watershed and distributed among watershed synthesis teams. Electronic images were retained in their current format.

Spatial Data Projection: spatial data were projected from their native format to Teale Albers, North American Datum (NAD) 1927 and Universal Transverse Mercator (UTM), Zone 10, NAD 1983. Both formats were used in data analysis and synthesis.

Scale: most data were created and analyzed at 1:24,000 scale to (1) match the minimum analysis scale for planning watersheds, and (2) coincide with base information (e.g., stream networks) on USGS quadrangle maps (used as Digital Raster Graphics [DRG]).

Data Sources: data were obtained from a variety of sources including spatial data libraries with partner departments or were created by manually digitizing from 1:24,000 DRG.

Spatial data sets that formed the foundation of most analysis included the 1:24,000 hydrography and the 10 meter scale Digital Elevation Models (DEM). Hydrography data were created by manually digitizing from a series of 1:24,000 DRG then attributing with direction, routing, and distance information using a dynamic segmentation process (for more information, please see http://arconline.esri.com/arconline/whitepapers/ao/ArcGIS8.1.pdf). The resulting routed hydrography allowed for precise alignment and display of stream habitat data and other information along the stream network. The DEM was created from base contour data obtained from the USGS for the entire study region.

Source spatial data were often clipped to watershed, planning watershed, and subbasin units prior to use in analysis. Analysis often included creation of summary tables, tabulating areas, intersecting data based on selected attributes, or creation of derivative data based on analytical criteria. For more information regarding the approach to analysis and basis for selected analytical methods, see Chapter 2, Assessment Strategy and General Methods, and Chapter 4, Interdisciplinary Synthesis and Findings.

Methods by Department

This section provides methods used for this report. Additional information on methods may be found in the NCWAP Methods Manual posted at the NCWAP web site (ncwatershed.ca.gov).

Geology and Fluvial Geomorphology

CGS developed the paper and digital geologic maps that accompany this report using a variety of information. Redwood National Park (RNSP) converted earlier mapping at a scale of 1:62,500 by Harden and others (1982) into a digital product for their in-house use in 2001. RNP finalized the map in late 2001 for use in this program. CGS converted additional unpublished mapping for the Prairie Creek portion of the watershed by Kelsey (written communication, 2001) into digital coverages. CGS merged most of the bedrock geology, faults, and other structural information from these sources to create a continuous geologic base map for the entire watershed. It should be noted that although the bedrock geology presented in this map series is at a scale of 1:24,000, the detail and accuracy is limited to the resolution of the original products. CGS performed very limited field checking of the final product because of time constraints.

The original mapped landslides, alluvium, and river terrace deposits were deleted or modified and replaced with more detailed landslide and fluvial coverages developed during this study. CGS geologists based the new coverages on detailed aerial photograph interpretation using historical aerial photographs dating back to 1947. Please refer to the CGS appendix report for detailed information regarding the specific coverages. In addition to the paper map products presented with this report, the GIS database is available as ArcInfo coverages through both NCWAP (www.ncwatershed.ca.gov) and CGS. Separate and multiple GIS layers were created for the geologic, landslide-related and fluvial geomorphic assessments. Each feature recorded in the landslide and fluvial layers was assigned numerous attributes, based on a pre-established method of assessment. Please refer to the CGS Appendix E plates 1 through 3 entitled Geologic and Geomorphic Features Related to Landsliding and report text for detailed information regarding the specific coverages.

CGS evaluated mass wasting in all modes of movement as a function of geologic unit and slope inclination when the final maps were completed. The analysis was performed to show the typical slope within mapped landslides in most of the units in the watershed because of time constraints. Geologic units appearing to have similar characteristics based on aerial photograph interpretation were grouped together for clarity. The data sets consisted of the mapped landslides, bedrock geology, and the 10-meter digital elevation model (DEM) for the watershed. These evaluations provide a means of generally assessing the relative rock strength and texture of individual units in the absence of formal geotechnical data. Data from this analysis contributed to the ranking of bedrock units during the development of our relative stability map.

The Relative Stability Map used a decision matrix developed and fine-tuned by CGS geologists familiar with the study area. The bedrock and landslide units were merged with a digital grid coverage for the entire watershed. The relative stability of individual cells was determined based on bedrock unit (see Figure III-8), landslide type and activity, and other geomorphic features as a function of slope depending on their location. The higher ranking was used on the map when a cell received two potential values (e.g.: a bedrock ranking and landslide ranking). CGS converted the grid coverage of relative landslide potential into a polygon coverage and generated the final relative stability maps (Plates 4 through 6, Relative Landslide Potential with Geologic and Geomorphic Features, CGS appendix) at a scale of 1:24,000 to match that of the Geologic and Geomorphic Features Map.

Fluvial methods

We created maps of the fluvial geomorphology for all streams in the Redwood Creek watershed designated by blue lines on published USGS 1:24,000-scale topographic quadrangle maps. Some additional watercourses were also mapped if they could be observed at the photo scale. We mapped fluvial features from 1:31,680-scale aerial photographs taken during 1984 and 1:24,000-scale photos taken during 2000. The 1984 photos provided a view of the watershed after a particularly wet water year, while the 2000 photos provided "existing" conditions. In 1983, annual runoff at Orick was 1,191,000 acre feet and annual runoff at Highway 299 - O'Kane (Blue Lake) was 284,900 acre feet, both of which were exceptionally high rates (See Appendix G, Department of Water Resources Report, this report). The air photos taken in 2000 were the most recent photos available.

We developed criteria to distinguish channel-disturbance features from natural sediment channel storage for reconnaissance study using small-scale aerial photographs. Features indicating channel disturbance include lateral, mid-channel, transverse and junction bars, wide and braided channels, aggrading and degrading reaches, tributary fans and eroding banks and exclude more stable features such as point bars and vegetated bars.

Every fluvial Mylar layer for each quadrangle and interpretation year was digitally scanned at a resolution of 400 dpi (dots-per-inch) or finer following compilation. Scanned mylars were then geo-referenced to the UTM-Zone 10, NAD 83 projection so that they could be digitized on the computer screen. Geo-referenced images were converted to ArcView grid files to allow for the background to be made transparent. On-screen digitizing was done by each project geologist or GIS specialists using ArcView 3.2 or ArcInfo 8.1 software. Digitized features were attributed (the database table, called a *.dbf file) was filled with information by the project geologist using ArcView 3.2 software and an ArcView Avenue extension created by CGS GIS staff specifically for NCWAP fluvial and landslide data entry. Final digital map products were produced both as ArcView shape files and ArcInfo coverages.

The design of the databases attached to the stream features layers were identical except that the planimetric unit field types differed by feature type (polygon, line, or point). The geologist could enter a primary channel characteristic attribute and as many as three additional secondary attributes for each mapped stream feature. Stream characteristic attributes were selected from a checklist of 32 channel features. Some of these features are indicative of channel instability (e.g., eroding banks), sediment storage (e.g., mid-channel bars) and other general channel attributes such as presence of pools or riffles. Channel characteristics were entered in order of importance. The primary characteristic field was used by the NCWAP Watershed EMDS to identify whether the feature represented channel instability or elevated sediment storage.

Following development of the ArcView shape files, the alluvial layer was used along with the geology and landslide layers to make maps the maps as follows: Plate 1, Sheets 1-3, Watershed Mapping Series, Map of Redwood Creek Watershed, Humboldt County, Geologic and Geomorphic Features Related to Landsliding and Plate 2, Sheets 1-3, Watershed Mapping Series, Map of Redwood Creek Watershed, Humboldt County, Relative Landslide Potential with Geologic and Geomorphic Features. The fluvial layers were analyzed in ArcView GIS with geology layers to evaluate relationships between landslides and negative stream characteristics and to estimate changes in channel characteristics between 1984 and the present. The alluvial contacts overlay was utilized in both the geology map and the landslide potential map, replacing previous alluvial contacts taken from the literature. The alluvial contact was mapped with input from Redwood National and State Parks (RNSP). However, alluvial contacts were terminated in channels where the alluvial valley width was less than 100 ft because of map scale constraints.

While mapping fluvial features from 1984 and 2000 aerial photographs, our fluvial staff mapped streamside landslides. We compiled these into a spatial database as points, without regard to the size and analyzed the number of small active landslides per acre and pre stream length. Results were compared between planning watersheds as described below.

We carried out a broad-level description of major stream types based on the Rosgen method of stream classification (Rosgen, 1996). This method provides a general physical characterization of stream channels for coarse assessment of the watershed. Stream gradients were generated from USGS topographic data. We assigned Rosgen channel types based on stream gradient and study of aerial photographs.

CDFG field crews trained in Rosgen techniques measured cross sections in Redwood Creek and some of its tributaries in 2001 for habitat typing surveys. The field crews identified channel type and measured channel cross sections at appropriate locations in the channel. They measured bankfull width by stretching a level tape from one bank to the other, perpendicular to the stream. Bankfull level was identified from changes in substrate composition, bank slope and perennial vegetation—all caused by frequent scouring events. The crews measured cross sections along a taut horizontal tapeline, starting at an assumed bankfull point and recording bankfull depth from the surface of the substrate to the level of the tape at 10 equally spaced stations to the bankfull point on the opposite bank. CDFG field crews measured channel gradients along steeper sections where channels appeared to be Rosgen types A or A+.

Hydrology

The role of the Department of Water Resources (DWR) in the NCWAP is to provide new stream flow data, compile historic stream flow data, and assist in compiling water rights information. Historical stream flow and water rights data are compiled from existing DWR, State Water Resources Board, and US Geological Survey information. Current water rights information is compiled from DWR and State Water Resources Board files.

A search of the SWRCBs Water Right Information System (WRIMS) was performed to determine the number and types of water rights within the Redwood Creek watershed. The WRIMS database is under development and may not contain all post-1914 appropriative water right applications that are on file with the SWRCB at this time. Some pre-1914 and riparian water rights are also contained in the WRIMS database for those water rights whose users have filed a "Statement of Water Diversion and Use." A location map of the point of diversion is shown in Section III, Figure III-7.

Vegetation and Land Use

The California Department of Forestry and Fire Protection (CDF) performed analysis of vegetation, land use and fire hazard assessment.

Analysis of vegetation in the Redwood basin was performed with use of the California Land Cover Mapping and Monitoring Program which can be viewed at http://www.frap.cdf.ca.gov/projects/land_cover/index.html. Stream buffer analysis was conducted to assess the amount of vegetation cover found along the watercourses within Redwood Creek as a whole. The data used for this analysis were the vegetation data, discussed above, plus a 1:24,000 stream coverage developed by CDF from the USGS digital line graphs. Three different zones based upon different buffer widths were assessed. First a 50-foot buffer (i.e., going out 50 feet from each side of the stream) was used to assess what the minimum conditions may be based on the old Forest Practice Rules. The second buffer width used was a 150-foot zone to represent the current Forest Practice Rules for the protection of a fish-bearing stream. The final zone was a 90-meter (300 feet) buffer based upon the approach taken in the Northwest Forest Plan.

Additional vegetation assessment was completed for the stream reach information collected by the Department of Fish and Game. Digital vegetation information was utilized to determine the area and vegetation type, size class, and canopy density for the 66 separate fish bearing stream reaches (located mostly in the Middle Subbasin) surveyed by CDFG (Table II-19). A buffer zone of 150 feet along each side of the stream reach was developed to determine specific vegetation information. The 150-foot buffer zone was used because it corresponds to the required watercourse and lake protection zones (WLPZ) outlined in the current Forest Practice Rules. This buffer width would closely resemble the buffer width required for fish bearing streams under the current Forest Practice Rules. The vegetation information was obtained from the CALVEG types. The minimum mapping size is 2.5 acres for contrasting vegetation types. The vegetation layers were then "clipped" to the GIS shape files for the stream reach assessment. Acres of cover type, percent canopy closure, and tree diameter class were then calculated utilizing ArcView GIS.

Assessment of timber harvesting history was completed with the use of aerial photographs. Various photo flights from different available years were employed. Starting with the year 1942, which was the earliest flight readily available, photo flights for 1942, 1948, 1952, 1954, 1958, 1964 and 1977 were utilized to determine past harvest areas. For the decades of the 1980s and 1990s actual timber harvest plans were utilized along with satellite multi-spectral scanned image data (MSS). This MSS data was used to indicate changes in the vegetation and not just timber harvesting.

In order to assess fire hazard in Redwood Creek and its potential threats to salmonid habitat, CDF used data and approaches developed as part of the CDF Fire Plan that can be found at (http://www.fire.ca.gov/FireEmergencyResponse/FirePlan/FirePlan.asp). "Fire hazard" refers to the degree of flammability of the fuels once a fire starts, including the fuel (type, arrangement, volume, and condition), topography and weather. Fire hazard was assessed using data that predict potential fire behavior of the flaming front (i.e., rate of spread, flame length, tree torching, etc.) under typical severe fire weather.

Specifically, this process involves mapping fuel conditions and slope features, applying a standardized fuel moisture and wind profile to predict surface fire behavior, then ranking the resultant behavior index into moderate, high, and very high categories. For forested areas, these surface fuel rankings were then subjected to an additional assessment of ladder fuel (fuels that are relatively continuous vertically from the ground surface upwards so as to facilitate the movement of surface fire up into the tree canopy) and crown fuel characteristics where the surface fuel ranking did not fully capture the expected fire hazard present (i.e., where aerial fuel structure would likely lead to torching of trees and crown fire). Areas not supporting wildland vegetation and unlikely to sustain fire (e.g., agricultural areas) were classified as "not mapped." A detailed discussion of the methodology for ranking fuels can be found on the Internet at http://frap.cdf.ca.gov/data/fire_data/fuel_rank/index.html.

A moderate fuel ranking for an area indicates that, should a fire ignition occur, flame lengths would likely be low enough for direct attack at the flaming edge by hand crews, and rates of spread slow enough for containment with initial attack at very small sizes. Fire effects in the moderate threat class would likely be of low severity, causing little vegetation mortality except to annual grasses and forbs that will reseed in the year following the fire. A high fuel ranking is interpreted as indicating that an ignition will lead to fire behavior exhibiting relatively intense fires, with flame lengths typically between 4 and 8 feet, and rates of spread indicating moderate chance of escape from initial attack depending on location of fire. Severity of fires occurring in the high fuel rank areas would likely result in mixed levels of vegetation mortality, with smaller trees and more sensitive species dominating the mortality distribution. Finally, a very high fuel ranking indicates that fires are likely to be intense, with surface flame lengths in excess of 8 feet, and moderate to high levels of crown fire. Severity of fire effects on dominant vegetation would likely be high, with widespread mortality, and a potentially stand-destroying fire killing even large, fire-resistant vegetation.

Water Quality

RWQCB Data Sources

The Regional Water Board compiled and evaluated existing data and collected new water quality data. The data analysis in this water quality assessment includes basic water chemistry, water temperature, sediment, and biological parameters. Although the data gathering, data collection, and data analysis techniques are explained in the subsequent sections, more detail can be found in the NCWAP methods manual (California Resources Agency 2001).

All the gathered raw data used in this assessment has been compiled and integrated into the KRIS Redwood Creek database for future access by interested parties.

Data Gathering

Data gathering is the process of compiling existing data from Regional Water Board files, other agency files, and other sources (such as landowners in the watershed). The Regional Water Board has several types of water quality information available within the organization, including Timber Harvest Plan (THP) files, water quality monitoring files, Total Maximum Daily Load (TMDL) files, grant files, environmental impact reports, and other documents. All of the available internal water quality information was evaluated for inclusion into this assessment. Sources outside the office included data and reports from other agencies, US EPAs StoRet water quality database, watershed groups, landowners, and public interest groups. As data are gathered, the location and general characteristics of the data were catalogued in a database regardless of if it was directly applicable to the Regional Water Board portion of the watershed assessment. This was done to track internal data and also to provide a record of the data that were reviewed. All the catalogued data were made available to the other NCWAP agencies for theirs and the public's use.

Landowners

Data were provided by several landowners of the Redwood Creek watershed for this watershed assessment. This included water temperature and sediment information from the Redwood National and State Parks (RNSP) and numerous references containing data from studies conducted in the Redwood Creek watershed from the Redwood Creek Landowners Association.

In the case of Simpson Timber Company, summary water temperature data was taken directly from Timber Harvest Plans because the company did not wish to share raw data or collection protocols.

Forest Science Project (FSP)

FSP was actively compiling and analyzing water temperature data in the North Coast area from 1990 to 1998. During one or more years over this time period, the major landowners in the Redwood Creek watershed contributed water temperature data to the project. This included Redwood National and State Parks (RNSP), Simpson Timber Company, Barnum Timber Company, and other private landowners.

In most cases, the data from FSP was used for this assessment. However, additional temperature data taken after 1998 was incorporated into the assessment from RNSP.

North Coast Regional Water Quality Control Board (Regional Water Board)

Various water quality samples were collected at one site on the mainstem of Redwood Creek between 1959 and 1988. This data is available at the Regional Water Board office and also in US EPA's Legacy StoRet database, which is available on the US EPA website.

The Regional Water Board collected water quality samples at one site in the Redwood Creek watershed from 2001-03. A total of thirteen samples were collected under the SWAMP program and used for this assessment. Regional Water Board water quality monitoring sites are shown in Water Chemistry Map 1.

United States Environmental Protection Agency (US EPA)

While the US EPA did not collect any original data in Redwood Creek, it made data from USGS and the Regional Water Board available through its Legacy StoRet database. This is available on the US EPAs website and includes all of the data collected by USGS and the Regional Water Board at two closely located sites, named Redwood Creek at Orick. For the purposes of this assessment, these sites are treated as one site because they are in close proximity to one another. It is believed that this will have a negligible effect on this assessment of water chemistry.

United States Geological Survey (USGS)

Various water quality samples were collected at 40 sites throughout the Redwood Creek watershed between 1973 and 1977. This data now resides in the USGS sample database and also the StoRet database, both of which are available at the respective agencies' website.

Watershed Groups

Watershed groups active in Redwood Creek include the Pacific Coast Fish, Wildlife, and Wetlands Restoration Association and the Redwood Community Action Agency. At the time of publication, no data were made available to the Regional Water Quality Control Board from these or any other watershed group.

Data Collection

Regional Water Board staff collected water quality measurements thirteen times during 2001-03 in Redwood Creek. This sample collection and analysis was done under the Surface Water Ambient Monitoring Program (SWAMP). Sample collection and analysis was in accordance with methods used by the USGS and the US

EPA. Those methods are explained and referenced in the NCWAP Methods Manual (CRA 2001). While in the field, staff recorded basic “point in time” water chemistry data including pH, specific conductance, temperature, turbidity, and dissolved oxygen. Grab water samples were also collected then analyzed by an independent, certified laboratory for chlorophyll-a, alkalinity, hardness, organic and inorganic compounds, metals, and mercury. While staff hoped to collect stream channel information, such as pebble counts, we were unable to accomplish this due to access and resource constraints. However, a joint monitoring effort with the RNSP resulted in the donation of two temperature recorders for monitoring water and air temperature.

Summary of Assessment Process

The assessment process involves four basic steps, as outlined below:

- **Collection and gathering of water quality data and other pertinent information.** This involves collection of new data, gathering existing data internally or from other agencies, landowners, etc. In some cases, there may be related information that is not numeric, but useful to the assessment process. This is discussed in further detail in the Data Gathering section.
- **Compile and assess data based on the data quality.** Once the new data have been collected and the existing data have been gathered, all of the data are compiled to prepare it for analysis. Each of the references reviewed is cataloged in a database and raw and summary data are compiled into spreadsheets or some other electronic file appropriate for the data type. At this point, the data are also reviewed for data quality to determine the level of confidence in the data for use in the assessment. The data are then analyzed and compared to various criteria that have been established. This is discussed in further detail in the Criteria Used for this Assessment, the Data Analysis, and the Limitations and Data Quality sections.
- **Form hypotheses based on the water quality data.** Where possible, hypotheses are drawn on stream conditions based primarily on the water quality analysis. This is discussed in further detail in the Data Analysis Methods section and in general in the Overall Conclusions and Subbasin sections.
- **Confirm/refute hypotheses during the synthesis process with data from other NCWAP team members and draft the synthesis report**. Once the individual water quality assessment report has been drafted and preliminary hypotheses have been formed, each of the NCWAP agencies met to create a “synthesis report.” During synthesis discussions, the hypotheses were tested against the data and findings from the other agencies to provide additional evidence to either support or detract from the hypotheses. At this point, each of the agencies combined the knowledge and data into a single comprehensive synthesis report covering all of the disciplines brought to the table by the NCWAP agencies. The discipline specific report and the combined synthesis report was then reviewed internally until a draft was released for public review and comment.

Past and current water quality data were evaluated regarding compliance with water quality objectives in the North Coast Regional Water Quality Control Board’s (NCRWQCB) Basin Plan. Those same water quality data, as well as sediment and habitat data, were evaluated against TMDL targets for Redwood Creek and data dependency relationships (ranges and thresholds) for the knowledge-based EMDS evaluation model, described in a subsequent section. The specific water quality thresholds and ranges (objectives, TMDL targets, EMDS ranges and thresholds) are shown in Table II- 1 and are detailed in the Appendix C.

Two metrics were used to evaluate summer water temperature suitability for salmonids of Redwood Creek. The first metric is the maximum weekly average temperature (MWAT), which is the upper temperature recommended for a species life stage or a threshold that should not be exceeded over any seven-day period (Armour 1991). The second metric is the seasonal maximum or the highest temperature observed during the hottest part of the year.

The MWAT is determined from data collected by continuous data recorders placed in the stream during the warmest part of the year, usually the months of June through October. An MWAT of 63°F or less is considered suitable for most anadromous fish production (Brett 1952, Reiser and Bjorn 1979). Coho salmon and coastal cutthroat trout are considered the most temperature sensitive species. Welsh et al. (2001) found in the Mattole basin that no streams with an MWAT greater than 62.5°F contained coho salmon. In addition, all of the streams where the MWAT was less than 58°F contained juvenile coho salmon. Hines and Ambrose (Draft, 2000) suggest that "the number of days a site exceeded an MWAT of 63.7°F (17.6°C) was one of the most influential variable predicting coho salmon presence and absence". "If a simple threshold were to be considered best, it would be 63.7°F (17.6°C)" (Hines and Ambrose Draft, 2000). The number of days above suitable temperature conditions were not examined in this assessment due to time constraints and uncertainty of how many days above the MWAT will adversely affect salmonids. However, the data are available through the KRIS Redwood database for future suitability assessments. Future study of time related impacts of temperature exposure should be conducted to more accurately assess the threat of high water temperatures to salmonid production.

Table II- 1 Criteria Used in the Assessment of Water Quality Data.

Water Quality Parameter	Range or Threshold Protective of Bus[1], Including Cold Water Fish Species	Source of Range or Threshold
PH	6.5-8.5	Basin Plan, p 3-3.00
Dissolved Oxygen	7.0 mg/L	Basin Plan, p 3-3.00
Temperature	No alteration that affects BUs 1 No increase above natural > 5°F 50-60°F MWAT[2] – Fully suitable 61-62°F MWAT – Moderately suitable 63°F MWAT – Somewhat suitable 64°F MWAT – Undetermined 65°F MWAT – Somewhat unsuitable 66-67°F MWAT – Moderately unsuitable ≥68°F MWAT – Fully unsuitable 75°F daily max (lethal)	Basin Plan, p 3-3.00 Basin Plan, p 3-4.00 Cold water fish rearing, RWQCB (2000), p. 37
Specific Conductance	<90% of upper limit at 220umhos <50% of upper limit at 145umhos	Basin Plan, p 3-6.00
Nutrients (Biostimulatory Substances)	No increase in concentrations that promote growths and cause nuisance or adversely affect beneficial uses	Basin Plan, p 3-3.00
Mean particle size diameter (D50) from riffle crest surfaces	>37mm (single minimum for a reach) >69mm (mean for a reach)	Redwood Creek TMDL, EPA (1998)
Percent fines <0.85 mm	<14% in fish-bearing streams [4]	Redwood Creek TMDL, EPA (1998) EMDS[3] Fully Suitable
Percent fines <6.5 mm	<30% in fish-bearing streams	Redwood Creek TMDL, EPA (1998) EMDS Fully Suitable

[1] BUs = Basin Plan beneficial uses
[2] MWAT= maximum average weekly temperature, to be compared to a 7-day moving average of daily average temperature
[3] EMDS = Ecological Management Decision Support model used as a tool in the fisheries limiting factors analysis. These ranges and thresholds were derived from the literature and agreed upon by a panel of NCWAP experts.
[4] fish-bearing streams = streams with cold water fish species

To evaluate temperature data with respect to salmonid populations, specific criteria had to be developed to rate habitat conditions. The NCWAP Team developed MWAT ranges for the EMDS model as an average of the needs of several cold water fish species (note that we were unable to actually use this portion of the EMDS model due to an inadequate amount of MWAT data). All temperature data were compared to this EMDS suitability range.

The MWAT breakdowns for EMDS are as follows:

- Fully suitable = 50-60°F (10-15.6°C)
- Moderately suitable = 61-62°F
- Somewhat suitable = 63°F
- Undetermined (between somewhat suitable and somewhat unsuitable) = 64°F
- Somewhat unsuitable = 65°F
- Moderately unsuitable = 66-67°F
- Fully unsuitable = ≥68°F

Seasonal maximum or peak temperature data speak to the threat of harm from temporary or short-term exposure to extreme conditions. It is generally accepted that a threshold temperature exists that fish can withstand for short consecutive period of hours before damage is caused by stress (Armour 1991). The instantaneous seasonal maximum that may lead to salmonid lethality is >75°F (RWQCB 2000). This is the EMDS suitability criterion for seasonal maximum temperatures.

Existing data for percent of fine subsurface material in the <0.85 and <6.5mm fractions are comparable to numeric TMDL targets derived from sampling methods which include core samples from a McNeil type sampler sieved wet, with fines measured by volumetric displacement. See Valentine (1995) for a description of the McNeil sampling and analysis method. A discrepancy exists between the requirements of the US EPA approved TMDL for Redwood Creek and the Technical Support Document written by the NCRWQCB, on which the US EPA TMDL was based. The US EPA document states that subsurface sediment samples should be sieved dry, however the numeric targets derived in the Technical Support Document were based on the wet sieved method and volumetric displacement. The percent of fine materials in subsurface sediment samples sieved wet are not comparable to samples that are dried and measured gravimetrically, unless a conversion factor is empirically derived from the geologic formation through which the stream flows. The discrepancy between the two analysis methods has yet to be resolved between the two agencies. Consequently, streambed sediment data analyzed gravimetrically are not comparable to existing TMDL targets. These data were not discussed in this assessment but are included in Appendix C.

CDFG Anadromous Salmonid Populations and Stream Habitat Assessment

The California Department of Fish and Game's (CDFGs) role in the Redwood Creek watershed assessment involved working with local scientists and an extensive review of numerous reports describing historic and current salmonid populations and watershed conditions. The stream habitat assessment process depended largely on results from stream habitat surveys conducted by CDFG crews during 2001. Goals of the assessment include:

- Assess past and present status of anadromous salmonid populations;
- Assess anadromous salmonid habitat conditions;
- Identify potential limiting factors to anadromous salmonid production;
- Identify and characterize salmonid refugia habitat;
- Develop recommendations for salmonid habitat improvement projects.

Stream Surveys

Surveys of physical habitat conditions were conducted in the Redwood Creek basin June through September 2001. Stream surveys were performed in the Middle and Upper subbasins on approximately 27.5 miles of mainstem Redwood Creek and approximately 21 miles within 18 tributary streams. In addition, a set of randomly selected stream reaches were sampled in the Prairie Creek and Lower Redwood Creek subbasins. Stream survey and sample reach data collection used physical habitat and biological data collection protocols presented in the *California Salmonid Stream Habitat Restoration Manual* (Flosi et al. 1998). Streams were surveyed until the end of anadromy was determined. Crews based this judgment on either physical barriers to fish passage or steep gradient (8-10% for >1,000 ft.) present for long continuous stretches of the creek. The crews also made visual observations for fish presence above suspected barriers to help determine the end of an anadromous fish bearing reach.

Electrofishing was used to determine presence and distribution of salmonid species. CDFG fish biologists equipped with Smith Root Model 12 backpack electrofishing units performed the fish data collection. They sampled at least one pool, run and riffle per reach. Mainstem Redwood Creek was sampled only at a few sites due to the depths of pools that reduce the effectiveness of the electrofishing units and capture efficiency. Collected specimens were identified to species and age class (estimated based on size) and released. Non-salmonid species were also recorded but not classified by age class. Electrofishing was also part of the state wide coho distribution survey. Presence/absence Electrofishing Protocol for anadromous salmonids used in summer 2001 is presented below.

Objective: Identify the presence of anadromous salmonids and species composition within each stream survey reach using the following protocol:

- Electrofishing is conducted following completion of stream habitat and channel inventories for each creek;
- Stream reaches are designated based upon measurements recorded by surveyors using Rosgen channel type criteria;
- Electrofish sampling is conducted within each reach of the stream and above the end of anadromy (when possible). Sampling begins just upstream of the stream's mouth (out of the area of influence of the receiving stream or river) and continues upstream following methodology described below:
  - A total of 10 pools per reach are electrofished to determine if juvenile;
  - Anadromous fish are present. The pools are to be distributed throughout the length of the stream reach to be sampled. At least two electrofishing passes are made in each pool unit sampled. After the capture at least one specimen of each potential species, sampling in that reach is terminated and the surveyors move onto the next reach to continue sampling. The same protocol was used for each reach unless:
    - ◊ The reach is short (less than – ¼ mile), approximately five pools should be sampled;
    - ◊ There are several reaches present (e.g. more than 3 or 4) or time is an issue, then as many reaches as possible should be sampled in an upstream direction;
    - ◊ Access is not possible throughout the stream reach, then the above protocol should be applied to that portion which accessible.
- Approximately five pool, riffle, or run habitats should be sampled upstream of the suspected end of anadromy;
- Pools selected for sampling are pools where one would expect to find coho salmon, i.e. those with habitat complexity. If complex pools are not present after passing several pools, then the common pool type found within that section of stream are sampled;
- Fish captured were identified by species and then counted and categorized into young-of-the-year, one-plus, or two-plus age classes.

Sample Reaches

The CDFG in cooperation with the Corvallis, Oregon, EPA Field Station randomly selected sampling reaches located in the Prairie Creek and Lower subbasins. The reaches were selected using an unequal probability random tessellation stratified (RTS) survey design with an oversample (Stevens 1997, Olsen 2000). The RTS method was used for its ability to select a spatially balanced set of sampling points across the study area. Stevens and Olsen (1999) describe the RTS design applied to streams.

A base map of the Lower and Prairie Creek subbasins showing the stream network and limits of winter steelhead distribution served as the sampling frame. The RTS generated a set of GPS coordinated points (20 primary sites and 40 oversamples) on the fish bearing streams. Twenty primary sites were selected based on the limited amount of time (7 days) and staff available to conduct the sample surveys. Maps were made showing the approximate location of the sampling points. Crews equipped with GPS units then located the points as near as possible to the stream. Once a point was located, the length of the sampling reach was determined. A sample reach length was either 20 bankfull widths or a minimum length of 500 feet and a maximum length of 1500 feet (Gallo 2000). Average bankfull width was determined nearest the central location of the GPS coordinates identifying the location of the sample site. Half of the reach length was surveyed upstream and half downstream of the center point. Stream inventory surveys followed CDFG protocols (Flosi et al. 1998) sampling 100% of the selected reach.

CDFG fisheries biologist performed fish data collection using backpack electrofishers to determine presence of salmonid species. At least one pool, run, and riffle were electrofished from each sampling reach. Additionally, tributaries that were recently sampled by Humboldt State University students were not electrofished to minimize stress to fish and not to impact ongoing studies.

Analytic Tools and Interdisciplinary Synthesis

Integrated Analysis Tables

The multi-discipline team constructed a series of subject specific data tables, referred to as Integrated Analysis (IA) tables, to track the history and status of watershed processes. Through the use of IA tables the multidisciplinary data were synthesized, and the information used to respond to the six guiding assessment questions. The IA process also helped to identify and explain current watershed conditions. These integrated analyses are presented at both basin and subbasin levels. Land use and vegetation analyses have been further divided at the CalWater 2.2a Planning Watershed level.

The IA approach follows the down-slope movement of the five watershed products commonly delivered to streams by natural or human caused energy: water, sediment, organic woody debris, nutrients, and heat. Fundamental to these watershed processes and products are the underlying geology and geomorphology of the watershed. Geologic conditions determine, in large part, the landslide and sediment production potential of the terrain. Geologic processes are influenced in varying degrees by the vegetative community, which is often linked to human activities across the landscape. Current watershed conditions combine with natural events like fire, flood, and earthquakes to affect the fluvial geomorphology and water quality in the stream reaches of a watershed. Finally, the effects of these combined processes are expressed in stream habitats encountered by the organisms of the aquatic riparian community, including salmon and steelhead.

Links between cause and effect are complicated by spatial and temporal dynamics of watershed processes. A direct link between cause and effect may be the resulting increase in stream temperature in response to removal of shade canopy over a stream. Less clear examples include aggradation of the streambed and the series of related impacts to stream habitat. For example, which upstream sediment sources yielded the sediment, when did the sediment delivery occur and why, and can they be controlled or prevented. Many components act together at various spatial and temporal scales to elicit the effect or condition expressed by a watershed, stream, or a fish population. Thus cumulative effects form a variety of environmental and socio-economic factors also must be considered for this analysis.

Ecological Management Decision Support System

The assessment program selected the Ecosystem Management Decision Support system software to help synthesize information on watershed and stream conditions. The EMDS system was developed at the USDA-Forest Service, Pacific Northwest Research Station (Reynolds 1999). It employs a linked set of software that includes MS Excel, NetWeaver, the Ecological Management Decision Support (EMDS) ArcView Extension, and ArcView™. The NetWeaver software, developed at Pennsylvania State University, helps scientists model linked frameworks of various environmental factors called knowledge base networks (Reynolds et al. 1996).

These networks specify how various environmental factors will be incorporated into an overall stream or watershed assessment. The networks resemble branching tree-like flow charts, graphically show the assessment's logic and assumptions, and are used in conjunction with spatial data stored in a Geographic Information System (GIS) to perform assessments and render the results into maps. This combination of software is currently being used for watershed and stream reach assessment on federal lands included in the Northwest Forest Plan (NWFP).

Forest Plan scientists constructed knowledge base models to identify and evaluate environmental factors (e.g. watershed geology, land use impacts, water quality, stream sediment loading, stream temperature, etc.) that shape anadromous salmonid habitat. Using this adaptive model structure, EMDS evaluated available NWFP watershed data to provide insight into stream and watershed conditions in relationship to target conditions known to be favorable to salmonids.

Development of the North Coast California EMDS Model

Staff began development of EMDS knowledge base models with a three-day workshop in June of 2001 organized by the University of California, Berkeley. In addition to the assessment program staff, model developer Dr. Keith Reynolds and several outside scientists also participated. As a starting point, analysts used an EMDS knowledge base model developed by the Northwest Forest Plan for use in coastal Oregon. Based upon the workshop, subsequent discussions among staff and other scientists, examination of the literature, and consideration of localized California conditions, the assessment team scientists then developed preliminary versions of the EMDS models.

The Knowledge Base Network

For California's north coast watersheds, the assessment team originally constructed two knowledge base networks: 1) The Stream Reach Condition Model; and 2) The Watershed Condition Model. These models were reviewed in April 2002 by an independent nine-member science panel, which provided a number of suggestions for model improvements. According to their suggestions, the team revised the two original models and added three others focused on the analysis of specific components of instream and watershed conditions that affect salmonids:

- **The Stream Reach Condition model** addresses conditions for salmon on individual stream reaches and is largely based on data collected using CDFG stream survey protocols found in the California Salmonid Stream Habitat Restoration Manual, (Flosi et al. 1998);
- **The Sediment Production Risk model** evaluates the magnitudes of the various sediment sources in the basin according to whether they are natural or management related;
- **The Water Quality model** has not yet been developed, but will offer a means of assessing characteristics of instream water (flow and temperature) in relation to fish;
- **The Fish Habitat Quality model** has not yet been developed, but will incorporate the Stream Reach model results in combination with data on accessibility to spawning fish and a synoptic view of the condition of riparian vegetation for shade and large woody debris;
- **The Fish Food Availability model** has not yet been developed, but will evaluate the watershed based upon conditions for producing food sources for anadromous salmonids.

In creating these EMDS models, the team used what is termed a tiered, top-down approach. For example, the Stream Reach Condition model (Figure II- 2) tested the truth of the proposition: *The overall condition of the stream reach is suitable for maintaining healthy populations of native Chinook, coho, and steelhead trout*. A knowledge base network was then designed to evaluate the truth of that proposition, based upon existing data from each stream reach. The model design and contents reflected the specific data and information analysts believed were needed, and the manner in which they should be combined, to test the proposition.

In evaluating stream reach conditions for salmonids, the model uses data from several environmental factors. The first branching tier of the knowledge base network shows the data based summary nodes on: 1) in-channel condition; 2) stream flow; 3) riparian vegetation and: 4) water temperature. These nodes are combined into a single value to test the validity of the stream reach condition suitability proposition. In turn, each of the four summary branch node's values is formed from the combination of its more basic data components. The process is repeated until the knowledge base network incorporates all information believed to be important to the evaluation.

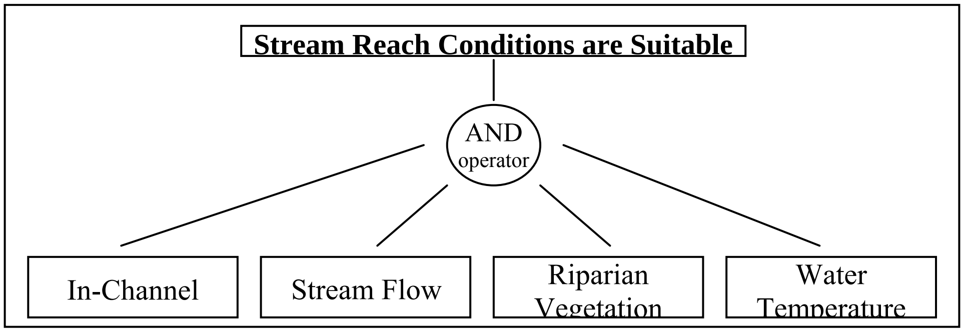

Figure II- 2. Tier one of the EMDS stream reach knowledge base network.

In Figure II- 3, the AND operator indicates a decision node that means that the lowest, most limiting value of the four general factors determined by the model will be passed on to indicate the potential of the stream reach to sustain salmonid populations. In that sense, the model mimics nature. For example, if summertime low flow is reduced to a level deleterious to fish survival or well being, regardless of a favorable temperature regime, instream habitat, and/or riparian conditions, the overall stream condition is not suitable to support salmonids.

Although model construction is typically done top-down, models are run in EMDS from the bottom up. That is, stream reach data are usually entered at the lowest and most detailed level of the several branches of the network tree (the leaves). The data from the leaves are combined progressively with other related attribute information as the analysis proceeds up the network. Decision nodes are intersections in the model networks where two or more factors are combined before passing the resultant information on up the network.

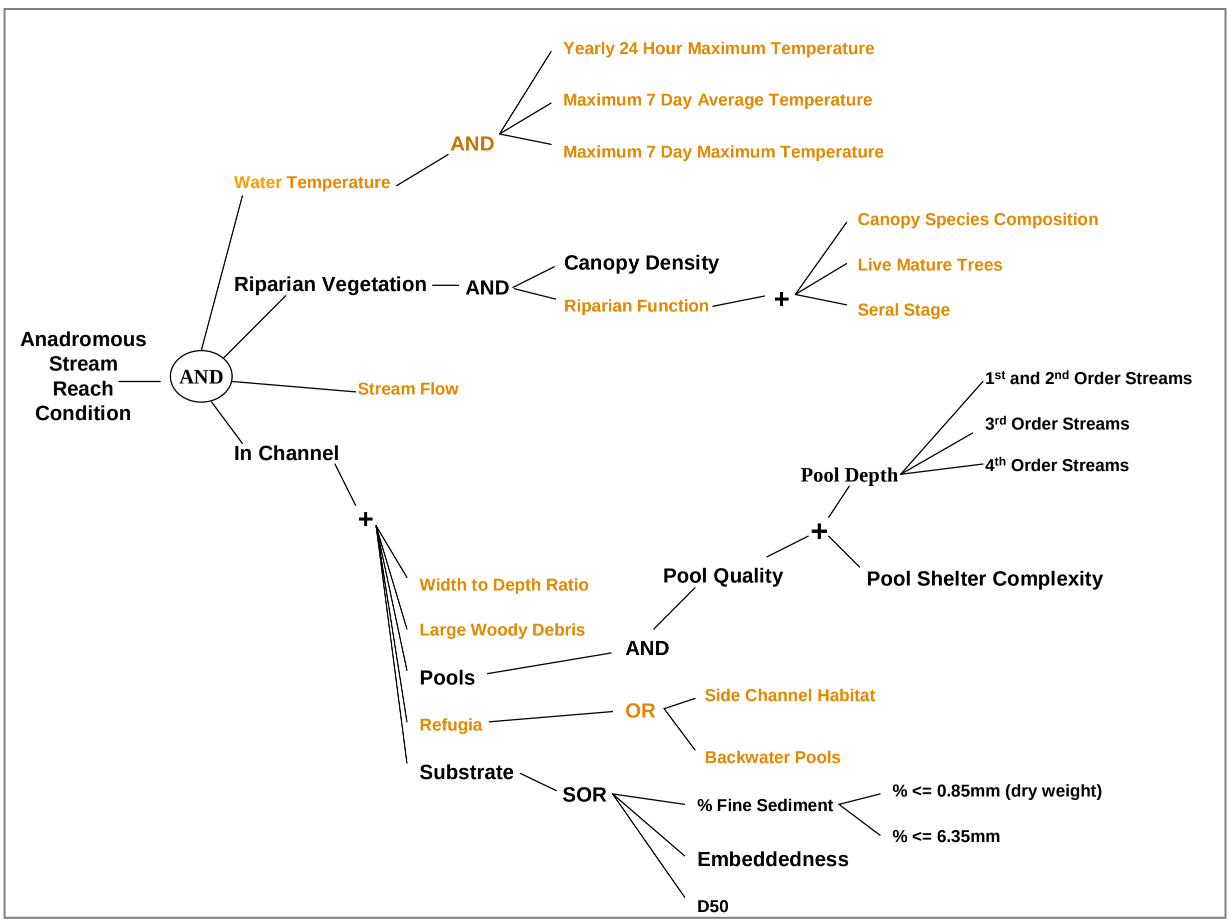

Figure II- 3. Graphic representation of the Stream Reach Condition model.

Habitat factors populated with data in the Albion assessment model are shown in black. Other habitat factors considered important for stream habitat condition evaluation, but data limited in the Albion assessment, are included in orange.

EMDS models assess the degree of truth (or falsehood) of each model proposition. Each proposition is evaluated in reference to simple graphs called reference curves that determine its degree of truth/falsehood, according to the data's implications for salmon. Figure II- 4 shows an example reference curve for the proposition *stream temperature is suitable for salmon*. The horizontal axis shows temperature in degrees Fahrenheit, while the vertical axis is labeled Truth Value and ranges from values of +1 to -1. The upper horizontal line arrays the fully suitable temperatures from 50-60°F (+1). The fully unsuitable temperatures are arrayed at the bottom (-1). Those in between are ramped between the fully suitable and fully unsuitable ranges and are rated accordingly. A similar numeric relation is determined for all attributes evaluated with reference curves in the EMDS models.

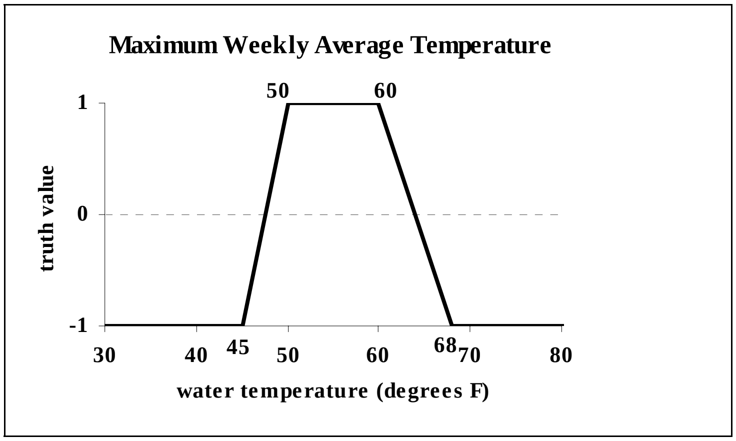

Figure II- 4. EMDS reference curve for stream temperature.

EMDS uses this type of reference curve in conjunction with data specific to a stream reach. This example reference curve evaluates the proposition that the stream's water temperature is suitable for salmonids. Break points on the curve can be set for specific species, life stage, or season of the year. Curves are dependent upon the availability of data in order to be included in an analysis.

For each evaluated proposition in the EMDS model network, the result is a number between –1 and +1. The number relates to the degree to which the data support or refute the proposition. In all cases a value of +1 means that the proposition is completely true, and –1 implies that it is completely false, while in-between values indicate degrees of truth (i.e. values approaching +1 being closer to true and those approaching –1 converging on completely untrue). A zero value means that the proposition cannot be evaluated based upon the data available. Breakpoints occur where the slope of the reference curve changes. For example, in Figure II- 4 breakpoints occur at 45, 50, 60, and 68°F.

EMDS map legends use a seven-class system for depicting the truth-values. Values of +1 are classed as the highest suitability; values of –1 are classed as the lowest suitability; and values of 0 are undetermined. Between 0 and 1 are two classes which, although unlabeled in the legend, indicate intermediate values of better suitability (0 to 0.5; and 0.5 to 1). Symmetrically, between 0 and –1 are two similar classes which are intermediate values of worse suitability (0 to –0.5; and –0.5 to –1). These ranking values are assigned based upon condition findings in relationship to the criteria in the reference curves. Table II- 2 summarizes important EMDS Stream Reach Condition model information.

Table II- 2. Reference curve metrics for EMDS stream reach condition model.

Stream Reach Condition Factor	Definition and Reference Curve Metrics
Aquatic / Riparian Conditions	
Summer MWAT	Maximum 7-day average summer water temperature <45°F fully unsuitable, 50-60°F fully suitable, >68°F fully unsuitable. Water temperature was not included in current EMDS evaluation.
Riparian Function	Under development.
Canopy Density	Average percent of the thalweg within a stream reach influenced by tree canopy. <50% fully unsuitable, ≥85% fully suitable.
Seral Stage	Seral stage composition of near stream forest. Under development
Vegetation Type	Forest composition Under development.
Stream Flow	Under development.
In-Channel Conditions	
Pool Depth	Percent of stream reach with pools of a maximum depth of 2.5, 3, and 4 feet deep for first and second, third, and fourth order streams respectively. ≤20% fully unsuitable, 30 – 55% fully suitable, ≥90% fully unsuitable.
Pool Shelter Complexity	Relative measure of quantity and composition of large woody debris, root wads, boulders, undercut banks, bubble curtain, overhanging and instream vegetation. ≤30 fully unsuitable, ≥100 - 300 fully suitable.
Pool Frequency	Percent of pools by length in a stream reach. Under development.
Substrate Embeddedness	Pool tail embeddedness is a measure of the percent of small cobbles (2.5" to 5" in diameter) buried in fine sediments. EMDS calculates categorical embeddedness data to produce evaluation scores between –1 and +1. The proposition is fully true if evaluation scores are 0.8 or greater and -0.8 evaluate to fully false
Percent Fines in Substrate <0.85mm (dry weight)	Percent of fine sized particles <0.85 mm collected from McNeil type samples. <10% fully suitable, >15% fully unsuitable. There was not enough of percent fines data to use percent fines in EMDS evaluations.
Percent Fines in Substrate < 6.4 mm	Percent of fine sized particles < 6.4 mm collected from McNeil type samples. <15% fully suitable, >30% fully unsuitable. There was not enough of percent fines data to use percent fines in EMDS evaluations.
Large Woody Debris (LWD)	The reference values for frequency and volume is derived from Bilby and Ward (1989) and is dependent on channel size. See EMDS Appendix for details. Most watersheds do not have sufficient LWD surveys for use in EMDS.
Winter Refugia Habitat	Winter refugia is composed of backwater pools and side channel habitats and deep pools (>4 feet deep). Under development.
Pool to Riffle Ratio	Ratio of pools to riffle habitat units. Under development.
Width to Depth Ratio	Ratio of bankfull width to maximum depth at velocity crossovers. Under development.

Advantages Offered by EMDS

EMDS offers a number of advantages for use in watershed assessments. Instead of being a hidden black box, each EMDS model has an open and intuitively understandable structure. The explicit nature of the model networks facilitates open communication among agency personnel and with the general public through simple graphics and easily understood flow diagrams. The models can be easily modified to incorporate alternative assumptions about the conditions of specific environmental factors (e.g., stream water temperature) required for suitable salmonid habitat.

Using ESRI Geographic Information System (GIS) software, EMDS maps the factors affecting fish habitat and shows how they vary across a basin. At this time, no other widely available package allows a knowledge base network to be linked directly with a geographic information system such as ESRIs ArcView™. This link is vital to the production of maps and other graphics reporting the watershed assessments. EMDS models also provide a consistent and repeatable approach to evaluating watershed conditions for fish. In addition, the maps from supporting levels of the model show the specific factors that, taken together, determine overall watershed conditions. This latter feature can help to identify what is most limiting to salmonids, and thus assist to prioritize restoration projects or modify land use practices.

Another feature of the system is the ease of running alternative scenarios. Scientists and others can test the sensitivity of the assessments to different assumptions about environmental factors and how they interact, through changing the knowledge-based network and breakpoints. What-if scenarios can be run by changing the shapes of reference curves, or by changing the way the data are combined and synthesized in the network.

NetWeaver/EMDS/ArcView tools can be applied to any scale of analysis, from reach specific to entire watersheds. The spatial scale can be set according to the spatial domain of the data selected for use and issue(s) of concern. Alternatively, through additional network development, smaller scale analyses (i.e., sub-watersheds) can be aggregated into a large hydrologic unit. With sufficient sampling and data, analyses can be done even upon single or multiple stream reaches.

Limitations of the EMDS Model and Data Inputs

While EMDS-based syntheses are important tools for watershed assessment, they do not by themselves yield a course of action for restoration and land management. EMDS results require interpretation, and how they are employed depends upon other important issues, such as social and economic concerns. In addition to the accuracy of the EMDS model constructed, the currency and completeness of the data available for a stream or watershed will strongly influence the degree of confidence in the results. External validation of the EMDS model using fish population data and other information should be done.

One disadvantage of linguistically based models such as EMDS is that they do not provide results with readily quantifiable levels of error. Therefore, EMDS should only be used as an indicative model, one that indicates the quality of watershed or instream conditions based on available data and the model structure. It is not intended to provide highly definitive answers, such as from a statistically based process model. It does provide a reasonable first approximation of conditions through a robust information synthesis approach; however, its outputs need to be considered and interpreted in the light of other information sources and the inherent limitations of the model and its data inputs. It also should be clearly noted that EMDS does not assess the marine phase of the salmonid life cycle, nor does it consider fishing pressures.

Program staff has identified some model or data elements needing attention and improvement in future iterations of EMDS. These currently include:

- Completion of quality control evaluation procedures;
- Adjust the model to better reflect differences between stream mainstems and tributaries, for example, the modification of canopy density standards for wide streams;
- Develop a suite of Stream Reach Model reference curves to better reflect the differences in expected conditions based upon various geographic watershed locations considering geology, vegetation, precipitation, and runoff patterns.

At this time, all of the recommendations made by our peer reviewers have not been implemented into the models. Additionally, EMDS results should be used as valuable but not necessarily definitive products, and their validation with other observations is necessary. The EMDS Appendix provides added detail concerning the system's structure and operations.

Management Applications of Watershed Synthesis Results

EMDS syntheses can be used at the basin scale- to show current watershed status. Maps depicting those factors that may be the largest impediments, as well as those areas where conditions are very good, can help guide protection and restoration strategies. The EMDS model can also help to assess the cost-effectiveness of different restoration strategies. By running sensitivity analyses on the effects of changing different habitat conditions, it can help decision makers determine how much effort is needed to significantly improve a given factor in a watershed and whether the investment is cost-effective.

At the project planning level, EMDS model results can help landowners, watershed groups, and others select the appropriate types of restoration projects and places (i.e., planning watersheds or larger) that can best contribute to recovery. Agencies will also use the information when reviewing projects on a watershed basis.

The main strength of using NetWeaver/EMDS/ArcView knowledge base software in performing limiting factors analysis is its flexibility, and through explicit logic, easily communicated graphics, and repeatable results, it can provide insights as to the relative importance of the constraints limiting salmonids in North Coast watersheds. Thus the results have utility to assess fish habitat conditions in watersheds and to help prioritize restoration efforts. They also facilitate an improved understanding of the complex relationships among environmental factors, human activities, and overall habitat quality for native salmon and trout.

Adaptive Application for EMDS and CDFG Stream Habitat Evaluations

CDFG has developed habitat evaluation standards, or target values, to help assess the condition of anadromous salmonid habitat in California streams (Flosi et al. 1998). These standards are based upon data analyses of over 1500 tributary surveys, and considerable review of pertinent literature. The EMDS reference curves have similar standards. These have been adapted from CDFG, but following peer review and professional discussion, they have been modified slightly due to more detailed application in EMDS. As such, slight differences occur between values found in Flosi et al. (1998) and those used by EMDS. The reference curves developed for the EMDS are provided in the EMDS Appendix of this report.

Both habitat evaluation systems have similar but slightly different functions. Stream habitat standards developed by CDFG are used to identify habitat conditions and establish priorities among streams considered for improvement projects based upon standard CDFG tributary reports. The EMDS compares select components of the stream habitat survey data to reference curve values and expresses degrees of habitat suitability for fish on a sliding scale. In addition, the EMDS produces a combined estimate of overall stream condition by combining the results from several stream habitat components. In the fish habitat relationship section of this report, we utilize target values found in Flosi et al. (1998), field observations, and results from EMDS reference curve evaluations to help describe and evaluate stream habitat conditions.

Due to the wide range of geology, topography and diverse stream channel characteristics which occur within the North Coast region, there are streams that require more detailed interpretation and explanation of results than can be simply generated by EMDS suitability criteria or tributary survey target values.

For example, pools are an important habitat component and a useful stream attribute to measure. However, some small fish-bearing stream channels may not have the stream power to scour pools of the depth and frequency considered to be high value “primary” pools by CDFG target values, or to be fully suitable according to EMDS. Often, these shallow pool conditions are found in low gradient stream reaches in small watersheds that lack sufficient discharge to deeply scour the channel. They also can exist in moderate to steep gradient reaches with bedrock/boulder dominated substrate highly resistant to scour, which also can result in few deep pools.

Therefore, some streams may not have the inherent ability to attain conditions that meet the suitability criteria or target values for pool depth. These scenarios result in pool habitat conditions that are not considered highly suitable by either assessment standard. However, these streams may still be very important because of other desirable features that support valuable fishery resources. As such, they receive additional evaluation with our refugia rating system and expert professional judgment. Field validation of any modeling system’s results is a necessary component of watershed assessment and reporting.

Limiting Factors Analysis

A main objective of NCWAP watershed assessment is to identify factors that limit production of anadromous salmonid populations in North Coast watersheds. This process is known as a limiting factors analysis (LFA). The limiting factors concept is based upon the assumption that eventually a population must be limited by the availability of necessary support resources (Hilborn and Walters 1992) or that a population’s potential may be constrained by an over abundance, deficiency, or absence of a watershed ecosystem component. Identifying stream habitat factors that limit or constrain anadromous salmonids is an important step towards setting priorities for habitat improvement projects and management strategies aimed at the recovery of declining fish stocks and protection of viable fish populations.

Although several factors have contributed to the decline of anadromous salmonid populations, habitat loss and modification are major determinants of their current status (FEMAT 1993). Our approach to a LFA integrates two habitat based methods to evaluate the status of key aspects of stream habitat that affect anadromous salmonid production- species life history diversity and the stream’s ability to support viable populations.

The first method uses priority ranking of habitat categories based on a CDFG team assessment of data collected during stream habitat inventories. The second method uses the EMDS to evaluate the suitability of key stream habitat components to support anadromous fish populations. These habitat-based methods assume that stream habitat quality and quantity play important roles in a watershed's ability to produce viable salmonid populations.

The LFA assumes that poor habitat quality and reduced quantities of favorable habitat impairs fish production. The program LFA is focused mainly on those physical habitat factors within freshwater and estuarine ecosystems that affect spawning and subsequent juvenile life history requirements during low flow seasons. Two general categories of factors or mechanisms limit salmonid populations:

- Density independent and
- Density dependent mechanisms.

Density independent mechanisms generally operate without regard to population density. These include factors related to habitat quality such as stream flow and water temperature or chemistry. In general, fish will die regardless of the population density if flow is inadequate, or water temperatures or chemistry reach lethal levels. Density dependant mechanisms generally operate according to population density and habitat carrying capacity. Competition for food, space, and shelter are examples of density dependant factors that affect growth and survival.

The program's approach considers these two types of habitat factors before prioritizing recommendations for habitat management strategies. Priority steps are given to preserving and increasing the amount of high quality (density independent) habitat in a cost effective manner. More details of the LFA are presented in the CDFG Appendix.

Restoration Needs/Tributary Recommendations Analysis

CDFG inventoried 13 tributaries to the Albion River and the headwaters of the Albion from 1994 to 2003 using protocols in the *California Salmonid Stream Habitat Restoration Manual*. The tributaries and the headwaters of the Albion River surveyed were composed of 30 stream reaches, defined as Rosgen channel types. The stream inventories are a combination of several stream reach surveys: habitat typing, channel typing, biological assessments, and in some reaches LWD and riparian zone recruitment assessments. An experienced biologist and/or habitat specialist conducted QA/QC on field crews and collected data, performed data analysis, and determined general areas of habitat deficiency based upon the analysis and synthesis of information.

CDFG biologists selected and ranked recommendations for each of the inventoried streams, based upon the results of these standard CDFG habitat inventories, and updated the recommendations with the results of the stream reach condition EMDS and the refugia analysis (Table II- 3). It is important to understand that these selections are made from stream reach conditions that were observed at the times of the surveys and do not include upslope watershed observations other than those that could be made from the streambed. They also reflect a single point in time and do not anticipate future conditions. However, these general recommendation categories have proven to be useful as the basis for specific project development, and provide focus for on-the-ground project design and implementation. Bear in mind that stream and watershed conditions change over time and periodic survey updates and field verification are necessary if watershed improvement projects are being considered.

Table II- 3. List of tributary recommendations in stream tributary reports.

Recommendation	Explanation
Temp	Summer water temperatures were measured to be above optimum for salmon and steelhead
Pool	Pools are below CDFG target values in quantity and/or quality
Cover	Escape cover is below CDFG target values
Bank	Stream banks are failing and yielding fine sediment into the stream
Roads	Fine sediment is entering the stream from the road system
Canopy	Shade canopy is below CDFG target values
Spawning Gravel	Spawning gravel is deficient in quality and/or quantity
LDA	Large debris accumulations are retaining large amounts of gravel and could need modification
Livestock	There is evidence that stock are impacting the stream or riparian area and exclusion should be considered
Fish Passage	There are barriers to fish migration in the stream

In general, the recommendations that involve erosion and sediment reduction by treating roads and failing stream banks, and riparian and near stream vegetation improvements precede the instream recommendations in reaches that demonstrate disturbance levels associated with watersheds in current stress. Instream improvement recommendations are usually a high priority in streams that reflect watersheds in recovery or good health. Various project treatment recommendations can be made concurrently if watershed and stream conditions warrant.

Fish passage problems, especially in situations where favorable stream habitat reaches are being separated by a man-caused feature (e.g., culvert), are usually a treatment priority. Good examples of these are the recent and dramatically successful Humboldt County/CDFG culvert replacement projects in tributaries to Humboldt Bay. In these regards, the program's more general watershed scale upslope assessments can go a long way in helping determine the suitability of conducting instream improvements based upon watershed health. As such, there is an important relationship between the instream and upslope assessments.

Additional considerations must enter into the decision process before these general recommendations are further developed into improvement activities. In addition to watershed condition considerations as a context for these recommendations, there are certain logistic considerations that enter into a recommendation's subsequent ranking for project development. These can include work party access limitations based upon lack of private party trespass permission and/or physically difficult or impossible locations of the candidate work sites. Biological considerations are made based upon the propensity for benefit to multiple or single fishery stocks or species. Cost benefit and project feasibility are also factors in project selection for design and development.

Salmonid Refugia

Establishment and maintenance of salmonid refugia areas containing high quality habitat and sustaining fish populations are activities vital to the conservation of our anadromous salmonid resources (Moyle and Yoshiyama 1992; Li et al. 1995; Reeves et al. 1995). Protecting these areas will prevent the loss of the remaining high quality salmon habitat and salmonid populations. Therefore, a refugia investigation project should focus on identifying areas found to have high salmonid productivity and diversity. Identified areas should then be carefully managed for the following benefits:

- Protection of refugia areas to avoid loss of the last best salmon habitat and populations. The focus should be on protection for areas with high productivity and diversity;
- Refugia area populations which may provide a source for re-colonization of salmonids in nearby watersheds that have experienced local extinctions, or are at risk of local extinction due to small populations;
- Refugia areas provide a hedge against the difficulty in restoring extensive, degraded habitat and recovering imperiled populations in a timely manner (Kaufmann et al. 1997).

The concept of refugia is based on the premise that patches of aquatic habitat provide habitat that retains the natural capacity and ecologic functions to support wild anadromous salmonids in such vital activities as spawning and rearing. Anadromous salmonids exhibit typical features of patchy populations; they exist in dynamic environments and have developed various dispersal strategies including juvenile movements, adult straying, and relative high fecundity for an animal that exhibits some degree of parental care through nest building (Reeves et al. 1995). Conservation of patchy populations requires conservation of several suitable habitat patches and maintaining passage corridors between them.

Potential refugia may exist in areas where the surrounding landscape is marginally suitable for salmonid production or altered to a point that stocks have shown dramatic population declines in traditional salmonid streams. If altered streams or watersheds recover their historic natural productivity, through either restoration efforts or natural processes, the abundant source populations from nearby refugia can potentially re-colonize these areas or help sustain existing salmonid populations in marginal habitat. Protection of refugia areas is noted as an essential component of conservation efforts to ensure long-term survival of viable stocks, and a critical element towards recovery of depressed populations (Sedell 1990; Moyle and Yoshiyama 1992; Frissell 1993, 2000).

Refugia habitat elements include the following:

- Areas that provide shelter or protection during times of danger or distress;
- Locations and areas of high quality habitat that support populations limited to fragments of their former geographic range;
- A center from which dispersion may take place to re-colonize areas after a watershed and/or sub-watershed level disturbance event and readjustment takes place.

Spatial and Temporal Scales of Refugia

These refugia concepts become more complex in the context of the wide range of spatial and temporal habitat required for viable salmonid populations. Habitat can provide refuge at many scales from a single fish to groups of them, and finally to breeding populations. For example, refugia habitat may range from a piece of wood that provides instream shelter for a single fish, or individual pools that provide cool water for several rearing juveniles during hot summer months, to watersheds where conditions support sustaining populations of salmonid species. Refugia also include areas where critical life stage functions such as migrations and spawning occur. Although fragmented areas of suitable habitat are important, their connectivity is necessary to sustain the fisheries. Today, watershed scale refugia are needed to recover and sustain aquatic species (Moyle and Sato 1991). For the purpose of this discussion, refugia are considered at the fish bearing tributary and subbasin scales. These scales of refugia are generally more resilient to the deleterious effects of landscape and riverine disturbances such as large floods, persistent droughts, and human activities than the smaller, habitat unit level scale (Sedell et al. 1990).

Standards for refugia conditions are based on reference curves from the literature and CDFG data collection at the regional scale. The program uses these values in its EMDS models and stream inventory, improvement recommendation process. Li et al. (1995) suggested three prioritized steps to use the refugia concept to conserve salmonid resources.

- Identify salmonid refugia and ensure they are protected;
- Identify potential habitats that can be rehabilitated quickly;
- Determine how to connect dispersal corridors to patches of adequate habitat.

Refugia and Meta-population Concept

The concept of anadromous salmonid meta-populations is important when discussing refugia. The classic metapopulation model proposed by Levins (1969) assumes the environment is divided into discrete patches of suitable habitat. These patches include streams or stream reaches that are inhabited by different breeding populations or sub-populations (Barnhart 1994; McElhany et al. 2000). A metapopulation consists of a group of sub-populations which are geographically located such that over time, there is likely genetic exchange between the sub-populations (Barnhart 1994). Metapopulations are characterized by 1) relatively isolated, segregated breeding populations in a patchy environment that are connected to some degree by migration between them, and 2) a dynamic relationship between extinction and re-colonization of habitat patches.

Anadromous salmonids fit nicely into the sub-population and metapopulation concept because they exhibit a strong homing behavior to natal streams forming sub-populations, and have a tendency to stray into new areas. The straying or movement into nearby areas results in genetic exchange between sub-populations or seeding of other areas where populations are at low levels. This seeding comes from abundant or source populations supported by high quality habitat patches which may be considered as refugia.

Habitat patches differ in suitability and population strength. In addition to the classic metapopulation model, other theoretical types of spatially structured populations have been proposed (Li et al. 1995; McElhany et al. 2000). For example, the core and satellite (Li et al. 1995) or island-mainland population (McElhany et al. 2000) model depicts a core or mainland population from which dispersal to satellites or islands results in smaller surrounding populations. Most straying occurs from the core or mainland to the satellites or islands. Satellite or island populations are more prone to extinction than the core or mainland populations (Li et al. 1995; McElhany et al. 2000). Another model termed source-sink populations is similar to the core-satellite or mainland-island models, but straying is one way, only from the highly productive source towards the sink subpopulations. Sink populations are not self-sustaining and are highly dependant on migrants from the source population to survive (McElhany et al. 2000). Sink populations may inhabit typically marginal or unsuitable habitat, but when environmental conditions strongly favor salmonid production, sink population areas may serve as important sites to buffer populations from disturbance events (Li et al. 1995) and increase basin population strength. In addition to testing new areas for potential suitable habitat, the source-sink strategy adds to the diversity of behavior patterns salmonids have adapted to maintain or expand into a dynamic aquatic environment.

The metapopulation and other spatially structured population models are important to consider when identifying refugia because in dynamic habitats, the location of suitable habitat changes (McElhany et al. 2000) over the long term from natural disturbance regimes (Reeves et al. 1995) and over the short term by human activities. Satellite, island, and sink populations need to be considered in the refugia selection process because they are an integral component of the metapopulation concept. They also may become the source population or refugia areas of the future.

Methods to Identify Refugia

Currently there is no established methodology to designate refugia habitat for California's anadromous salmonids. This is mainly due to a lack of sufficient data describing fish populations, meta-populations and habitat conditions and productivity across large areas. This lack of information holds true for all study basins especially in terms of meta-population dynamics. Studies are needed to determine population growth rates and straying rates of salmonid populations and sub-populations to better utilize spatial population structure to identify refugia habitat.

Classification systems, sets of criteria and rating systems have been proposed to help identify refugia type habitat in north coast streams, particularly in Oregon and Washington (Moyle and Yoshiyama 1992; FEMAT 1993; Li et al. 1995; Frissell et al. 2000; Kisup County 2000). Upon review of these works, several common themes emerge. A main theme is that refugia are not limited to areas of pristine habitat. While ecologically intact areas serve as dispersal centers for stock maintenance and potential recovery of depressed sub-populations, lower quality habitat areas also play important roles in long-term salmonid metapopulation maintenance. These areas may be considered the islands, satellites, or sinks in the metapopulation concept. With implementation of ecosystem management strategies aimed at maintaining or restoring natural processes, some of these areas may improve in habitat quality, show an increase in fish numbers, and add to the metapopulation strength.

A second common theme is that over time within the landscape mosaic of habitat patches, good habitat areas will suffer impacts and become less productive, and wink out and other areas will recover and wink in. These processes can occur through either human caused or natural disturbances or succession to new ecological states. Regardless, it is important that a balance be maintained in this alternating, patchwork dynamic to ensure that adequate good quality habitat is available for viable anadromous salmonid populations (Reeves et al. 1995).

NCWAP Approach to Identifying Refugia

The program's interdisciplinary refugia identification team identified and characterized refugia habitat by using professional judgment and criteria developed for North Coast watersheds. The criteria used considered different values of watershed and stream ecosystem processes, the presence and status of fishery resources, habitat quality, water quality, and other factors that may affect refugia productivity. The refugia team encouraged other specialists with local knowledge to participate in the refugia identification and categorization process.

The team also used results from information processed by the programs EMDS at the stream reach and planning watershed/subbasin scales. Stream reach and watershed parameter evaluation scores were used to rank stream and watershed conditions based on collected field data. Stream reach scale parameters included pool shelter rating, pool depth, embeddedness, and canopy cover. Water temperature data were also used when available. The individual parameter scores identified which habitat factors currently support or limit fish production (see EMDS and limiting factors sections).

Professional judgment, analyzing field notes, local expert opinion, habitat inventory survey results, water quality data results, and EMDS scores determined potential locations of refugia. If a habitat component received a suitable ranking from the EMDS model, it was cross-referenced to the survey results from that particular stream and to field notes taken during that survey. The components identified as potential refugia were then ranked according to their suitability to encourage and support salmonid health.

When identifying anadromous salmonid refugia, the program team took into account that anadromous salmon have several non-substitutable habitat needs for their life cycle. A minimal list (NMFS 2000) includes:

- Adult migration pathways;
- Spawning and incubation habitat;
- Stream rearing habitat;
- Forage and migration pathways;
- Estuarine habitat.

The best refugia areas are large, meet all of these life history needs, and therefore provide complete functionality to salmonid populations. These large, intact systems are scarce today and smaller refugia areas that provide for only some of the requirements have become very important areas, but cannot sustain large numbers of fish. These must operate in concert with other fragmented habitat areas for life history support and refugia connectivity becomes very important for success. Therefore, the refugia team considered relatively small, tributary areas in terms of their ability to provide at least partial refuge values, yet contribute to the aggregated refugia of larger scale areas. Therefore, the team's analyses used the tributary scale as the fundamental refugia unit.

Tributary ratings were determined by combining the results of NCRQCB water quality results, EMDS results, and data in CDFG tributary reports by a multi-disciplinary, expert team of analysts. The various factors' ratings were combined to determine an overall tributary rating on a scale from high to low quality refugia. Tributary ratings were subsequently aggregated at the subbasin scale and expressed a general estimate of subbasin refugia conditions. Factors with limited or missing data were noted. In most cases there were data limitations on 1–3 factors. These were identified for further investigation and inclusion in future analysis.

The program has created a hierarchy of refugia categories that contain several general habitat conditions. This descriptive system is used to rank areas by applying results of the analyses of stream and watershed conditions described above and are used to determine the ecological integrity of the study area. A basic definition of biotic integrity is "the ability [of an ecosystem] to support and maintain a balanced, integrated, and functional organization comparable to that of the natural habitat of the region" (Karr and Dudley 1981).

The Report of the Panel on the Ecological Integrity of Canada's National Parks submitted this definition:

A DEFINITION OF ECOLOGICAL INTEGRITY

The Panel proposes the following definition of ecological integrity: "An ecosystem has integrity when it is deemed characteristic for its natural region, including the composition and abundance of native species and biological communities, rates of change and supporting processes." "In plain language, ecosystems have integrity when they have their native components (plants, animals and other organisms) and processes (such as growth and reproduction) intact."

Salmonid Refugia Categories and Criteria:

High Quality Habitat, High Quality Refugia

- Maintains a high level of watershed ecological integrity (Frissell 2000);
- Contains the range and variability of environmental conditions necessary to maintain community and species diversity and supports natural salmonid production (Moyle and Yoshiyama 1992; Frissell 2000);
- Relatively undisturbed and intact riparian corridor;
- All age classes of historically native salmonids present in good numbers, and a viable population of an ESA listed salmonid species is supported (Li et al. 1995);
- Provides population seed sources for dispersion, gene flow and re-colonization of nearby habitats from straying local salmonids;
- Contains a high degree of protection from degradation of its native components.

High Potential Refugia

- Watershed ecological integrity is diminished but remains good (Frissell 2000);
- Instream habitat quality remains suitable for salmonid production and is in the early stages of recovery from past disturbance;
- Riparian corridor is disturbed, but remains in fair to good condition;
- All age classes of historically native salmonids are present including ESA listed species, although in diminished numbers;
- Salmonid populations are reduced from historic levels, but still are likely to provide straying individuals to neighboring streams;
- Currently is managed to protect natural resources and has resilience to degradation, which demonstrates a strong potential to become high quality refugia (Moyle and Yoshiyama 1992; Frissell 2000).

Medium Potential Refugia

- Watershed ecological integrity is degraded or fragmented (Frissell 2000);
- Components of instream habitat are degraded, but support some salmonid production;
- Riparian corridor components are somewhat disturbed and in degraded condition;
- Native anadromous salmonids are present, but in low densities; some life stages or year classes are missing or only occasionally represented;
- Relative low numbers of salmonids make significant straying unlikely;
- Current management or recent natural events have caused impacts, but if positive change in either or both occurs, responsive habitat improvements should occur.

Low Quality Habitat, Low Potential Refugia

- Watershed ecological integrity is impaired (Frissell 2000);
- Most components of instream habitat are highly impaired;
- Riparian corridor components are degraded;
- Salmonids are poorly represented at all life stages and year classes, but especially in older year classes;
- Low numbers of salmonids make significant straying very unlikely;

- Current management and / or natural events have significantly altered the naturally functioning ecosystem and major changes in either of both are needed to improve conditions.

Other Related Refugia Component Categories:

Potential Future Refugia (Non-Anadromous)

- Areas where habitat quality remains high but does not currently support anadromous salmonid populations;
- An area of high habitat quality, but anadromous fish passage is blocked by man made obstructions such as dams or poorly designed culverts at stream crossings etc.

Critical Contributing Areas

- Area contributes a critical ecological function needed by salmonids such as providing a migration corridor, conveying spawning gravels, or supplying high quality water (Li et al. 1995);
- Riparian areas, floodplains, and wetlands that are directly linked to streams (Huntington and Frissell 1997).

Data Limited

- Areas with insufficient data describing fish populations, habitat conditions, watershed conditions, or management practices.

Section III
Basin Profile and Overview
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Redwood Creek Profile and Synthesis

Redwood Creek flows into the Pacific Ocean near the town of Orick, approximately 35 miles north of Eureka, in northern Humboldt County, California Figure III- 1). The basin contains approximately 285 square miles (about 180,000 acres) of mostly forested and mountainous terrain. The basin's elongate shape is controlled by the Grogan Fault which extends in a NW/SE direction for approximately 65 miles. The basin averages only about 6 miles wide. Elevation ranges from sea level near the town of Orick up to 5,200 feet at headwaters near Board Camp Mountain, located at the south-east end of the basin. With the exception of Prairie Creek, most tributary streams are relatively short and steep, while the mainstem Redwood Creek is low gradient until rising to the headwaters. The basin provides approximately 125 miles of anadromous salmonid habitat.

Subbasin Scale

The complexity of large basins like Redwood Creek makes it difficult to address watershed assessment and recommendation issues except in very general terms. In order to be more specific and of value to planners, managers, and landowners, it is useful to subdivide the larger basin into smaller subbasin units whose size is determined by the commonality of many geographic attributes. Attributes that can distinguish subbasins include differences in elevation, geology, soil types, climate, vegetation, human population, and land use.

Redwood Creek basin was divided into five subbasins for assessment (Figure III- 2 and Table III- 1). The subbasins conform to CalWater 2.2 Planning Watershed boundaries when possible and the 22 planning watersheds as defined by the CalWater 2.2 system.

Estuary Subbasin: The Estuary Subbasin includes the drainage of Redwood Creek below the confluence with Prairie Creek, including Sand Cache Creek, Dorrance Creek and the lower Strawberry Creek basin.

Prairie Creek Subbasin: The Prairie Creek Subbasin contains all of Prairie Creek basin except for a small portion of Skunk Cabbage Creek. Ninety-eight percent of the Prairie Creek subbasin is managed by Redwood National and State Park (RNSP).

Lower Subbasin: The Lower Subbasin includes the area above the confluence of Redwood and Prairie Creeks to the confluence of Redwood and Devil's Creeks including Devil's Creek. The Lower Redwood Creek Subbasin is managed by RNSP.

Middle Subbasin: The Middle Subbasin includes the area above the confluence of Redwood/Devil's Creeks excluding Devil's Creek up to the confluence of Redwood and Lupton Creeks, including Lupton Creek. The Middle Subbasin includes the Park Protection Zone, Redwood Valley, and ends at the valley confinement upstream of State Highway 299 Bridge. This subbasin is predominantly managed for timber production and some cattle grazing.

Upper Subbasin: The Upper Subbasin is defined as the area above but not including Lupton Creek and covers the same area as the CalWater 2.2 Lake Prairie Hydrologic Area. This subbasin has the highest relief and the greatest proportion of natural prairies. This subbasin is predominantly managed for timber production and also has the greatest number of individual private ownerships per square mile of all Redwood Creek Subbasins.

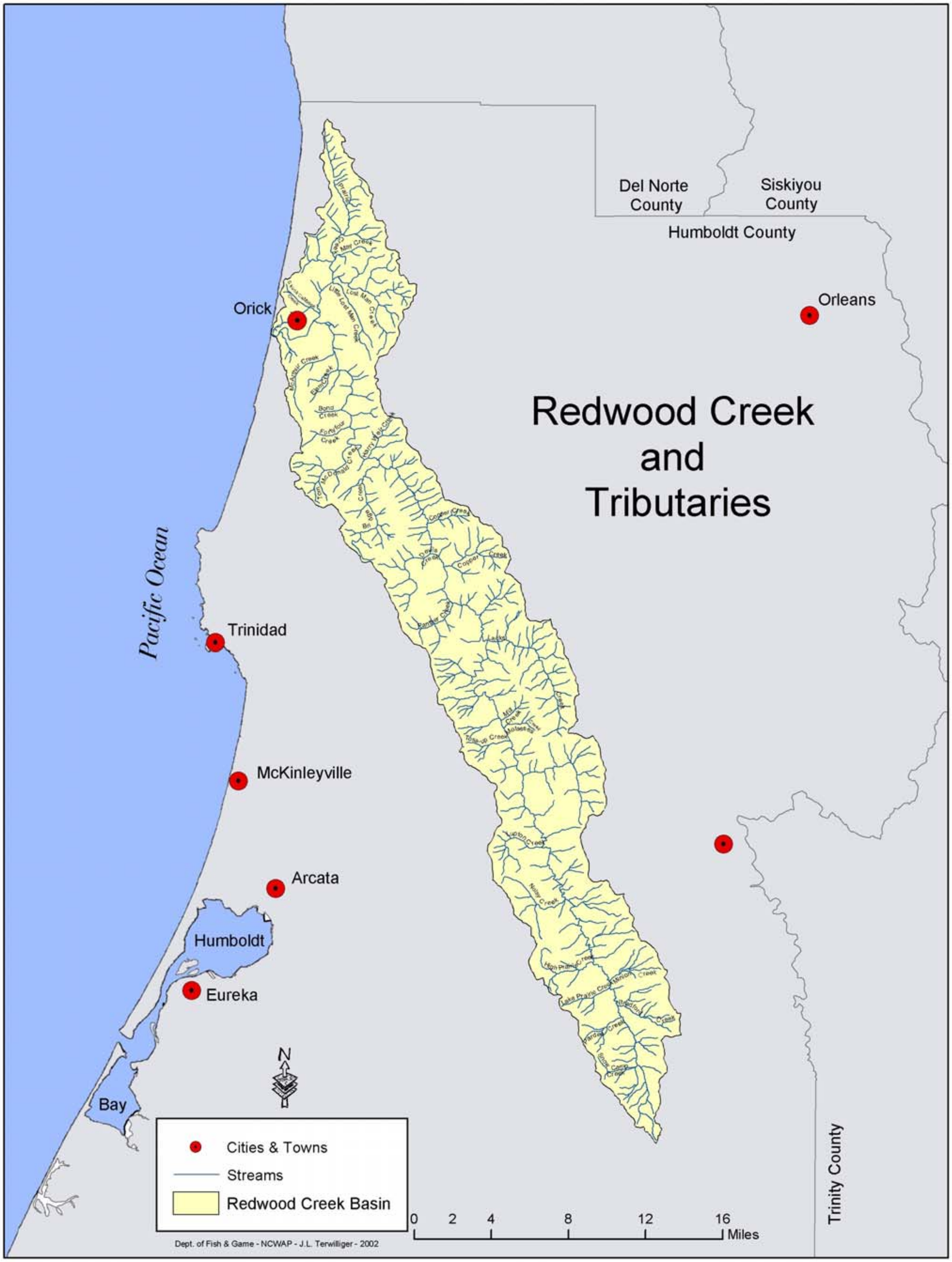

Figure III- 1. The Redwood Creek basin and major stream network.

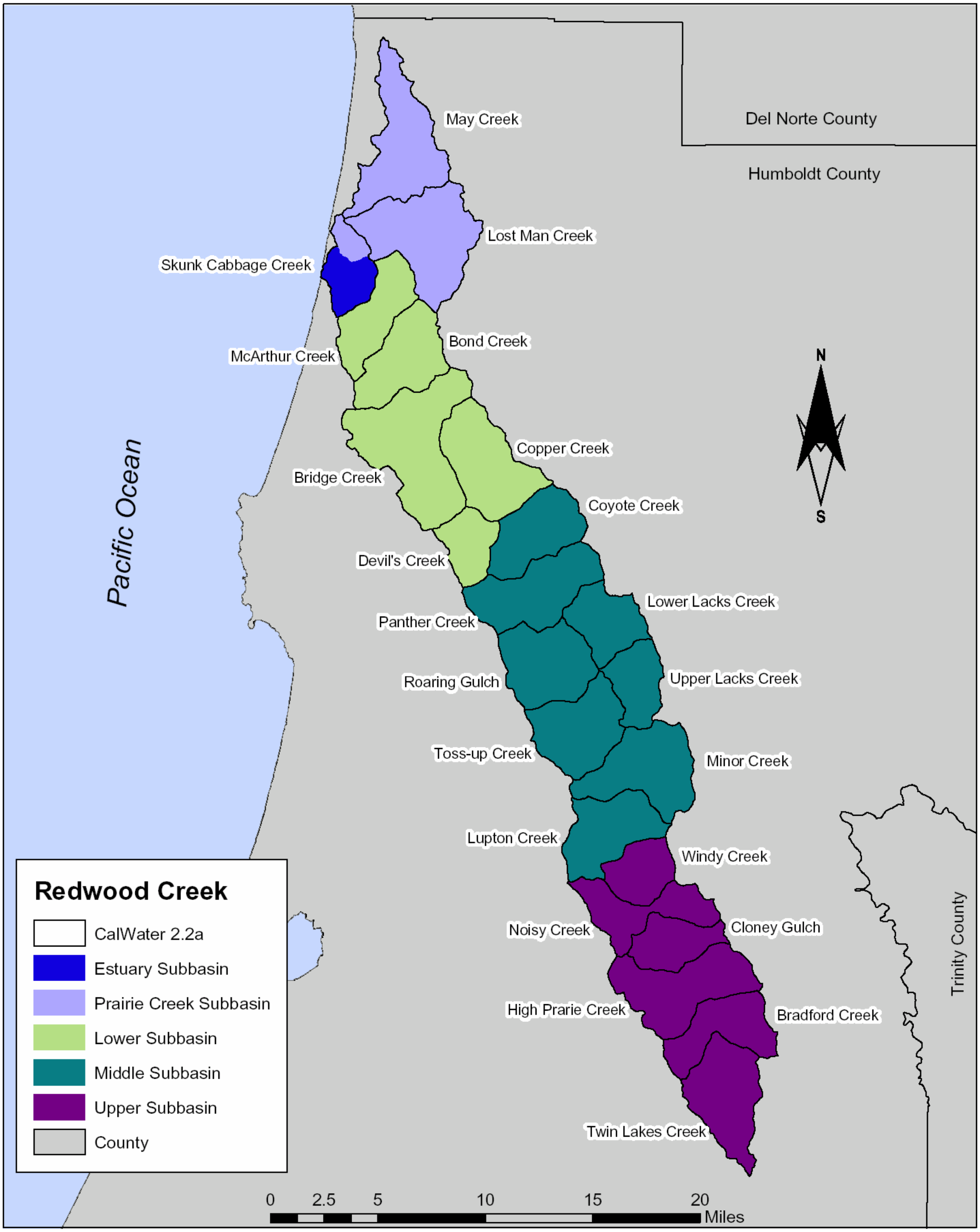

Figure III- 2. The five subbasins of the Redwood Creek basin and their planning watersheds.

Table III- 1. Redwood Creek subbasin summary.

Basin	Estuary	Prairie Creek	Lower Redwood	Middle Redwood	Upper Redwood	Total
Square Miles	5.5	39.5	69.5	100	68	285
Total Acres	3,429	25,339	44,487	63,681	42,880	179,807
Private Acres	2,007	463	275	57,843	40,640	101,228
Federal Acres	1,422	18,247	44,212	5,838	2,240	71,959
State Acres	0	6,629	0	0	0	6,620
Principal Communities	Orick			Redwood Valley		
Predominant Land Use	Livestock Grazing	Park Land	Park Land	Timber Production	Timber Production	
Predominant Vegetation Type	Pasture Land	Redwood Forest	Redwood Forest	Douglas-fir Forest	Hardwood Douglas-fir Forest	
Anadromous Fish Access (stream miles)	5	24	28	42	23	122
Lowest Elevation	0	26	26	325	866	
Highest Elevation	1,243	2,270	1,286	4,091	5,322	

Climate

The climate of the Redwood Creek basin varies from moderate seasons along the coast to the more extreme seasons common to the higher inland areas. The predominant influence on the climate in the lower basin, extending some ten to twenty miles inland, is moist marine air, which moves inland by prevailing onshore winds. Fog is a dominant climatic feature along the coast, generally occurring daily in the summer and not infrequently throughout the year. This oceanic influence has a greatly moderates the climate of the coastal areas over most of the year. Temperatures in the coastal region of the Redwood Creek basin vary only slightly, with a seasonal difference of only 10–15°F. For example, mean temperatures at Redwood Park are 47°F in January and 59°F in June.

The inland portion of the basin is removed from the oceanic influence, both by elevation and intervening ridges, that it is not strongly influenced by the marine air mass. Higher elevations and inland areas tend to be relatively fog free. The temperatures of the inland regions range from below freezing to above 100°F.

Precipitation within the Redwood Creek basin is characterized by profuse rainfall during the winter. Prevailing winter storms move inland in a northeasterly direction from the Pacific Ocean. Across the basin, annual precipitation ranges in amount from 32 inches at lower elevations to 98 inches at the headwaters. Precipitation falls mostly during the winter and spring. Average rainfall is approximately 70 to 80 inches per year, with frequent snow above 1600 feet during winter months. The headwaters region of the Redwood Creek basin can accumulate a fairly large snow pack and this may have an effect on high flow events given the right conditions. Rain-on-snow events may contribute to high flow events; however, there are no data to quantify its contribution.

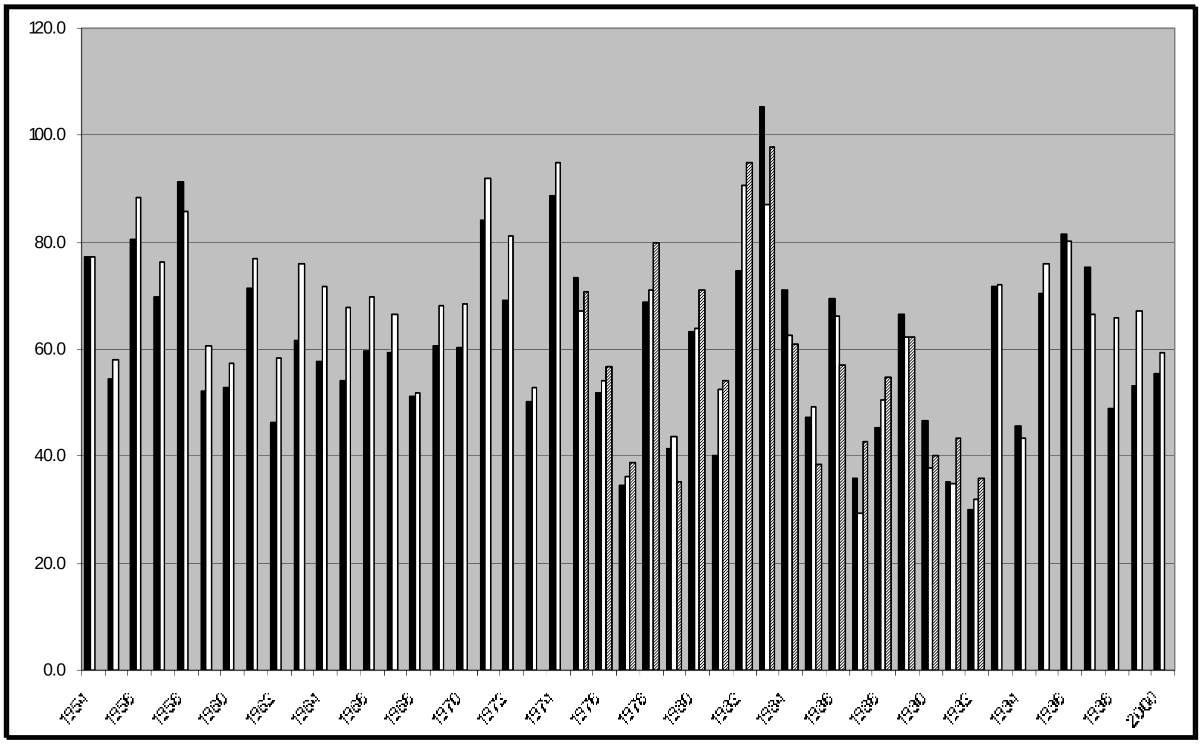

Figure III- 3. Estimated annual precipitation (inches per year), 1954-2000, at Highway 299 (O'Kane, black), Orick (white), and Little Lost Man Creek (striped), Redwood Creek, Humboldt County, California.

Hydrology

Stream Flow

Stream flow data are an important component in determining the existing conditions and assisting assessment, restoration, and management activities in North Coast basins. Stream flow can be a limiting factor for anadromous fisheries, affecting passage and the quantity and quality of spawning, rearing, and refugia areas. Stream flow also has a direct effect on other factors such as water temperature, dissolved oxygen, and sediment and chemical transport.

A list of the existing and discontinued stream flow gauging stations in Redwood Creek, along with their location, flow data type, and period of record is shown in Appendix G. There are only two gauges within the Redwood Creek basin with a period of operation long enough to be of statistical relevance for use in the frequency analysis. The two gauges are "Redwood Creek at Orick" (operating mid-1950s to date) and "Redwood Creek at O'Kane bridge or Blue Lake gauge, near Highway 299 (operating uninterrupted from the early 1970s to date).

The highest instantaneous peak discharge of record at the Orick gauge occurred in 1965, with a discharge of just above 50,500 cubic feet per second (cfs) (Figure III- 4). Other high peak flows occurred in water years 1956, 1972, and 1975. At the O'Kane gauge (see Appendix G), the highest instantaneous peak discharge of 12,200 cfs occurred in 1975. The record annual minimum seven-day running average low flow at Orick was 2 cfs in 1988. Although, the lower mainstem was dry near the HWY 101 bridge in 2001 and 2002 At the O'Kane gauge, the record low was 1 cfs in 1993. Tables showing low flows are found in Appendix G.

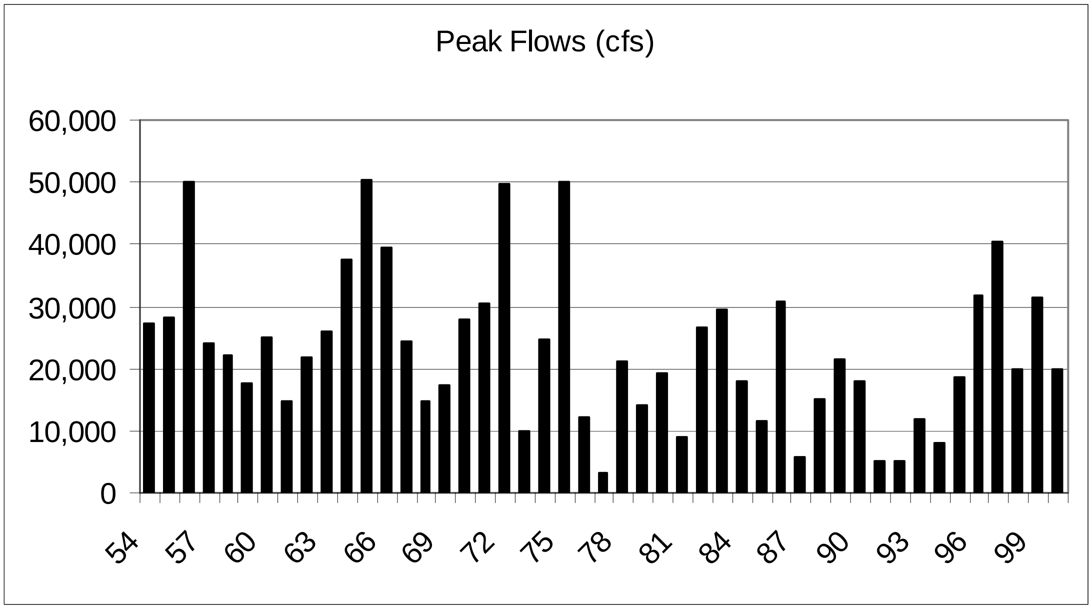

Figure III- 4. Peak Flows (cfs) at Orick, near the mouth of Redwood Creek, from 1954 through 2000.

Data from USGS and Redwood National and State Parks.

Looking to the more recent period, 1997 saw the 5th highest instantaneous peak discharge on record at Orick: 40,300 cfs. For more recent annual minimum seven-day running average low flows, Orick had 10 cfs in 1997, the 8th lowest low flow on record; for O'Kane located near the Highway 299 Bridge, 2000 had the 5th lowest low flow on record, 2 cfs. Charts III-11 and III-12 in Appendix G show the peak discharge return periods for the Redwood Creek gauges at Orick and at O'Kane.

Trends in peak flows and low flows over time can provide indicators of watershed disturbance and water withdrawals. Land use activities that remove vegetation and compact soils (resulting in lower rates of precipitation infiltration) can result in higher peak flows and lower low flows for a given amount of precipitation than would occur in the absence of the disturbance. The types of disturbance that can cause such effects include development, road networks, and timber management. Withdrawal of water from streams or fluvially connected groundwater, such as for agricultural or domestic use, can result in a decrease in both peak flows and low flows. Charts III-9, III-10, III-13, and II-14 in Appendix G show moving averages for peak and low flow discharges for the Orick and Blue Lake gauges. While the data are somewhat ambiguous, there may be a trend of decreasing peak flows and decreasing low flows at these two gauges (note: data for Blue Lake are incomplete). The potential data trends have not been controlled for actual precipitation levels, however. Thus, further analysis is needed to draw any conclusions.

When precipitation versus stream discharge is plotted against each other (Figure III- 5), a linear relationship is seen. A steeper trend line is seen at the O'Kane gage, indicating a quicker response of discharge to precipitation. This station is located in the Upper Subbasin and has a smaller upstream drainage area than the station at Orick, and is more immediately affected by rain and rain-on-snow events upstream at the higher elevations in Redwood Creek. Though discharge shows a quicker response to rainfall at O'Kane, there is more scatter in the data than at Orick. The response at the stream gauge is not as predictable as at Orick, where the trendline shows a higher correlation coefficient. Obviously, immediate rainfall as measured at the O'Kane gage does not tell the whole story.

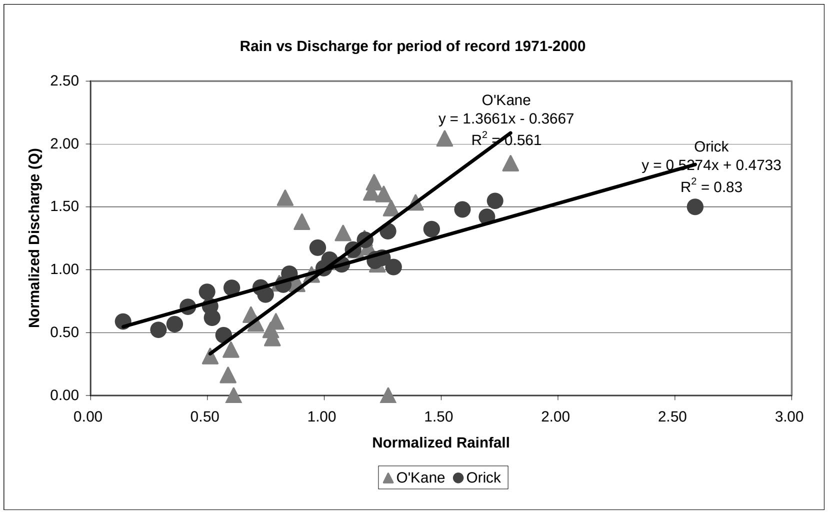

Figure III- 5. Precipitation and streamflow (Discharge) at the O'Kane and Orick gaging stations, 1971 to 200.

All amounts were normalized by dividing by their respective means for the time interval considered.

The Orick station is located very close to the river's mouth, and influenced by nearly the entire Redwood Creek basin. At Orick, the response of discharge to rainfall is slower and more predictable than at O'Kane. It should be noted that very high discharge is very hard to measure accurately (Mary Ann Madej, personal com. 2002). So at higher discharges, it may be difficult to accurately determine a relationship between discharge and other parameters.

The graph showing suspended sediment versus discharge (Figure III- 6) depicts an exponential relationship, as expected. The O'Kane station had one outlier in water year 1973 (probably due to the storms of 1972 and 1973) where the suspended sediment recorded was abnormally high compared to the discharge. This may be due to remobilization of the sediment deposited in the waning stages of the large and catastrophic storm of 1964. Following that storm, there were no large storms until water year 1973, which contained two big storms. A great deal of 1964 sediment was remobilized from stream channels according to previous work (Madej and Ozaki 1996). The remobilized 1964 sediment included fine material, which was carried in suspension and contributed to the much-elevated suspended sediment load. This remobilization may have continued long after the 1964 flood, perhaps explaining the scatter between the suspended sediment and discharge data seen at the Orick station. The large tributary, Prairie Creek, converges with mainstem Redwood Creek just upstream of the gauge. The input of flow and sediments from Prairie Creek may be reflected in the unpredictable fluxes recorded at the gauge. The Orick station is located within the levees constructed in the lower channel, thus perhaps affecting the suspended sediment measurements due to backwater effects caused by the levee design.

Water Diversions and Dams

California law recognizes various types of water rights to surface water flow. Their proof of existence and exercise can often be a complicated and controversial issue. Surface water diversions can have a major impact on stream flow and consequently fisheries habitat. Ground water extractions, with a few exceptions (for example, underground water extractions from "subterranean streams flowing through known and definite channels") are not subject to California law and can also affect stream flow.

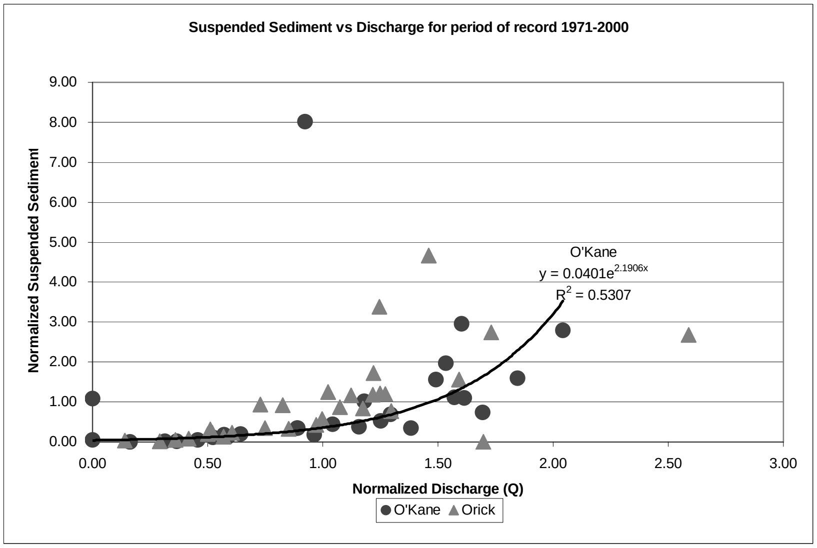

Figure III- 6. Streamflow (Discharge) and suspended sediment at O'Kane and Orick, 1971 to 2000.

All amounts were normalized by dividing by their respective means for the time interval considered.

A description of the different types of surface water rights can be found at the State Water Resources Control Board (SWRCB) web site (waterrights.ca.gov).

The two predominant types of water rights within the Redwood Creek basin are riparian and appropriative. Riparian water rights generally apply to the diversion and use of surface water from a natural watercourse on lands that the watercourse passes through or borders. Appropriative water rights generally apply to the diversion and use of water on lands that do not border the watercourse, or are for water stored for more than 30 days.

A search of the SWRCBs Water Right Information System (WRIMS) was performed to determine the number and types of water rights within the Redwood Creek basin. The WRIMS database is under development and may not contain all post-1914 appropriative water right applications that are on file with the SWRCB at this time. Some pre-1914 and riparian water rights are also contained in the WRIMS database for those water rights whose users have filed a "Statement of Water Diversion and Use". A location map of the known points of diversion is shown in Figure III- 7.

Appropriative water right permits exist for a total of about 780 acre-feet per year (ac-ft/yr) of water from the Redwood Creek basin, at a maximum diversion rate of about 1.1 cfs. Riparian and pre-1914 appropriative water rights for those water users who have filed a "Statement of Water Use" total about 370 ac-ft/yr, at a maximum rate of about 0.5 cfs.

Due to the steep mountainous terrain and most of the basin being owned by private lumber companies or the RNSP, surface water diversions for commercial irrigated agriculture are essentially nonexistent today and are expected to remain so in the future. Water extraction for residential use also appears to be minimal at this time, however there remains a potential to impair stream habitat by any form of water extraction. Ground water sources provided most agricultural water use (Table III- 2 and Table III- 3).

DWR estimates water use for municipal and industrial purposes for the Bulletin 160 series. Table III- 3 presents DWR estimates for water use in 1995 and 2020. Any future water development projects in the Redwood basin should consider cumulative impacts to watershed processes and fisheries resources.

There are a few summer dams on the Redwood Creek mainstem. The dams are mainly used for recreation. Summer dams may impair fish passage and interrupt natural flow and temperature regimes while also modifying aquatic habitat characteristics. Construction and decommissioning of these dams can cause large sediment plumes that extend for miles downstream. All dams need careful review for impacts to stream resources under the CDFG 1600 series permits before construction. The largest dam and associated impoundment is the Chezem dam located in the Redwood Valley area of the Middle Subbasin. The Chezem dam inundates approximately one mile of Redwood Creek channel.

Table III- 2. Agricultural land, water source, and water use within the Redwood Creek basin.

Redwood Creek basin Agricultural Land And Water Use For 1996									
Crop	Water Source (gross acres)				Unit Applied Water (acre-feet per acre)		Water Use (acre-feet per year)		
	Dry	Ground	Surface	Total	Ground	Surface	Ground	Surface	Total
Pasture	663	321	0	984	2.0	na	640	0	640
Potatoes	1	0	0	1	na	na	0	0	0
Total	664	321	0	985	na	na	640	0	640

Table III- 3. Population and water use within the Redwood Creek basin.

Redwood Creek basin Population and Water use DWR Detailed Analysis Unit #28				
Year	Permanent Population	Water Use (Acre-feet Per Year		
		Surface Water	Ground Water	Total
1995	1,000	0	88	88
2020	1,060	0	93	93

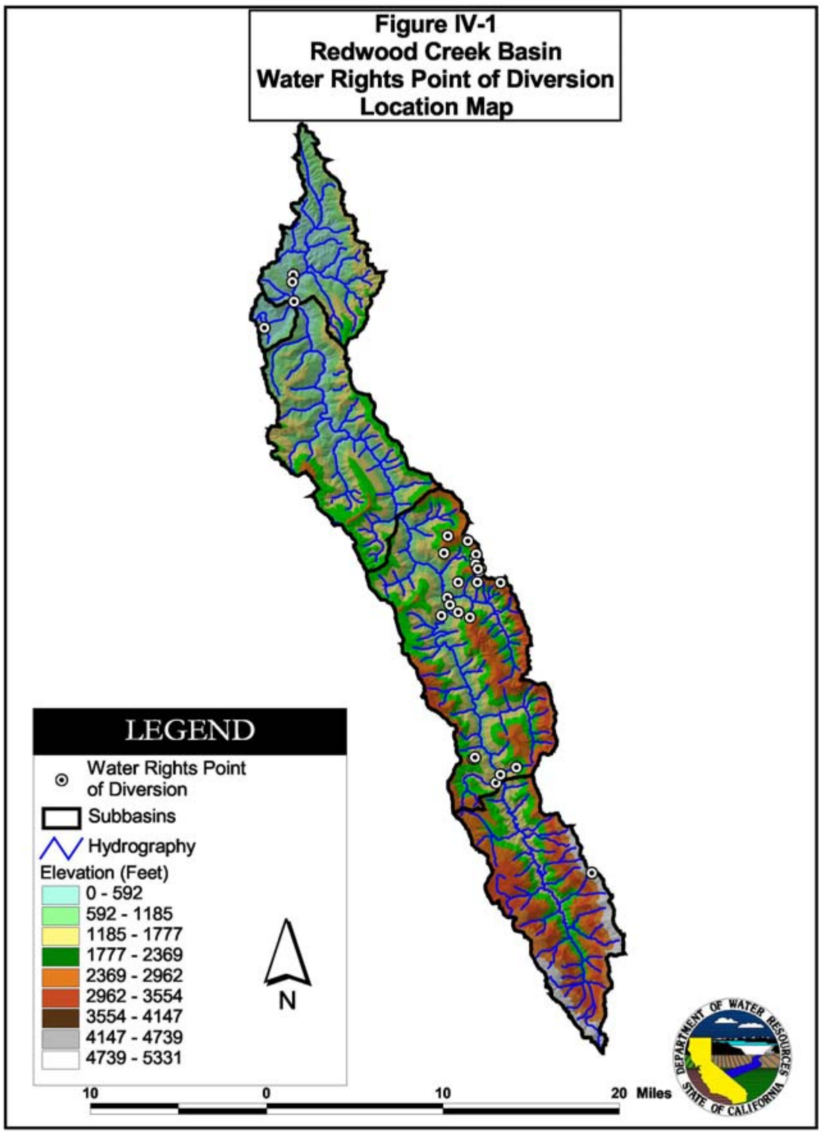

Figure III- 7. Redwood Creek water rights location map.

Geology

The Redwood Creek basin is situated in a tectonically active and geologically complex area, with some of the highest rates of uplift, and seismic activity in North America (Cashman et al. 1995, Merritts 1996). Most of the bedrock underlying the basin has been broken and sheared by tectonic action making it relatively weak, easily weathered, and naturally susceptible to landsliding and erosion. Heavy rainfall, high regional uplift rates, seismicity and weak bedrock combined with impacts from land use produce widespread landsliding and high sediment input to streams.

The overall geologic structure and topography of the basin is dominated by a series of sub-parallel north-northwest trending faults that run parallel to the structural grain of northwest California (Strand 1962; Janda and others 1975; Harden and others 1982). Eleven bedrock units underlie much of the Redwood Creek basin (Figure III-8). The Franciscan bedrock within the basin is divided into fault-bounded units. Progressing generally to the southwest through the basin are the South Fork Mountain Schist, coherent unit of Lacks Creek, incoherent unit of Coyote Creek, altered rocks within the Grogan fault zone, the Redwood Creek schist and the sandstone and mélange unit of Snow Camp Mountain. Older rocks associated with the Klamath Province to the east occupy only a small area in the southeast section of the basin (approximately 380 acres). Relatively young rocks of the Prairie Creek Formation overlying Franciscan Complex rocks underlie most of the basin north of Orick.

The three main units of management concern are the Redwood Creek schist, incoherent unit of Coyote Creek, the coherent unit of Lacks Creek.

Redwood Creek schist (KJfr) Eastern Belt Franciscan Complex. This unit is mostly light green to dark gray fine-grained foliated and crenulated (numerous small folds) quartz-mica schist and underlies the western portion of the basin. The unit is distinctive because of its strongly developed platy (metamorphic) textures and high quartz/mica content. The Redwood Creek schist and South Fork Mountain Schist units appear nearly identical at hand-sample scale. Several other types of rocks occur within the unit, including meta-sandstone, greenstone (altered basalt) and tuff.

Large dormant rotational/translational landslide complexes and earthflows are common along the main channel of Redwood Creek and its western tributaries. These features typically are seen as broad, bowl-shaped depressions in the hillsides that often extend from the Creek to the ridge top. The large features do not appear to be recently active from a geomorphic perspective, but rather contain occasional areas of localized activity. Careful field reconnaissance is necessary to evaluate the relative stability of specific areas on these slopes.

Incoherent unit of Coyote Creek (KJfc) Eastern Belt Franciscan Complex. The Coyote Creek unit consists dominantly of a fine-grained sandstone and shale assemblage that has been pervasively sheared into a mélange by tectonic processes. The unit underlies the Redwood Creek basin east of the Grogan fault (Figure III- 8). The Coyote Creek unit is further characterized by the presence of greenstone, chert and minor conglomerate. Greenstone blocks are found as “floaters” in pervasively sheared mudstone matrix. Soils developing on the bedrock are typically clay rich and highly susceptible to sliding. A small body of igneous rock, the Coyote Peak diatreme is approximately five miles north of Pine Ridge Summit.

Areas dominated by mélange generally form rounded hilltops with gentle slopes and poorly developed side hill drainages. Several large topographic amphitheaters along the east side of the basin appear to have formed in the Coyote Creek unit over time from the long-term episodic action of numerous earthflows. The amphitheaters do not appear to be active throughout their entirety, but rather contain areas of localized activity at any given time. Careful field reconnaissance is necessary to evaluate the relative stability of specific areas within the amphitheaters.

Active earthflows are the main modes of mass wasting in the mélange matrix of the Coyote Creek unit. Mélange matrix typically underlies the expansive grassland and lightly wooded areas present in the southeastern portion of the basin. Well-developed gully networks are common within the more active portions of earthflow complexes and are considered significant sediment sources because they are directly connected to the drainage system.

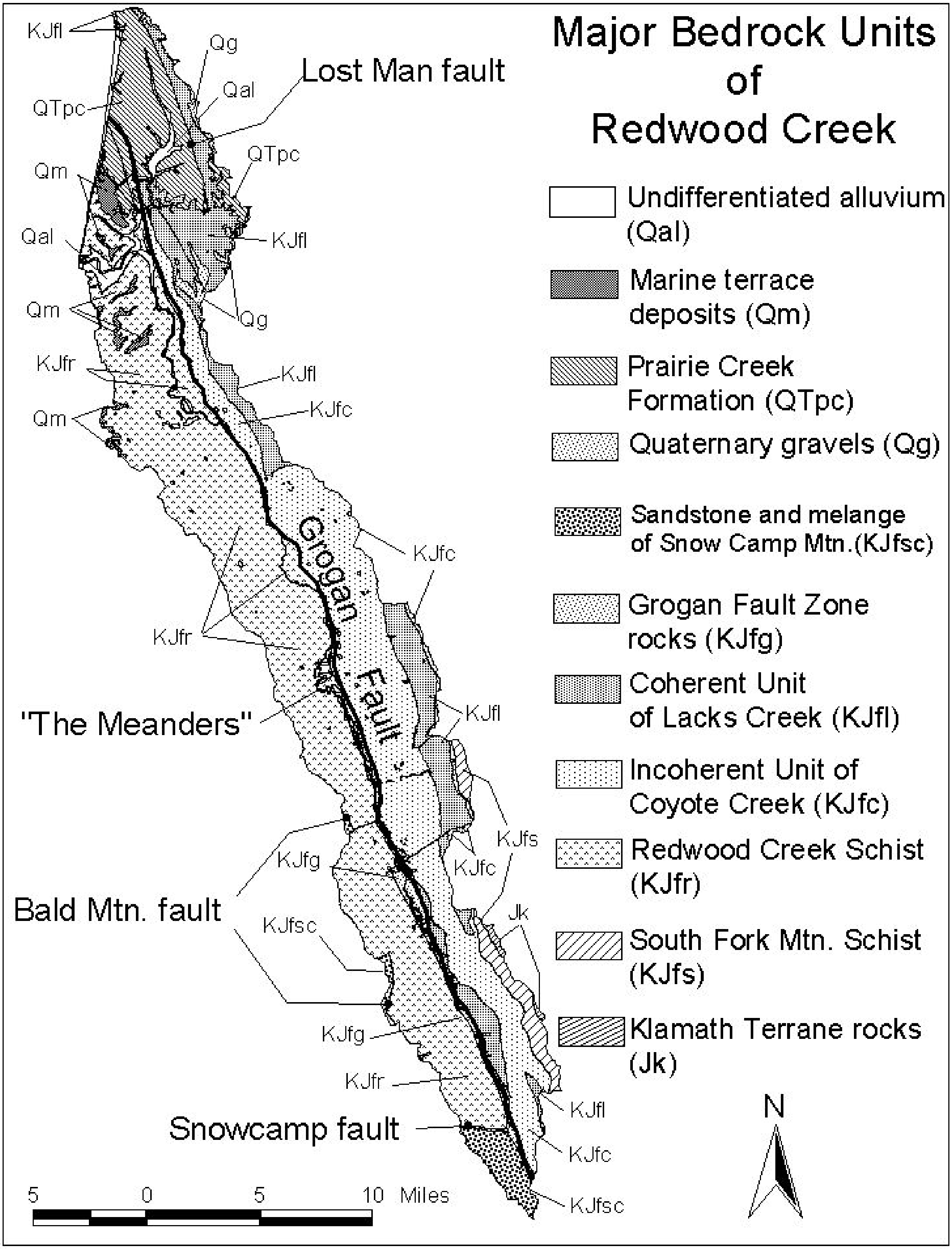

Figure III- 8. Generalized geologic map for the Redwood Creek basin showing distribution of major bedrock units.

<u>Coherent unit of Lacks Creek (KJfl) Eastern Belt Franciscan Complex</u>. This unit underlies the east side of the basin and appears to have two distinct facies. The type locality of the Lacks Creek Unit ("south Lacks Creek facies" in this report) consists of a relatively resistant assemblage of sandstone and mudstone. Relatively intact sections of interbedded sandstone and mudstone show rhythmic bedding and sedimentary structures characteristic of turbidites (repeating sequences of sandstone and siltstone deposited underwater by density currents). Sandstones are composed of lithic greywacke and quartzofeldspathic greywacke (Cashman and others, 1995). Massive sandstone beds are up to 10 m thick and are typically 0.1–3m thick where interbedded with mudstone. Topography is steep and rugged and debris slides slopes are common. This unit is best seen along the northeast side of the basin in the Lacks Creek and Minor Creek drainages.

Harden and others (1982) also mapped the Lacks Creek unit adjacent to the Redwood Creek channel in the Upper Subbasin. The "north Lacks Creek facies" forms gentle topography compared to the "south facies" and is populated with numerous dormant rotational landslides and occasional debris slide slopes. The north facies appears to be more closely related, at least from an overall rock texture basis, to the incoherent unit of Coyote Creek (KJfc), because its topographic style and mode of mass wasting more closely resemble the incoherent unit of Coyote Creek than the south Lacks facies.

Faulting

Faulting dominates the geomorphology of the basin. The faults exhibit a range of orientations from vertical to shallowly dipping (Cashman et al. 1995), are probably Mesozoic in age (older than 66 million years), and appear to have recently reactivated in Quaternary time (past 1.8 million years). The different fault orientations probably represent multiple episodes of deformation and accretionary wedge emplacement.

The Grogan Fault controls the basic shape of the basin and mainstem Redwood Creek flows along its trace of for most of its length. The fault is composed of bedrock units with strikingly different physical properties juxtaposed against one another. This juxtaposition directly influences the topography and the style of and relative amount of mass wasting locally. The degree of activity along the Grogan fault is unclear, but earlier researchers in the basin have reported locations along the fault where river terrace sediments appear to exhibit a sheared fabric and also whe0re Pliocene and Pleistocene sediments have been juxtaposed against Franciscan rocks. Kelsey and Hagans (1982) suggest at least 47 miles of right lateral offset that may have occurred in late Tertiary time (more than 1.8 million years ago). The Grogan fault is mapped by CGS (Jennings and Saucedo 1994) as Quaternary in age (there is no evidence of recent movement, but it appears to have moved within the past 1.8 million years).

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Two additional faults, the Lost Man and Sulphur Creek faults, are oriented parallel to the Grogan fault and offset the Prairie Creek Formation (also mapped as the "Gold Bluffs Formation" in Cashman et al. 1995) in the northern part of the basin. All three faults are readily recognized by their topographic expression and that they cut and offset the Prairie Creek Formation.

Numerous topographic lineaments visible on aerial photographs and hillshade DEMs are present in the basin. The majority of the lineaments are oriented generally parallel to the Grogan fault. It is unclear at this time if these lineaments represent active faulting, coseismic structure, bedrock structure, or a combination of all three. One of the most visible lineaments, the Bridge Creek Lineament (BCL) of Harden, et. al. (1982), may be up to eight miles long based on Hardens mapping. CGS extends the BCL another 10 miles based on aerial photograph, topographic map, and DEM interpretation. The BCL appears to define the channel of Bridge Creek and two Panther Creek tributaries. To the south the BCL appears to coincide with a subtle slope break that continues parallel to the Grogan fault zone southeast toward Highway 299.

Another set of lineaments (Snow Camp Lineaments) occurs in the southwest part of the basin and is expressed as numerous ridge-parallel swales, undrained depressions and wet areas along the ridge top. Irwin (1997) has several of these localities mapped as possible old topographic surfaces. CGS suspects these features may be associated with possible sackungen (depressions formed through gravitational or earthquake-induced spreading of ridge tops; Hart 1997) or pull-apart basins formed at fault step-over zones where blocks between the fault strands drop relative to the ground on either side (Reading 1980; Zachariasen and Seih 1995). Additional lineaments are suggested by straight sections of drainages and changes in the topography. The combined presence of these topographic features strongly suggests geologically recent, possibly Holocene (<10,000 years old) movement along the Grogan fault system (Cashman et al. 1995).

Seismicity

The region experiences a high level of seismic activity, and major earthquakes have occurred along the Cascadia subduction zone as well as within the individual tectonic plates and along well-defined faults (Dengler et al. 1992). The epicenter of the "Eureka Earthquake" of 1954 (magnitude between 6.5 and 6.9; Toppozada, et al. 2000) was mapped very near the trace of the Grogan fault. However, surface rupture was only observed in the Mad River basin near Maple Creek, (T.E. Stephens, personal communication).

Regional Uplift and Erosion

High rates of regional uplift provide a continual source of large amounts of sediment to the basin (Madej 1985). Relative uplift of the Prairie Creek portion of the Redwood Creek drainage is estimated at nearly 1000 feet in Quaternary time (last 1.8 million years) (Cashman et al. 1995). Elevated Quaternary alluvial terraces along the mainstem of Redwood Creek suggest continued uplift and down cutting within the basin. Most of the higher, older fluvial terraces occur on the east side of Redwood Creek, suggesting a significant amount of uplift of the east side of the Grogan fault in its recent geologic history. This regional uplift also generated a tremendous amount of sediment eroded from uplands in the area and deposited offshore.

This regional uplift also generated a tremendous amount of sediment that was eroded from uplands in the area and deposited offshore. Estimates of late Quaternary sediment accumulation in the portion of the Eel River Basin offshore of Redwood Creek are on the order of one mile during the last 600,000 years (McCrory 1989).

An emerging view regarding erosion in regions of rapid uplift is that erosion rates adjust to high rates of tectonically driven uplift primarily through changes in the frequency of landsliding rather than increases in slope-wash, other hillside erosion, or hillslope steepness (Montgomery and Brandon 2002). Evaluation of the relation between erosion rate and local relief reveals a linear trend for areas with low erosion rates (slow increase in erosion rate as elevation increases) and a highly non-linear relation where erosion rates are highest, as in the case of tectonically active mountain ranges (dramatic increase resembling a quadratic/hyperbolic curve in erosion rate as elevation increases). This has been demonstrated quantitatively using 10-m DEM data in the Pacific Northwest and larger, global-scale analyses. The Pacific Northwest data appear to be very similar to the "global" results when comparing climate, erosion rates, and topography in tectonically equivalent regions. The implication is that climatically driven changes in rates of valley incision play only a small role in controlling landscape-scale erosion rates indicating that the main factor may be the rate of regional uplift.

Inland, relatively steep inner gorge (or "valley-within-valley") topography appears to have developed in the Upper and Middle subbasins in response to this uplift. Slopes immediately adjacent to the creek tend to be steeper than those further uphill and appear to have developed in response to uplift, active channel incision (down-cutting to reach original base level) and attendant accelerated mass wasting close to the channel in response the regional uplift. These mass-wasting sources are significant, natural sediment sources in the Redwood Creek Basin.

Transitional rocks of the Grogan Fault zone underlie much of the inner gorge, particularly in the southern half of the basin (Figure III- 8). Statistical determination of the typical slope at which mass wasting occurs within the Grogan fault zone indicates that this unit tends to fail at a steeper slope (42%) than any of the surrounding units (32 to 35%). The steeper slope is probably related to inner gorge development. Inner gorge areas appear to be particularly unstable because the steep slopes combine with emergent groundwater (Fetter 1980; Freeze and Cherry 1979) to reduce overall slope stability within the hillsides (Bell 1998; Rahn 1996; Griggs and Gilchrist 1977; Duncan 1996; Sowers and Royster 1978). The combination of tectonic, geologic, topographic and groundwater factors have formed a broadly convex topographic profile from the Redwood Creek channel up to the ridge crests (Kelsey 1988; Janda and others 1975).

The steepest slopes near the creek reportedly have thinner soil profiles indicating that these surfaces are younger and more dynamic than the hill slopes farther away from the channels (Janda and others 1975) and this correlates with the high rate of mass wasting observed on these types of slopes. Inner-gorge areas appear to be particularly unstable because they are steeper slopes and emergent groundwater combines with the steepness to increase driving forces within the hillsides, making them naturally more susceptible to mass wasting.

Numerous broad, concordant upland surfaces and even-crested ridges have been identified throughout Northwest California and Southwest Oregon. These features were first described a century ago by Diller (1902) and have also been interpreted and mapped by numerous other geologists as ancient remnants of a widespread, low relief landscape (Irwin 1997). Although this surface is thought to be early Pliocene (Batt 2002) or late Miocene aged (Irwin 1997), fossils indicate that portions of these surfaces are early Pleistocene aged east of Crescent City (1.8 million years old; Irwin 1997). Many of these topographic features are also present in the Redwood Creek region. Typical examples are Christmas Prairie on the west side of the drainage south of Highway 299, Schoolhouse Prairie to the northeast, and broad flat-topped ridges on both sides of the basin southeast of Orick. CGS interprets many of these features in the north portion of the basin as underlain by marine terrace deposits or sediments associated with the Prairie Creek Formation.

Roads, Timber Harvest, and Mass Wasting

Roads have been long been identified as major sources of sediment in watersheds, through a combination of surface erosion, watercourse diversion, and mass wasting (Best and others 1995; USEPA 1998; Gucinski and others 2000; Weaver and Hagans 1994; Packer and Christiansen 1977). We evaluated the incidence of “point landslides” (less than 1/5 acre) relative to their distance from mapped roads. The incidence of point landslides within about 75 feet of roads is approximately 58% greater than that beyond 150 feet. The incidence of point landslides is relatively linear between 75 and 300 feet away from mapped roads and may represent the natural, or “background” rate.

This higher incidence of sliding near roads is similar to qualitative road/landslide interaction observations by CGS representatives during timber harvest reviews and quantitative findings by Redwood National Park and USEPA researchers. For example, Madej (U.S. Geological Survey 2001, written communication.) and geology staff from Redwood National and State Parks evaluated 358 landslides that occurred in Redwood Creek basin during the 1997 storm season. Researchers determined which slides were associated with roads using air photos taken the summer after the flood. Madej found that although the number of landslides associated with roads was about the same as other areas, the road-related landslides were larger and accounted for a much greater volume of sediment than non-road-related landslides. Pitlick (1995) earlier found that the frequency of landslides was the same for logged and unlogged slopes. However, he found that slides in cut areas were substantially larger and account for nearly 80% of the total landslide related erosion in his study of seven sets of aerial photographs spanning the period from 1954 to 1978. Failures were more often associated with roads in the logged areas and these slides produced the largest amount landslide-related sediment. Sediment production by mass-movement processes and streambank erosion is sometimes less clearly related to land use, and also more difficult to control, than fluvial hillslope processes on roads.

Results and Analysis from Landslide and Relative Landslide Potential Mapping

Historically active landslide features comprise 5.6% (>10,000 acres) of the Redwood Creek basin area (Table III- 4). Of these, earthflows predominate, comprising 4.2% of the basin area and 75% of the area of historically active landslide features. Rockslides are the next most dominant feature, comprising 0.9% of the basin area and 17% of the area of historically active landslide features. The Lower, Middle and Upper subbasins have the highest proportions of their areas in historically active landslide features. The Estuary and Prairie Creek subbasins have less area in historically active landslide features (0.1% and 1.4%, respectively) relative to the other three subbasins and to the basin as a whole.

Table III- 4. Historically active landslide features of the Redwood Creek basin and subbasins.

Basin or Subbasin	Historically Active Landslide Feature1	Entire Basin or Subbasin	
		Area (acres)	% of Area
Redwood Creek basin 180,688 acres 1,479 road miles	Earthflow	7,602	4.2%
	Rock Slide	1,710	0.9%
	Debris Slide	591	0.3%
	Debris Flow	170	0.1%
	All Features	10,073	5.6%
Estuary Subbasin	All Features	2	0.1%
Prairie Creek Subbasin	All Features	348	1.4%
Lower Redwood Subbasin	All Features	2,662	6.0%
Middle Redwood Subbasin	All Features	4,166	6.5%
Upper Redwood Subbasin	All Features	2,892	6.7%

Dormant landslides are the predominant slope instability feature in the Redwood Creek basin, accounting for 38,837 acres or over 21% of the basin (Table III- 5). The term “dormant” is used to refer to landslides that do not exhibit evidence of recent movement to approximately 150 years ago. Some of the dormant landslides may have ages dating back into the Quaternary. The relationship between recent shallow small landslides (represented as points on the maps) and the surrounding deep seated, dormant landslides has not been studied in sufficient detail to resolve the amount of instability that is the result of recent land use versus the amount that is due to underlying long-term geologically driven effects. Disrupted ground is the second largest slope instability feature, covering 18,782 acres or over 10% of the basin. These are areas of irregular slope that cannot be conclusively shown to be mass wasting related. The topography may be caused by shallow soil creep or differential erosion of the underlying bedrock, rather than discrete landslides or earthflows. Looking across the Redwood Creek Basin, the Upper Subbasin has the greatest signature of slope instability, with 85% of the subbasin covered by slope instability features. In contrast, only 19% of the area of Prairie Creek contains features indicative of slope instability.

Table III- 5. Combined indicators of slope instability.

Basin or Subbasin	Slope Instability Features	Acres	% of Area
Redwood Creek basin	Historically Active Landslide Features Total	10,073	5.6%
	Dormant Landslide Features Total	38,837	21.5%
	Selected Geomorphic Features Total	31,215	17.3%
	Disrupted Ground	18,782	10.4%
	Debris Slide Slope	10,599	5.9%
	Inner Gorge (area)[1]	1,834	1.0%
	Total of All Above Basin Features	**80,125**	**44.4%**
Estuary Subbasin	Historically Active Landslide Features Total	2	0.1%
	Dormant Landslide Features Total	700	20.0%
	Selected Geomorphic Features Total	617	18.0%
	Disrupted Ground	277	8.0%
	Debris Slide Slope	337	10.0%
	Inner Gorge (area)	3	0.0%
	Total of All Above Subbasin Features	**1,319**	**38.5%**

Basin or Subbasin	Slope Instability Features	Acres	% of Area
Prairie Creek Subbasin	Historically Active Landslide Features Total	348	1.4%
	Dormant Landslide Features Total	2,022	8.0%
	Selected Geomorphic Features Total	2,493	10.0%
	Disrupted Ground	355	1.0%
	Debris Slide Slope	2,067	8.0%
	Inner Gorge (area)2	71	0.0%
	Total of All Above Subbasin Features	**4,863**	**19.2%**
Lower Redwood Subbasin	Historically Active Landslide Features Total	2,662	6.0%
	Dormant Landslide Features Total	5,263	11.8%
	Selected Geomorphic Features Total	5,540	12.5%
	Disrupted Ground	2,831	6.4%
	Debris Slide Slope	2,472	5.6%
	Inner Gorge (area)	236	0.5%
	Total of All Above Subbasin Features	**13,464**	**30.3%**
Middle Redwood Subbasin	Historically Active Landslide Features Total	4,166	6.5%
	Dormant Landslide Features Total	15,150	23.7%
	Selected Geomorphic Features Total	13,495	21.1%
	Disrupted Ground	10,099	15.8%
	Debris Slide Slope	2,943	4.6%
	Inner Gorge (area)	453	0.7%
	Total of All Above Subbasin Features	**32,811**	**51.2%**
Upper Redwood Subbasin	Historically Active Landslide Features Total	2,892	6.7%
	Dormant Landslide Features Total	15,702	36.3%
	Selected Geomorphic Features Total	9,070	21.0%
	Disrupted Ground	5,219	12.1%
	Debris Slide Slope	2,780	6.4%
	Inner Gorge (area)	1,071	2.5%
	Total of All Above Subbasin Features	**27,664**	**64.0%**

[1] Area based on inner gorges captured as polygons plus inner gorges captured as linear features, which are treated as having an average width of 100 feet.

Analysis of the resulting relative stability map enabled CGS to approximate the relative distribution of slope stability classes at the basin-wide, subbasin, and planning watershed scale (Figure III- 9). Overall, approximately 38% of the basin is in the very high landslide potential class and approximately 34% is in the high potential class; together, these two highest classes comprise about 72% of the Redwood Creek basin area, indicating that the basin is highly unstable. The most stable classes, very low and low, each comprise about 15% of the basin area.

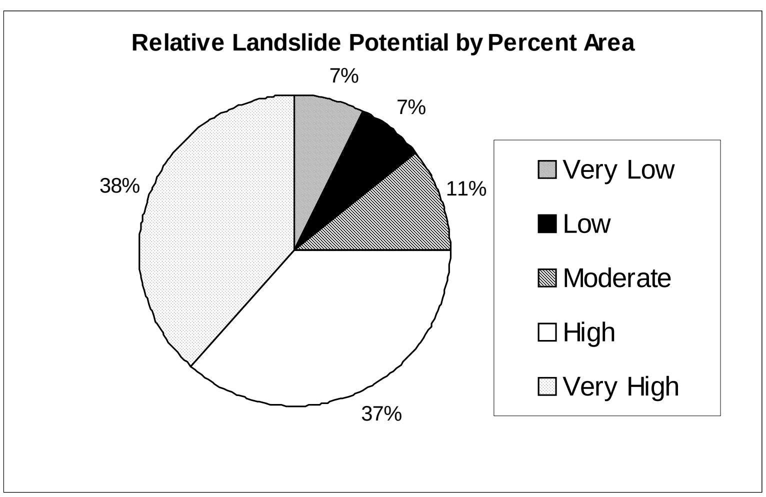

Figure III- 9. Overall landslide potential in the Redwood Creek basin.

Many of the naturally occurring problems resulting from slope instability have been, and may continue to be, compounded by human activities. As a result of approximately 72% of the basin being in the two highest landslide potential classes, adverse effects should be expected to continue unless proposed projects and existing problem sites are carefully evaluated and mitigated from a slope stability and potential sediment production perspective. Past land-use practices associated with road construction, timber harvesting, burning, and livestock grazing have contributed large volumes of sediment to streams. This, in turn, directly affects existing and potential fish habitat, water temperature, and chemistry. Adverse effects can continue for decades in certain parts of the basin, particularly the lower mainstem of Redwood Creek.

Looking across the Redwood Creek basin at the subbasin level, the data (Table III- 6) show that the estuary and Prairie Creek subbasins are significantly more stable than the basin as a whole. The Middle and Upper subbasins are less stable than the basin as a whole. Note that the Middle Subbasin has over 80% of its area in the high/very high relative landslide potential class and the Upper Subbasin is 73% covered by this class.

Taken together, the above data on historically active landslide features and relative landslide potential paint a picture of the geologic instability of the Redwood Creek subbasins. The Estuary and Prairie Creek subbasins appear significantly more stable than the other subbasins and the basin as a whole. The Middle and Upper subbasins appear to be the most geologically unstable parts of the basin based on this study. As will be illustrated repeatedly through this report, this picture has important ramifications for the generation and movement of sediment from the hillslope into the stream system and through the stream system to the ocean. Land management activities on these unstable areas often exacerbate slope instability and the release of sediment. Site-specific studies should be conducted by licensed geologists in order to recommend mitigation measures to reduce land disturbance and associated erosion.

Table III- 6. Relative landslide potential of the Redwood Creek basin, by acres and percent of area.

Basin or Subbasin	Relative Landslide Potential[1]	Entire Planning Watershed	
		Area (acres)	% of Area
Redwood Creek basin	Very Low	13,606	7.5%
	Low	14,298	7.9%
	Moderate	22,285	12.4%
	High	60,841	33.7%
	Very High	69,361	38.5%
	High/Very High Subtotal	**130,202**	**72%**
	Basin Total	180,391	100%
Estuary Subbasin	Very Low	1,457	42.4%
	Low	67	2.0%
	Moderate	216	6.3%
	High	1,200	35.0%
	Very High	486	14.2%
	High/Very High Subtotal	**1,686**	**49.0%**
	Subbasin Total	3,426	100%
Prairie Creek Subbasin	Very Low	3,492	13.8%
	Low	3,017	11.9%
	Moderate	4,565	18.0%
	High	9,480	37.5%
	Very High	4,750	18.8%
	High/Very High Subtotal	**14,230**	**56.0%**
	Subbasin Total	25,304	100%
Lower Subbasin	Very Low	2,666	6.0%
	Low	3,028	7.0%
	Moderate	7,259	16.3%
	High	17,431	39.2%
	Very High	14,033	31.6%
	High/Very High Subtotal	**31,064**	**71.0%**
	SUBBASIN TOTAL	44,417	100%
Middle Subbasin	Very Low	2,689	4.2%
	Low	28,68	6.0%
	Moderate	6,002	9.4%
	High	20,402	31.9%
	Very High	31,023	48.5%
	High/Very High Subtotal	**51,425**	**80.4%**

Basin or Subbasin	Relative Landslide Potential[1]	Entire Planning Watershed	
		Area (acres)	**% of Area**
	Subbasin Total	63,984	100%
Upper Subbasin	Very Low	3,302	7.6%
	Low	4,318	10.0%
	Moderate	4,243	9.8%
	High	12,328	28.5%
	Very High	19,069	44.1%
	High/Very High Subtotal	**31,397**	**72.6%**
	Subbasin Total	43,260	100%

[1] Refer to Relative Landslide Potential Map, Plate 2, and California Geological Survey Appendix. Percent of area is based on the unit of analysis: Basin or subbasin.

Slopes Greater than 35 Percent

CGS evaluated mass wasting in all modes of movement as a function of geologic unit and slope inclination (Figure III- 10). The analysis was performed to show the typical slope within mapped landslides in most of the bedrock units in the basin (including QTpc, QTg, and QTm). Geologic units appearing to have similar characteristics based on aerial photograph interpretation were grouped together for clarity. The data sets consisted of the mapped landslides, bedrock geology, and the DEM for the basin. The result was that, regardless of failure mode, 19–22° (34 to 40%) was the typical slope range within mapped landslides. The curve showing the population of landslides dropped off markedly beyond a 35% slope (called the "break point" in this document), indicating that failure was rare on slopes steeper than 35%. This phenomenon most probably occurred because earth materials available for mass wasting had already slid and/or the old landslides were so modified by erosion that they were unrecognizable. Based on this analysis, slopes beyond 35% in most of the bedrock units were treated as having the highest probability for failure.

Two geologic groups fell outside the main population (Figure III- 10). The break point for the remaining young Quaternary unit population (alluvium: "all other Q") was approximately 14° (25%). The lower break point is reasonable because these materials are unconsolidated and very young from a geologic point of view. The break point for rocks associated with the Grogan Fault was approximately 23° (42%) (KJfg). Grogan Fault rocks dominate most of the inner gorge of Redwood Creek. The higher typical slope at failure may indicate either that these rocks are more resistant to erosion than their neighbors, or that the slopes are merely steeper than adjacent land, possibly both. More study is required to resolve this issue.

Data used to develop Figure III- 10 contributed to the ranking of bedrock units as a function of slope during the development of our relative stability map. These types of GIS-based failure evaluations provided a means of generally assessing the relative rock strength of individual units in the absence of more formal geotechnical data. CGS also performed several GIS-based statistical evaluations regarding the relative amount of mapped active, dormant, and point landslides by geologic unit (see Appendix E). Dividing the total landslide area by the total area of the unit in question in all the analyses normalized the relative abundance of landslides unit by unit. This process was intended to prevent the "signal" from smaller map units on the maps from being overwhelmed by much larger units. General unit characteristics were more effectively compared statistically on a side-by-side basis in this manner. Land management activities on slopes greater than 35% should be reviewed by a licensed geologist and carefully mitigated (or avoided, if necessary) to reduce the potential for slope failure.

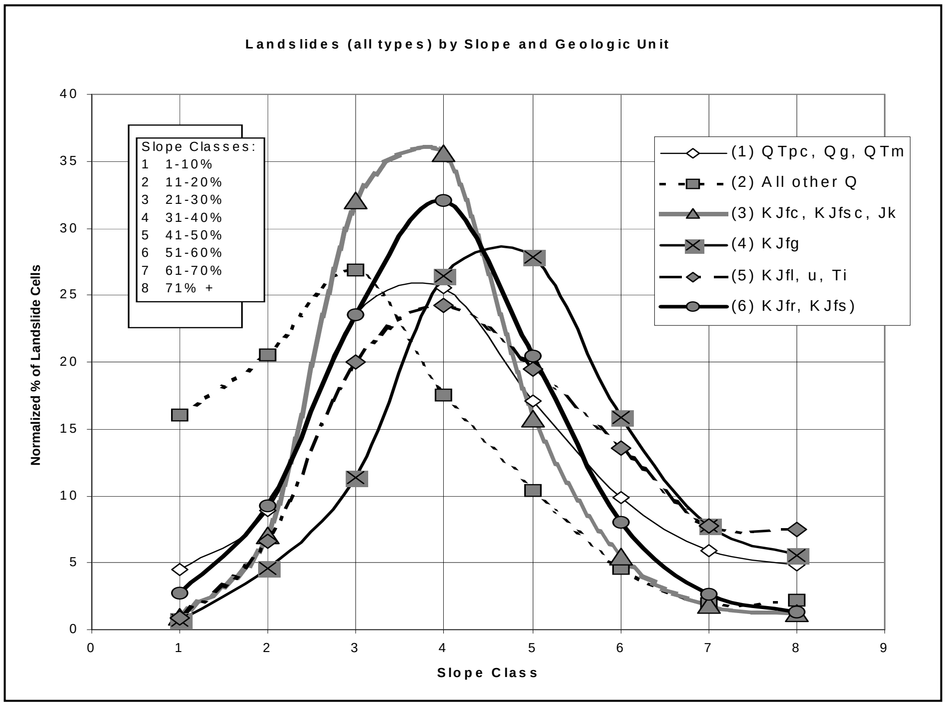

Figure III- 10. Rate of failure of all types of landslides by slope and geologic unit.

Burning and Schist Soils

Several factors appear to cause a significantly higher surface erosion rate after logging in areas underlain by schist (KJfr, KJfs) than on comparable slopes underlain by different parent material (Marron, et al. 1995). The main factor appears to be how exposure of schist soils to ash leachate causes them to become less cohesive and readily erodible. Schist soils (Sites series) in the basin are described as rich in kaolinite clay (http://www.statlab.iastate.edu/cgi-bin/osd/osdname.cgi?-P), and varying from non-sticky to slightly sticky when wet (University of California 1965).

Clay minerals have a platy form and many types of clay adhere together in tiny book-like clumps (flocculate) because of attractive charges between the particles. Such clays are known as flocculated clays and are cohesive (cling together well). Cohesive clays are relatively resistant to erosion as a result (Bell 1998). Not all clays are cohesive, however. Kaolinite is a clay mineral that has a relatively low cohesion and is susceptible to dispersion when exposed to ash leachate (Holcomb and Durgin 1979). Dispersed clays have an open structure because selected ions in groundwater have attached to the particle surfaces. Attractive forces between particles are weakened as a result. Kaolinite is commonly found in well-developed soils atop Redwood Creek Schist bedrock.

The western side of the Redwood Creek drainage, from the estuary subbasin to the upper part of the upper subbasin, is underlain by schist bedrock (KJfr) (Figure III- 8). As a general recommendation, the use of fire for site preparation purposes should be minimized on schist soils during warm, dry periods (late summer and fall). Such fires have the potential to burn excessively hot, potentially creating hydrophobic soils and sterilizing surface soils. Burning can also generate ash leachate that interacts adversely with schist soils, making them more erodible than other soils. Where fire is used, burning after fall rains or in the spring is recommended so the fires transfer less heat to soils, create less ash, and are easier to control.

Fluvial Geomorphology

Fluvial geomorphology is the study of stream processes and channel forms. To aid in the assessment of stream processes and stream-habitat quality, the NCWAP geomorphologists mapped stream features from aerial photographs. These included features indicative of disturbance (disturbance-features) associated with erosion and excessive in channel sediment such as widened and multi-thread channels, mid-channel bars, bank erosion, shallow landslides adjacent to channels, and excessive lateral bars. By photo year 2000, there were a greater proportion of more stable features including point bars and vegetated bars which are not considered disturbance features for the analysis.

The study of sediment conditions was particularly important in Redwood Creek since the basin is listed as sediment-impaired under Section 303(d) of the Federal Clean Water Act (see http://www.swrcb.ca.gov/rwqcb1/programs/tmdl/tmdlprogram.html).

Redwood Creek basin has been described as "one of the most highly erodible basins in the United States. The combination of naturally unstable terrain and infrequent, unusually severe storms (such as the one that occurred in northern California in December 1964) and intensive timber harvesting can trigger major episodes of erosion" Madej (1984b). Earlier studies showed that the damage caused by the flood of December 1964 was severe, widespread and simultaneous (Kelsey and others 1981; Madej 1984a,b; RNSP 1999). Previous workers concluded that the widespread damage to the stream network occurred because of the nature of pre-1964 land use (see U.S. Geological Survey Professional Paper 1454).

During the flood of 1964, stream sediment was greatly elevated by the erosion of instream landings and roads in Redwood Creek. Cut logs blocked active channels with massive logjams. Behind the logjams, flood sediment was found dammed upstream. Studies by RNSP showed that the logjams broke down over time, allowing trapped sediment to be released and transported downstream over decades. Bedload sediment, including volumes of fine sediment, accumulated in excess in lower gradient response reaches in the lower part of the mainstem channel. The sediment that accumulated in response reaches impacted fish habitat for decades, affecting such channel characteristics as pool depth (RNSP 1999), complexity, and spawning substrate embeddedness.

Meanwhile, upstream storm sediment from 1964 remained in storage, adjacent to the active mainstem channel and available for remobilization during subsequent storms and floods. Sediment stored outside the channel was temporarily stabilized by vegetation and could be remobilized during sufficiently high storm flows. As an example, in the discussion of RNSP cross sections that follow, sediment was remobilized from longer-term storage at cross section 25 causing a large dip in the longitudinal cross section for the mainstem channel.

The floods of 1972 and 1975 redistributed the 1964 flood sediment. Cross section data indicate the channel has aggraded (i.e., the channel bed has risen due to deposition of sediment) significantly across its entire width in the northern, lower portion of the mainstem of Redwood Creek (RNSP 1999). The elevated bedload sediment accumulated in lower gradient stream reaches has remained for decades.

Stream Gradient and Reach Classification

Stream gradients determine patterns of sediment transport and accumulation in the stream network. Stream classification is based in part on gradient. The NCWAP channel classification was modified from Montgomery and Buffington (1993) to be more compatible with the stream classification of Rosgen (1996). Montgomery and Buffington (1993) described several types of stream reaches as follows:

- **Source Reaches** are "transport-limited, sediment storage sites subject to intermittent debris flow scour;
- **Transport Reaches** are morphologically resilient, high-gradient, supply-limited channels that rapidly convey increased sediment inputs;
- **Response Reaches** are low-gradient, transport-limited channels *in which significant morphologic adjustment occurs in response to increased sediment supply* (emphasis added).

Montgomery and Buffington (1993) stated that the "…cumulative effects of upstream increases in sediment supply are magnified in a response reach where longer time and/or significant morphological change is required to transport the additional sediment." They further stated that response reaches "are of fundamental concern for aquatic resource management because of the associated habitat values."

The lower gradient response reaches of Redwood Creek basin streams (<4%) are predominantly where the coho and Chinook salmon occur. The accumulation of sediment in these response reaches over decades has impacted fish habitat for multiple generations of anadromous salmonids. RNSP and USGS cross section data show the progression of sediment down the mainstem since the storms in 1975. Aggradation has been so extensive in lower Redwood Creek that it has filled in deep pools and locally inhibited the surface flow of stream water (D. Anderson, RNSP, personal communication).

Most of the mainstem channel of Redwood Creek (90%) and Prairie Creek (>90%) are shallow response reaches, less than 4% in gradient. These are located mostly in the Redwood Creek mainstem and these areas accumulate sediment most readily and may hold it for decades. In contrast, more than half of the tributary channels are source reaches and have gradients >20% (Figure III- 11 and Table III- 7). Most stream reaches in the Estuary Subbasin have the lowest gradients <1% (Table III- 7), while 15% of Prairie Creek and 3.8% of lower Redwood Creek have such low gradients (<1%). In the lower subbasin, 15% of the stream network has a gradient below 4%. Length and percent of transport reaches make up 48% of Upper Redwood Creek and 43% of Prairie Creek. Source reaches dominate tributaries and comprise 44-61% of the subbasins as follows: Lower (44%), Middle (61%), and Upper (48%) (Figure III- 12 and Table III- 8). Source reaches in the tributaries are the areas that will generate sediment. Some sediment input is natural and the result of unstable hillslopes, whereas some erosion is excessive and caused by human activity on those unstable hillslopes (gully formation, for example) and near streams.

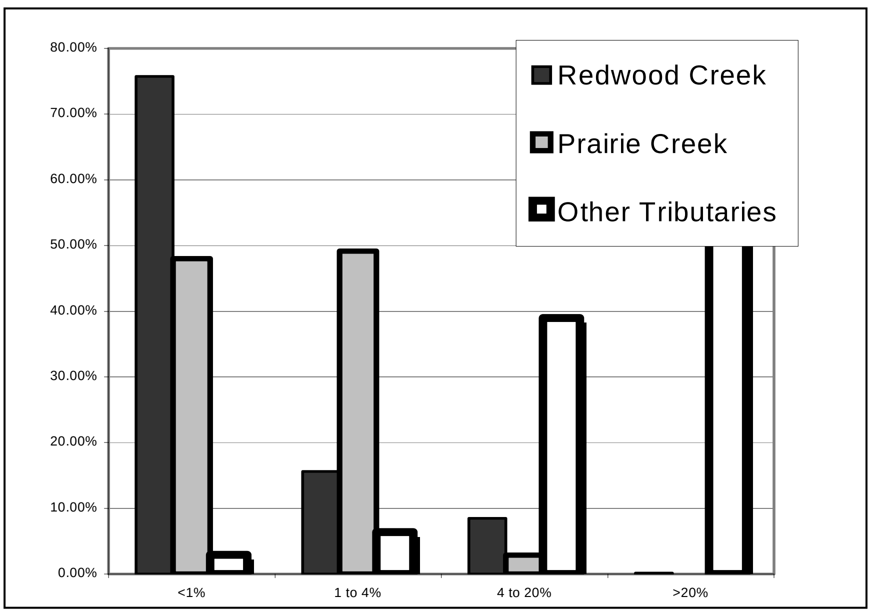

Figure III- 11. Distribution (percent by length) of stream gradients.

The tributaries are dominated by steeper gradients and contrast with the mainstem channel.

Table III- 7. Gradient distribution for the mainstems of Redwood and Prairie creeks, and other tributaries.

Redwood Creek Mainstem				
Gradient	**Reach Type**	**Meters**	**Miles**	**Percent**
<1%	Response	82,158	51.05	75.75%
1 to 4%	Response	16,942	10.53	15.62%
4 to 20%	Transport	9,182	5.71	8.47%
>20%	Source	180	0.00	0.17%
Total		**108,462**	**67.40**	**100.00%**
Tributaries				
<1%	Response	17,612	10.94	2.92%
1 to 4%	Response	38,508	23.93	6.39%
4 to 20%	Transport	234,765	145.88	38.97%
>20%	Source	311,503	193.56	51.71%
Total		**602,387**	**374.31**	**100.00%**
Prairie Creek Mainstem				
<1%	Response	7,073	4.39	47,99%
1 to 4%	Response	7,244	4.5	49.15%
4 to 20%	Transport	422	0.26	2.86%
>20%	Source	0	0.00	0.00%
Total		**14,739**	**9.16**	**100.00%**

The mainstem and Prairie Creek are dominated by lower gradients while the tributaries are dominated by steeper gradients.

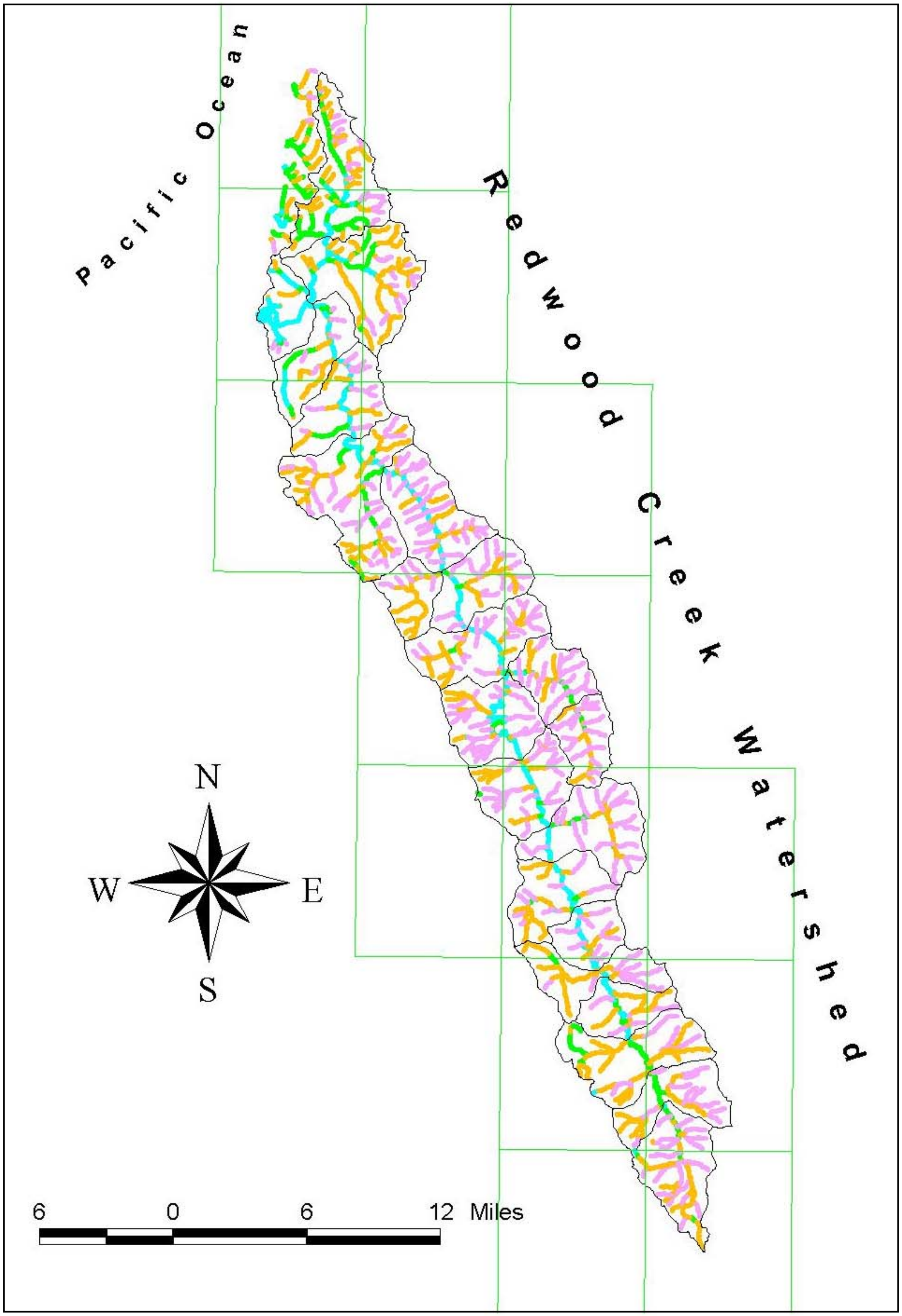

Figure III- 12. Redwood Creek basin channel reaches by channel gradient classes.

Source reaches are >20% (purple), transport reaches are 4-20% (gold), and response reaches are 1-4% (green) and 0-0.99% (blue). Channel gradients were calculated from USGS 10-meter-grid DEMs. Green grid lines are boundaries of USGS 7.5-minute topographic maps; gray lines are boundaries of CalWater 2.2 planning watersheds.

Table III- 8. Length and percent of stream reaches in source, transport, and response categories.

Reach Type and Gradient	Unit of Measure	Redwood Creek basin	Subbasin				
			Estuary	Prairie Creek	Lower	Middle	Upper
Response							
0-0.99%	Length (miles)	22.4	6.8	11.4	3.8	0.8	0.8
	% of stream length	5.0	69.1	15.3	3.8	0.5	0.7
1-3.99%	Length (miles)	43.2	0.9	19.1	10.9	8.5	3.8
	% of stream length	9.6	8.7	25.6	10.7	5.3	3.7
Transport							
4-9.99%	Length (miles)	84.0	1.0	21.6	20.5	23.7	17.3
	% of stream length	18.7	9.7	29.0	20.2	14.7	16.7
10-20%	Length (miles)	94.4	0.7	10.4	21.4	29.3	32.5
	% of stream length	21.0	6.8	14.0	21.2	18.1	31.4
Source							
>20%	Length (miles)	205.7	0.6	12.0	44.6	99.2	49.2
	% of stream length	45.7	5.6	16.1	44.1	61.4	47.5
Total Length (miles)		**449.7**	**9.8**	**74.5**	**101.3**	**161.6**	**103.7**
% of basin stream length		**100.0**	**2.2**	**16.6**	**22.5**	**35.9**	**23.1**

Suspended Sediment, Channel Cross Sections, and Sediment Budget

RNSP provided data regarding precipitation, peak discharge and suspended sediment loads. Precipitation records are available from stations near the mouth of Redwood Creek (above Orick), in the upper middle subbasin near the O'Kane bridge along Highway 299, and in Little Lost Man Creek (LLM). Records that were available from 1954 to 2000 showed that water year 1983 was the wettest, with more than 100 inches at Orick, while relatively large storms occurred in 1955, 1964, 1972, and 1975. Peak stream flow at the Orick gage occurred during the storms of 1955, 1964, 1972, and 1975. Peak flow during the recent storm of 1996/1997 was smaller than in those previous storms.

Figure III- 13 shows suspended-sediment load per area at the Orick and O'Kane gages. Orick had a very high value in water year 1973, which included the first large storm since 1964. Figure III- 14 shows the ratio between suspended sediment measured at O'Kane and Orick from 1973 to 1997. During the decade of the 1990's, the ratio exceeded one. This means that the upper basin above Highway 299 contributed more suspended sediment than was measured near Orick in the lowest part of the basin. The trend indicates that more sediment was entering the basin than was going out.

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

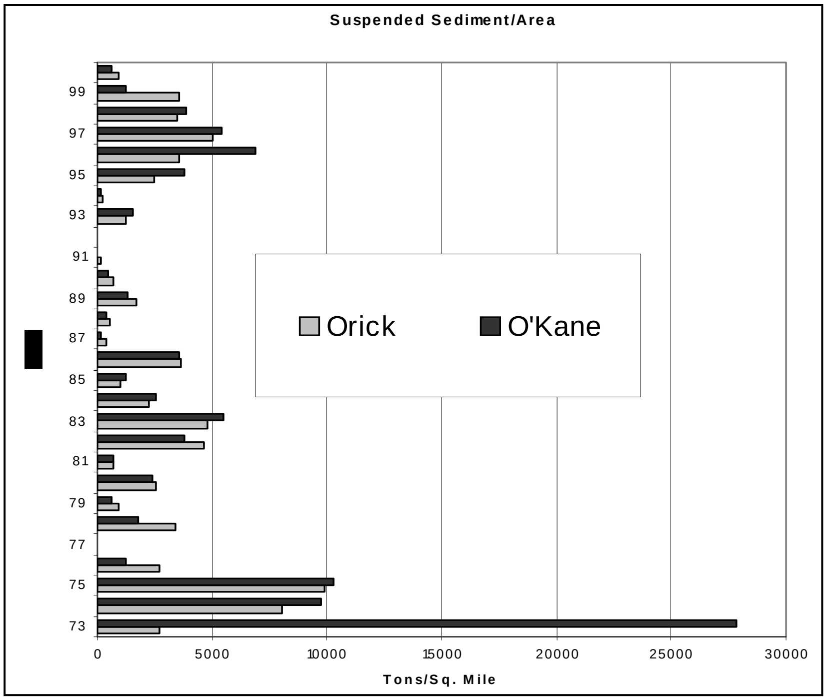

Figure III- 13. Suspended-sediment load per area from 1974 to 2000 at Orick and O'Kane (Hwy 299) stations.

Water years 1974 and 1975 show relatively high loads of suspended sediment

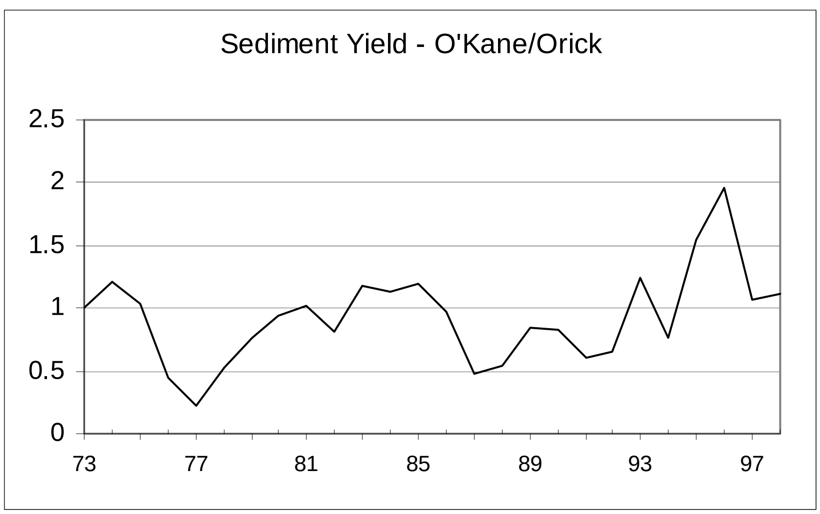

Figure III- 14. Ratio between suspended sediment load at O'Kane (Highway 299) and Orick, 1973-1998.

Time period is portrayed on the X axis and the ratio between O'Kane and Orick is shown on the Y axis. The proportion of sediment from the upper part of Redwood Creek has generally increased between 1987 and 1997 In 1993, the Upper Subbasin (measured at O'Kane) has generally produced more suspended sediment per acre than measured at Orick as indicated by the steady rise above the 1 to 1 ratio.

Cross Section Monitoring

In 1973, the USGS began to monitor long-term mainstem channel stability after Redwood Creek had experienced widespread timber harvest, road building, and a series of large floods (1953, 1955, 1964, 1972, and 1975). The purpose for the cross section monitoring study was to document channel responses in the basin. Following initiation of the monitoring program by the USGS, Redwood National and State Parks (RNSP) continued monitoring the mainstem channel. By the late 1990s, monitoring showed channel widening, and increased stored sediment and streambed elevation as well as decreased grain sizes in streambed sediment (Ozaki and Jones, 1998, written communication, Janda, 1977 and Nolan and Marron, 1995). The CGS Appendix shows more details of some of the 58 USGS and RNSP channel cross sections, including their locations in the mainstem channel and the changes in streambed surface elevation through time. While much of the mainstem channel showed scour, aggradation continued below the Tall Trees Grove in the lowest part of the mainstem channel (Figure III- 15).

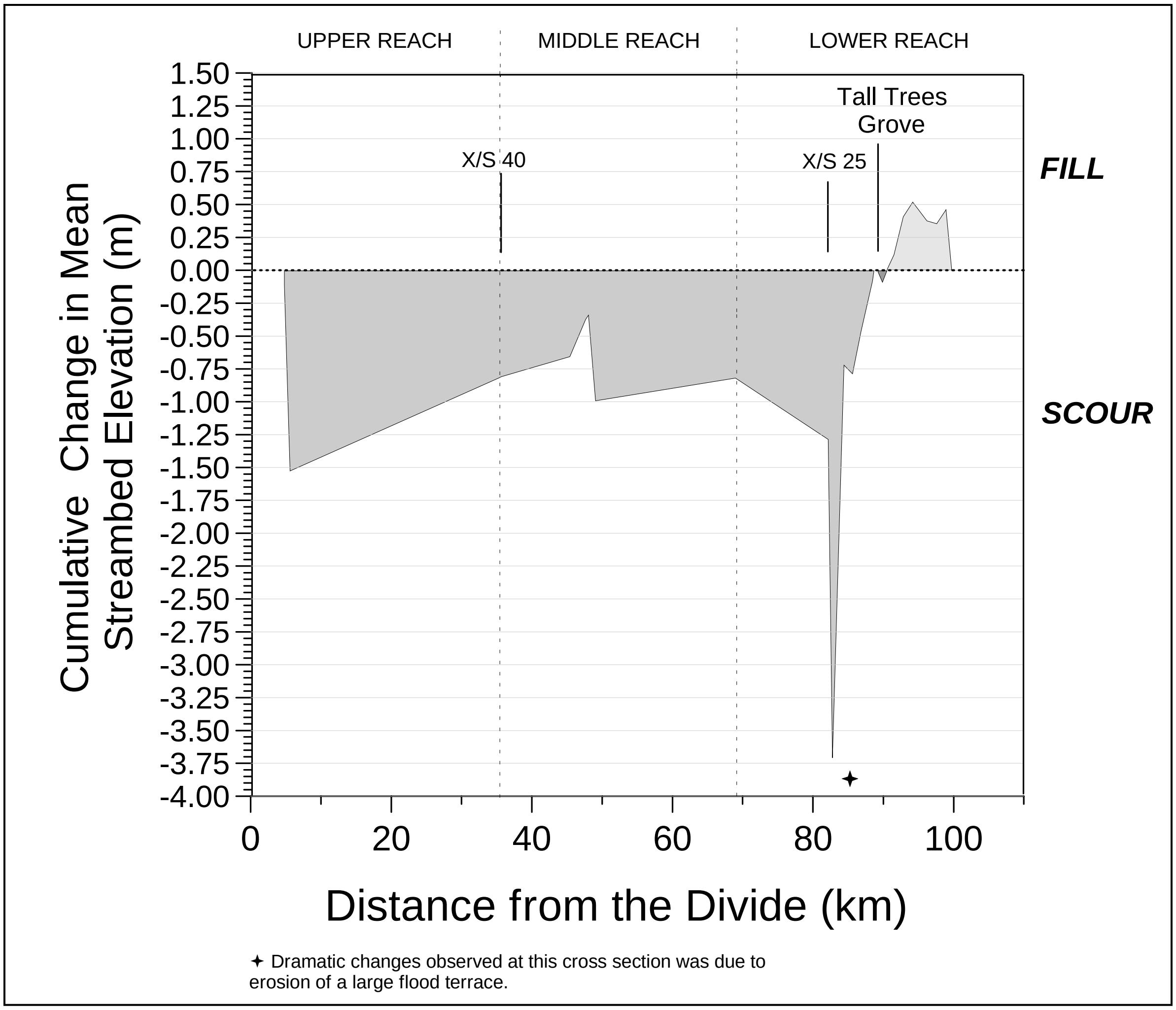

Figure III- 15. Longitudinal trend in changes in stream bed elevation at cross sections along Redwood Creek, 1973 – 1997 from the headwaters divide (RNSP 1999).

Cross section 25 changed dramatically due to the erosion of a large flood terrace. (100 km = 62 mi), illustrating the availability of stored sediment to subsequent transport.

While the mainstem channel bed has returned to a probable pre-disturbance elevation in the upper reaches, bed elevation is just one measure of channel recovery. For most of its length, the channel still remains wider than pre-1964 conditions. Madej (1987) determined the residence time of storm sediments based on her study of the tributary sections and their channel gradients. She concluded that 60-100% of the storm-generated sediment stored in steep, low-order tributaries was transported downstream and out of the tributary within 5-10 years of the last large storm, which occurred in 1975. Exceptions existed where sediment remained trapped in tributaries behind log debris jams.

RNSP cross sections measured since the early 1980s show scour and lowering of the streambed along most of the mainstem and sediment accumulation in the lower mainstem (Madej and Ozaki 1996; RNSP 1999). However, there was an increase in channel bed elevation at many sites after the storm of 1997. Channel cross sections also show that high influxes of sediment from hillslopes and stream channels during large storm events in the Redwood Creek basin can persist for decades. After more than 30 years, the effects of the 1964 flood event continue to impact the main channel in lower Redwood Creek (see Appendix, cross section number 6). As sediment is transported through the system, from the headwaters to the mouth, the volume of sediment diminishes. As the slug of sediment moves downstream its thickness decreases, sediment spreads out, and its movement downstream slows. The persistence for decades of a slug of sediment in lower Redwood Creek has contributed to a lack of channel diversity and complexity.

Expected impacts from another large flood event are unknown. While the Upper and Middle subbasins appear recovered to a pre-disturbance bed elevation, studies indicate that channel-storage reservoirs are still partially full from the last series of large floods (Madej 1992). The current volume of sediment stored in the channel has not been determined. Without an ability to store elevated amounts of sediment, the channel bed will respond by filling with sediment, widening, and potentially repeating impacts observed from earlier floods.

If there are no large influxes of sediment to Redwood Creek in the next decade or two, there will be continued flushing of sediment stored in the mainstem channel and channel recovery. Most changes will probably occur in lower Redwood Creek, below the Tall Trees Grove, as the slug of sediment from the storms of 1964-1975 moves out of the Redwood Creek system.

Sediment Budget

The rate of sediment yield to the stream network depends on many factors including the proportions of various geologic units exposed, their erodibility, their modes of mass wasting, tectonic uplift rates, climate, erosion rates relative to uplift rates, vegetation, slope aspect, and extent and types of human landuses. The purposes of a sediment budget are to identify sources and estimate the amounts of sediment generated by land use and natural, provide the rational for sediment reduction projects, and may induce development of land management techniques to control erosion and sediment inputs to steam channels.

The U.S. Environmental Protection Agency and the North Coast Water Quality Control Board developed a sediment budget based on data collected by RNSP and other researchers. For the period 1954- 1997, the average rate of sediment loading to stream channels over the basin was estimated at 4750 tons/mi^2/ year (Table III- 9). Road-related erosion makes the largest contribution to the sediment budget and accounts for approximately 50% of sediment inputs to stream channels. Road-related erosion includes both fluvial and mass wasting processes (USEPA 1998).

Table III- 9. Sediment source category estimates. Adapted from USEPA (1998).

Source Mechanism	Ave. Annual Sediment Load 1954-1997 (Ton/mi2/yr)	Percentage of Total Load Estimate
Roads and Skid Trails (Including silvicultural activities, agriculture, and public roads)	690	14.6
Gully Erosion (~90% road related)	1020	21.4
Bare Ground Erosion	400	8.4
Stream Bank Erosion	590	12.4
Tributary Landslides: natural	210	4.4
Tributary Landslides: road related	360	7.6
Tributary Landslides: timber harvest related	390	8.3
Mainstem Landslides	810	17.0
Debris Torrents	100	2.2
Other Mass Movements: earth flows and block slides	180	3.7
TOTAL ESTIMATED LOADS	**4750**	**100**

Natural background erosion was estimated to contribute 30 to 40% of sediment input. Natural sediment sources are mostly mass movements with some gullying and streambank erosion. According to RNSP and others, a significant amount of the erosion (approximately 60%) from past large storms was due to land use activities (CDFG 1966, Janda et al. 1975, RNSP, 1997, 1999 and USEPA, 1998).

Total daily maximum load (TMDL) targets derived from the sediment budget analysis call for a 60% reduction in sediment load over the basin by the year 2038 measured by 10 year moving averages. Using ten-year moving averages reduces the affects from annual variables such as droughts and floods that influence sediment loading. The estimated sediment load of 1900 tons/mi2/year over the basin is target determined to remove adverse impacts associated with sediment to aquatic resources and anadromous salmonids. The target was met for the years 1983-92 through 1987-96, but was exceeded in 1988-97 (USEPA 1998).

The sediment budget has a high degree of uncertainty (accurate within a factor of ±40%), but should be adequate for estimating relative share of loadings from different source categories (USEPA 1998) and to help focus efforts for reducing erosion in the basin. The USEPA (1998) noted that opportunities will arise in the future to make adjustments to the sediment budget. The following discussion may help to further refine the Redwood Creek sediment budget.

CGS mapped hillslope features over the entire basin using numerous photo years to depict the geologic nature of hillslopes in Redwood Creek. The NCWAP geologists in CGS, believed that the areal extent of earthflows was underestimated by the sediment budget calculations (only 10% of the basin area, with 2% being very active). CGS estimated that more than 16% of the area (46 square miles) is underlain by earthflows (active and dormant combined) with 4.2% of the entire basin being underlain by active earthflows (but lacking detailed field study of the mapping). With regard to rock slides, estimated tons of sediment derived from forested blockslides recognized within the schist geologic units. In contrast, CGS mapped “rock slides” in a variety of geologic units in addition to schist. CGS estimated that rock slides cover about 30.7 square miles, or 11% of the area of the basin. In summary, CGS increased the area of deep seated landsliding in the Redwood Creek Basin, based on study of aerial photographs. The increase in landslide-prone area would lead to an increase in the overall rate of natural sediment yield (as opposed to human-caused sediment yield) to the stream network. CGS estimated the natural contribution of sediment to the stream network from deep-seated landslides and from more stable “other” terrain in Redwood Creek. CGS predicts a denser drainage pattern and a higher rate of streambank exposure to erosion in active landslides, which is believed to contribute relatively more natural sediment to the stream network than surrounding areas. Therefore, the area of landslides is important in determining sediment yield.

CGS applied the same range of annual unit sediment load used for the 2003 Gualala Basin assessment, adjusting areas of active and dormant landslides (Klampt et al. 2003). Based on these new estimates, natural sediment yield to Redwood Creek would be 586 - 1,783 tons/mi^2/year. The higher value of 1,783 tons exceeds the RNSP 1954 to 1980 estimate of natural annual sediment load by 15%. (See Appendix E for more information).

Primary Sediment Sources

The channels have been affected by various hillslope processes, which yield sediment into streams. This section contains descriptions of sediment sources other than sediment stored in the channel from previous events and includes ideas for reducing sediment yield.

Streamside Landslides

Streamside landslides are major direct sources of stream sediment inputs. These landslides are numerous and some are quite voluminous (RNSP 1999). Streamside landslides come and go, they activate then vegetate and stabilize, as shown in numerous studies by Redwood National and State Parks and by CGS NCWAP photo mapping. The number and densities of the streamside slides vary from decade to decade, and year to year. Debris slides account for most of the streamside landslide volume according to Kelsey and others (1995), though the types of streamside landslides include debris avalanches and earth flows as well. The erosional landform map of Nolan and others (1976) shows streamside landslides along most of the mainstem and major tributary channels in the Upper and Middle subbasins. Streamside landslides may be caused in part by channel aggradation (Janda and others 1975) and subsequent widening of the channel. In this case, excessive sediment deposited in the channel raises water levels during storms. The higher levels of flowing water undercut the steep hillslopes that subsequently fail as debris slides.

Emergent groundwater, which is exacerbated by timber harvest and development on hillslopes, combines with the steepness of slopes near stream channels to increase driving forces within the hillsides, making them naturally more susceptible to mass wasting. This effect would be expected during and after large storms (1955, 1964, 1972, and 1975) and years of high overall precipitation (1958, 1971, 1974, 1983, 1993, 1995, and 1996).

Streamside landslides appear to be more frequent within the larger landslides (active and dormant) mapped on the hillslopes, within debris-slide slopes (areas sculpted by numerous debris slides or debris flows), and in the inner gorge of Redwood Creek. These are often associated width roads or timber harvest related activities. Dormant landslides contain poorly consolidated material and continue to yield sediment into streams from relatively small slides. Sediment derived from these streamside landslides is eventually transported downstream and becomes disconnected from its source. It is difficult to assign a disturbance to a source once the sediment has been transported in the stream network.

Smaller streamside landslides commonly occur in rocks of the Grogan fault zone within the inner gorge. The frequency of point landslides per acre within the fault zone is approximately 400% higher than the frequency within the Snow Camp Mountain Schist and the Coherent Unit of Lacks Creek, which are the next two most susceptible units.

This propensity for debris slides probably occurs because slopes underlain by transitional rocks of the Grogan fault zone underlie most of the inner gorge of mainstem Redwood Creek. Another factor may be that debris from large landslides in the basin appears to overrun the Grogan Fault Zone on the way downhill to the mainstem channel. Many of the observed debris slides may not actually originate or even occur within rocks of the Grogan Fault zone, but within the landslide deposits farther upslope.

Gully Erosion

Small natural streams evolve in upslope areas over hundreds and thousands of years and develop a coarse sediment armor formed by lag deposits within the channel. This protects the landscape from gullies. However, where drainage is diverted to new areas, gullies form because unarmored soil is readily washed away. Gully formation can be triggered by human land use as well as infrequent large natural events such as storms and earthquakes.

Gullies are particularly difficult to mitigate in areas underlain by soils that have developed on mélange (much of the eastern side of the basin). Even small amounts of concentrated runoff onto this type of soil can initiate gully incision. Once initiated, gullies grow rapidly in size until the water source is eliminated. Small gullies (0.1 to 1.2 square yards in cross-section) are often numerous (approximately 60% of total gully network length), but account for only 6% of the total volume of gully-related sediment. In contrast, large gullies (>5.4 square yards in cross-section) produce over 80% of the sediment; yet represent only 25% of the total gully network (Weaver et al. 1995).

Kelsey (1978) suggested that earthflow activity was accelerated or initiated during the last century by livestock grazing and subsequent conversion of prairie vegetation from perennial long-rooted native bunch grasses to annual short-rooted exotic grass, though earthflows may be largely natural erosional features. Between 1865 and 1940, there were an estimated 15,000 to 20,000 sheep within the Bald Hills and Redwood Creek area (Stover, pers. com). Historic overgrazing of the Redwood Creek land base probably contributed to the incipient stages of erosion in the basin.

Grazing was simultaneous with, and followed by, timber harvesting. A legacy system of roads, skid trails, and landings still crisscrosses many hillsides and disrupts the natural drainage patterns, particularly on private lands in the middle and upper parts of the basin. Commonly, where roads and skid trails concentrate flows, deep gullies have formed. Conventional attempts to provide road drainage, such as the installation of ditches and culverts, do not always reduce erosion. Inboard ditches divert runoff away from many small natural channels and concentrate the flow, which is often turbid, inside the road. This runoff eventually discharges through culverts. Runoff is commonly inadvertently directed into new areas, where channels evolved under conditions of lower volumes of water and sediment. This increase in flow causes an expansion of the smaller channels and accelerates erosion of sediment, which ends up in streams.

Road-related gully erosion was documented as a major source of sediment in the Redwood Creek system, accounting for about 21% of the total basin output (Weaver et al. 1995; EPA 1998). In areas of intensive timber harvest, roads were the primary cause of accelerated mass wasting (RNSP, 1999). Approximately 90% of the total gully erosion within the 1995 study area was attributed to 1st and 2nd order watercourse diversions. Diversions consisted typically of plugged culverts (41%), skid trail crossings that diverted existing watercourses (32%), and road crossings installed without culverts (27%). Pitlick (1995) determined that the number of landslides was nearly the same on harvested and unharvested lands; however, landslides associated with roads and harvested slopes were larger and accounted for nearly 80% of the total landslide mass entering streams.

Culvert failures typically occur as a result of insufficient maintenance, debris jams, and undersized pipes. Culvert failures and diversions often produce the largest gullies, because culverts tend to be installed on larger, perennial watercourses having higher discharge volumes. Fills that make up these larger crossings are commonly much more voluminous than typical skid trail crossings and can deliver larger volumes of sediment directly into streams when they fail.

Skid trail crossings usually involve smaller, ephemeral streams. These are streams that run seasonally or sporadically and have lower discharge volumes in the winter season. Diversions can produce moderate-sized gullies that traverse long sections of hillside. These typically occur when watercourses are diverted because the channels are not as deeply incised as adjacent perennial streams. Diverted water often ends up in adjacent streams (Weaver et al. 1995).

CGS's THP field staff noted several large gullies within the basin, which were created or exacerbated as a result of long-term, concentrated road runoff from heavily used public roads including County roads and State Highway 299 (J.N. Falls, personal communication, 2002). The road surfaces form extensive hardscapes and seasonally deliver large amounts of storm runoff very rapidly to gully systems that have developed over the years. One of the larger gullies draining into Captain Creek was approximately 20 feet deep and 35 to 40 feet wide and several hundred feet long when observed in May 2000 (Falls 2000). Runoff from State Highway 299 was found to be added to runoff from the County's Chezem Road, and the combined runoff fed the gully system in Captain Creek. The significance here is that the roads providing the runoff cannot be removed or decommissioned; they are needed roads.

Even if the runoff is redirected away from a gully, however, gully sidewalls commonly continue to fail and generate debris until they equilibrate with their surroundings. Protective vegetation is very difficult to establish in gullies under these conditions. The upper layers of soil are gone and the remaining, less weathered material usually does not support vegetation well. Mitigation of large gullies often requires an engineering solution.

Most (85%) of the observed gully-related sediment in the lower Redwood Creek subbasin "could have been prevented by careful land management and erosion control practices" (Weaver et al. 1995). Weaver et al. (1995) state, "On sites of equal erodibility, the severity of the erosional problems reflects not so much the actual logging methods as the practices employed to reduce stream diversions during and following the harvest operations." Erosion control performed after harvest is usually in response to a problem and is typically much more costly and less effective than careful planning and layout of the original THP. Many post-harvest problem sites become inaccessible, or expand to the point where they are uncontrollably large.

The NCWAP mapped gullies if they were large enough to be visible at the scale of the air photos studied. Many of the gullies were seen near shallow landslides and roads. The ground surface is obscured under forested and more densely vegetated areas, so the gullies in these areas are missed when mapping from air photos. Thus, on the NCWAP maps, gullies, including road-related ones, are very likely under-represented in the more vegetated areas.

The NCWAP staff compared the locations of gullies with active and dormant deep-seated landslides, so as to determine if gullies were more frequent in these areas. The comparison shows that 79% of the gullies from photo year 2000 are within 10 m of mapped deep-seated landslides and 98% are within 10 m of areas having the highest landslide potential. This analysis suggests that gullies are more frequent in and near deep-seated landslides. Thus, it would be wise to take special care with considerations of drainage when building and removing roads in these areas of mapped landslides. Natural drainage patterns should be followed so surface runoff remains in naturally armored hillslope areas and away from more erodible areas.

Gullies show a high correlation with grasslands and with the earthflows that commonly underlie them. About 99% of the gullies (3,339 of 3,385) that were mapped from the 2000 photos lie within grasslands according to the NCWAP vegetation map. Though it is uncertain whether earthflow activity has been initiated or accelerated by gully erosion, it is clear that gullies tend to form on earthflows. Gully and stream erosion at the toes (bottom) of earthflows could accelerate earthflow movement. Walter (1985) found that road construction has accelerated gully erosion on earthflows, so it would be wise to be very cautious when planning or building roads or doing any development in earthflows. Human land use and associated gully formation could initiate and accelerate earthflow activity.

It is essential to identify and map deep-seated landslides, so as to delineate areas with a known propensity for gully formation and hillslope creep. These natural processes can be initiated and accelerated by human activity, particularly when that activity is poorly planned.

Stream Disturbance Features

CGS fluvial staff examined complete sets of aerial photos from two photo years, 1984 and 2000, for evidence of channel disturbance throughout the Redwood Creek basin. This was done to compare the results between photo years and to assess improvement or deterioration of the channel system in recent decades. The 1984 photos were taken after the record high precipitation year of 1983. The 2000 photos were taken after an 11-year recurrence flood in December 1996 and January 1997. The years between 1984 and 1997 were relatively average or below average precipitation years. CGS mapped and analyzed channel features, including those we deemed to indicate stream disturbance, such as widened channels, lateral and mid-channel bars, multi-thread channels, channel bank erosion, and shallow landslides adjacent to channels. This analysis does not address the volume of sediment transported and stored.

Channel disturbance features were more widespread in the basin in the 1984 photos than in the 2000 photos (Table III- 10, Figure III- 16, Figure III- 17, and Figure III- 18). The total miles of stream-disturbance by length decreased 54%, from 100 to 42 miles, between photo years 1984 and 2000. The decrease in length of stream disturbance features between 1984 and 2000 is especially noticeable in the Middle and Upper subbasins. Though this suggests a trend toward recovery from past disturbances, the time period we studied excluded large storms. Large storms could initiate large sediment inputs that may be observed as stream disturbance features.

Recovery in Redwood Creek resulted at least in part, if not entirely, because of the absence of large floods between 1975 and 2000. The storm event of 1996/1997 resulted in considerable change to the channel but, did not truly test the disturbance potential and the contribution of land-use activities to stream sediment in the basin. Larger, 20+-year storms could quickly and even more seriously reverse the trend towards recovery.

Channel studies showed that the 11-12 -year storm of 1996-1997 reversed trends toward formation of regularly spaced bedforms in the mainstem and at least some tributary channels (Madej 1999). Even at the coarse time scale we studied, between 1984 and 2000, CGS found that some stream reaches in Redwood Creek basin showed an increase in disturbance features in photo year 2000, while other reaches improved. New sediment entered the stream network between 1984 and 2000 and was transported during relatively small storm events.

In some reaches, features mapped in 1984 were not observed in 2000. There are at least two reasons: 1) much sediment was transported from the reach and 2) streamside landslides healed. Although, a few tributaries gained disturbance feature length between 1984 and 2000. In Twin Lakes, Snowcamp, Bradford and Noisy Creeks, stream disturbance features were observed in the 2000 photos that were not seen in 1984 (See CGS Appendix). The new sediment in these steeper reaches has been or will be transported downstream into the mainstem response reaches that support anadromous fish. The lower gradient channel reaches where sediment accumulates from upstream and upslope erosion also deteriorated.

Table III- 10. Length of stream disturbance features, stream disturbance feature index, and percent change for 1984 to 2000.

Basin, Subbasin, or Planning Watershed Unit of Analysis	Analysis Unit Area (sq. km.)	Length of Disturbance Features 1984 (m)	Length of Disturbance Features 2000 (m)	Indexed Disturbance Features 1984*	Indexed Disturbance Features 2000*	% Change 1984-2000
Redwood Creek basin	731.3	158,984	73,874	217	101	-54
Estuary Subbasin	19.6	2,936	5,734	150	293	95
Prairie Creek Subbasin	96.9	5,035	603	52	6	-88
Lost Man Creek	51.4	4,565	279	89	5	-94
May Creek	45.5	470	324	10	7	-31
Lower Redwood Subbasin	180.1	44,861	25,259	249	140	-44
Bond Creek	33.2	12,076	4,358	364	131	-64
Bridge Creek	60.9	14,078	7,231	231	119	-49
Copper Creek	40.6	14,223	4,073	350	100	-71
Devil's Creek	17.8	468	0	26	0	-100
McArthur Creek	27.6	4,016	9,597	146	348	139
Middle Redwood Subbasin	259.2	69,000	15,215	266	59	-78
Coyote Creek	31.1	10,192	988	328	32	-90
Lower Lacks Cr	24.0	5,756	2,343	240	98	-59
Lupton Creek	32.6	11,252	1,641	345	50	-85
Minor Creek	40.3	19,369	979	481	24	-95
Panther Creek	39.4	3,356	402	85	10	-88
Roaring Gulch	36.0	5,669	2,750	157	76	-51
Toss-Up Creek	35.3	10,602	5,075	300	144	-52
Upper Lacks Cr	20.5	2,804	1,037	137	51	-63
Upper Redwood Subbasin	175.5	37,152	27,063	212	154	-27
Bradford Creek	28.4	6,906	1,511	243	53	-78
Cloney Gulch	20.7	10,206	1,177	493	57	-88
High Prairie Cr	42.1	3,607	3,688	86	88	2
Noisy Creek	27.6	2,163	5,633	78	204	160
Twin Lakes Cr	37.1	8,384	13,427	226	362	60
Windy Creek	19.6	5,886	1,627	300	83	-72

*Index = length of disturbance feature/analysis unit area.

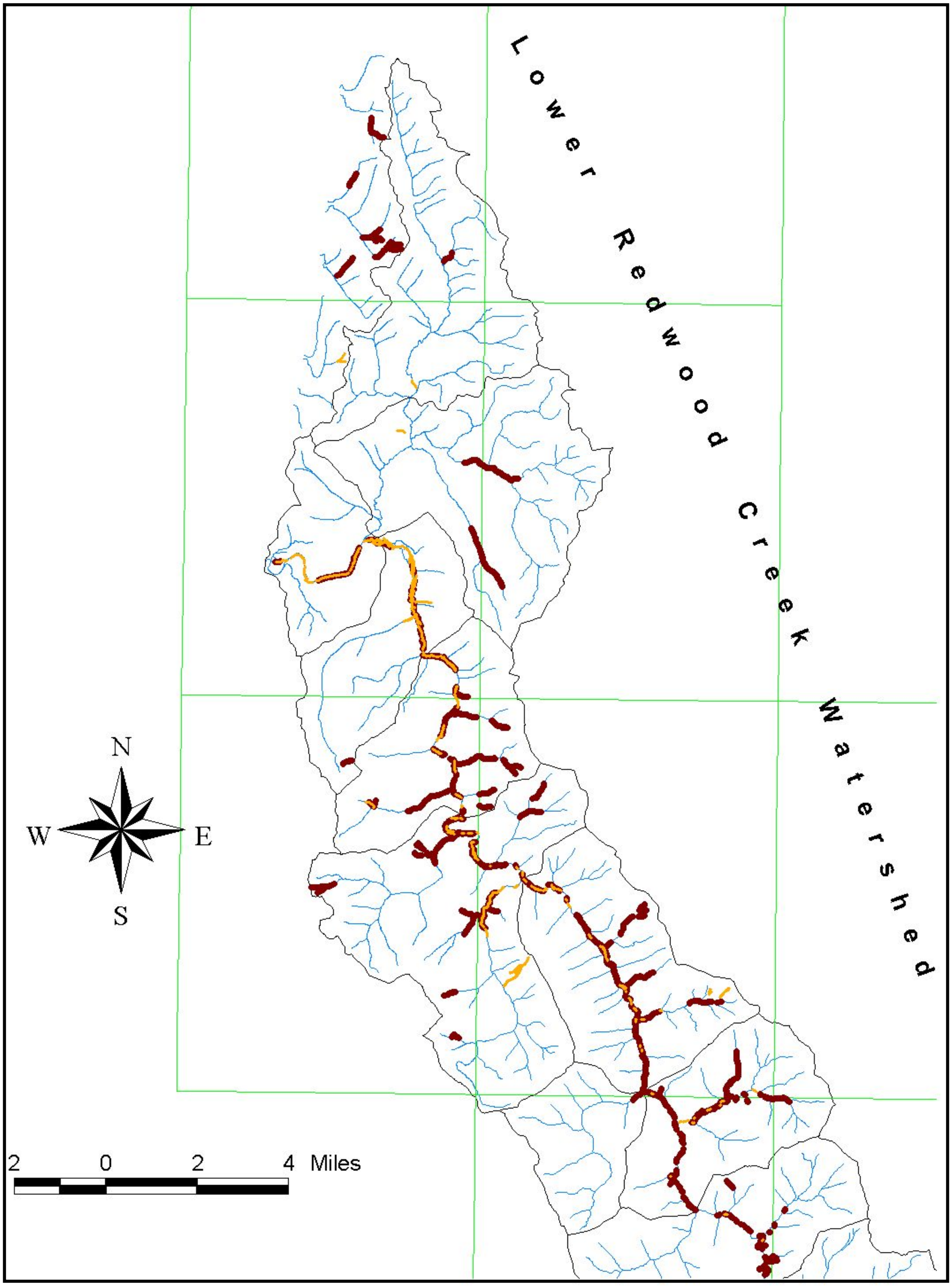

Figure III- 16. Lower Redwood Creek basin and Prairie Creek Basin elevated sediment deposition, 1984 and 2000.

The figure shows reaches with delivery and deposition of elevated sediment in 1984 (brown) and 2000 (gold). Blue lines are streams; green grid represents boundaries of USGS 7.5-minute topographic maps; gray lines are boundaries of CalWater 2.2 planning watersheds.

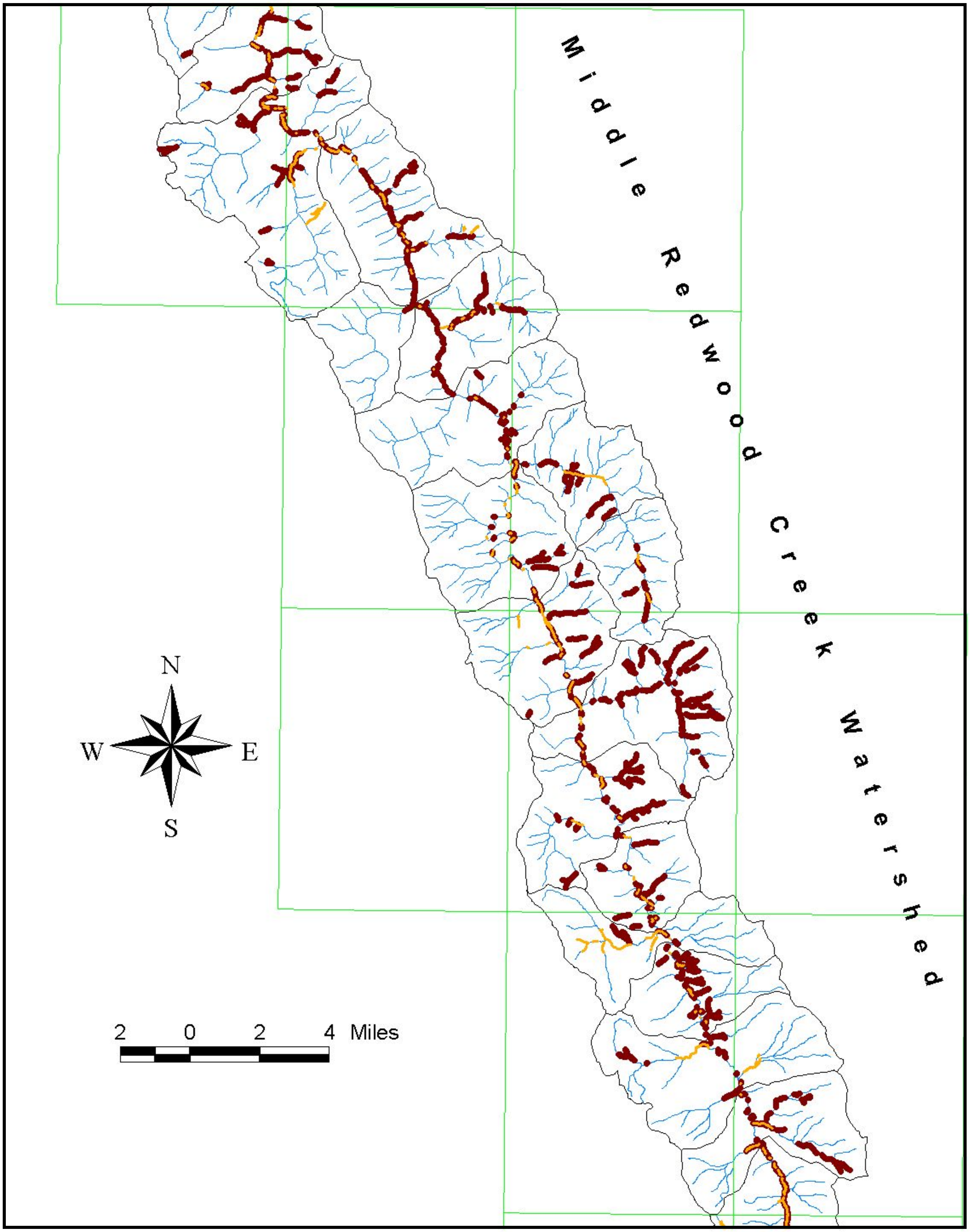

Figure III- 17. Middle Subbasin elevated sediment deposition, 1984 and 2000.

The figure shows reaches with delivery and deposition of elevated sediment in 1984 (brown) and 2000 (gold). Blue lines are streams; green grid represents boundaries of USGS 7.5-minute topographic maps; gray lines are boundaries of CalWater 2.2 planning watersheds.

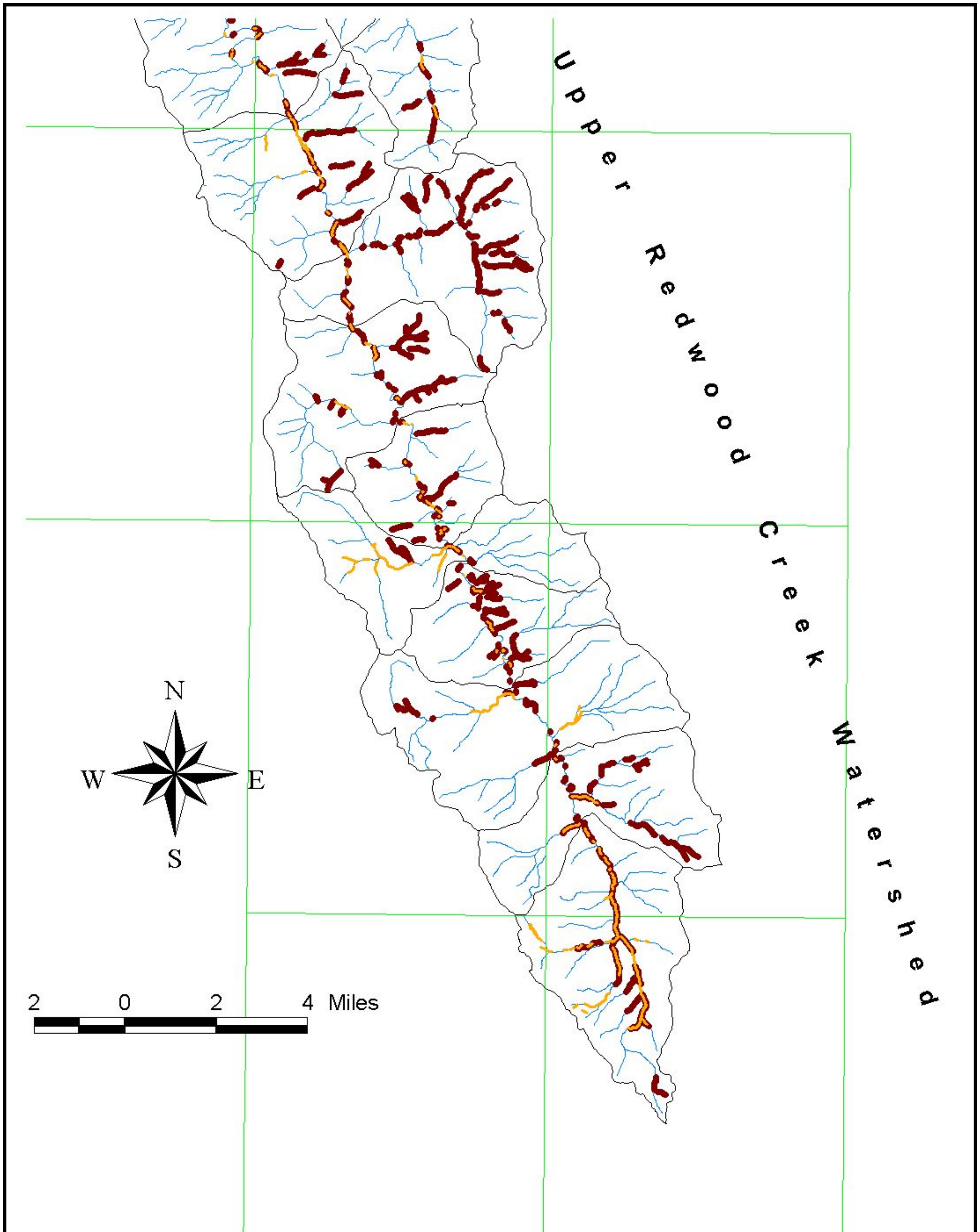

Figure III- 18. Upper Redwood Creek Subbasin elevated sediment deposition, 1984 and 2000.

The figure shows reaches with delivery and deposition of elevated sediment in 1984 (brown) and 2000 (gold). Blue lines are streams; green grid represents boundaries of USGS 7.5-minute topographic maps; gray lines are boundaries of CalWater 2.2 planning watersheds.

Stream Disturbance, Landslide Features, and Landslide Potential

The NCWAP CGS considered how stream disturbance related spatially to landslides. We found that elevated levels of sediment in storage in lateral and mid-channel bars show a high to moderately high spatial correlation with deep-seated landslides (landslides that were mapped in earlier USGS studies as well as in the NCWAP). However, the bedload features that indicate excess sediment are particularly mobile, such as lateral bars, which could move downstream and away from the unstable landslide and other source areas. In photo year 1984 there was a higher spatial correlation between stream disturbance and landslides than in photo year 2000. In photo year 1984, 82% of the stream disturbance features were within 100 m of landslides (active and dormant), whereas in photo year 2000, 67% of the stream disturbance features were within 100m of landslides (Figure III-19, Figure III- 20, and Table III- 11). The figures show only the features indicative of stream disturbance, not the more stable features such as point bars and vegetated bars.

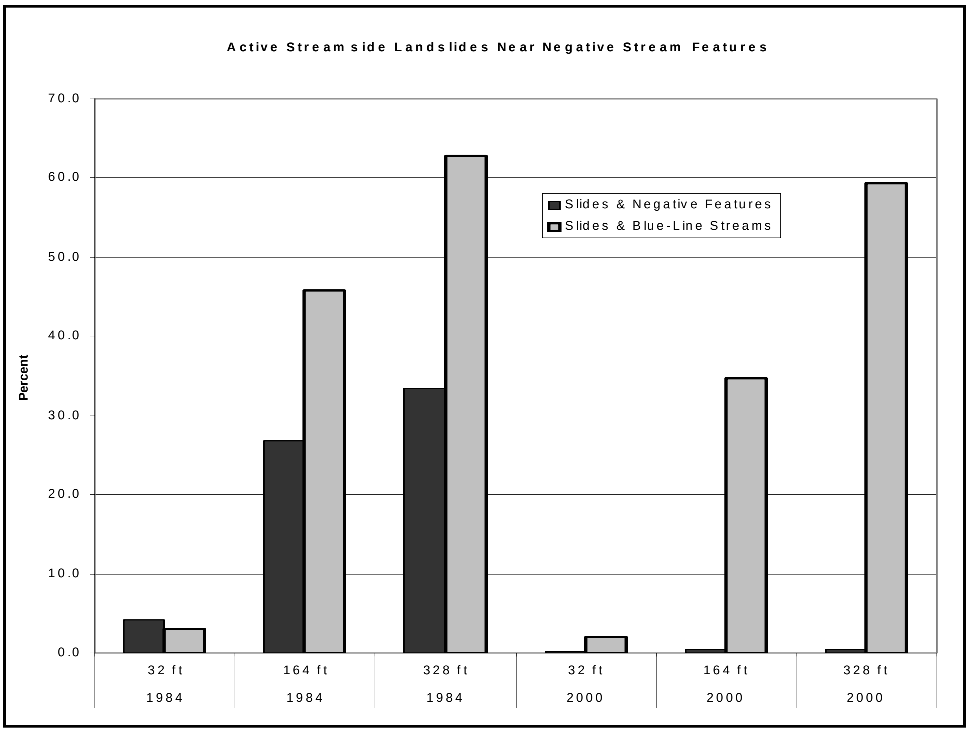

Figure III- 19. Change in the proximity between active streamside landslides and negative stream features between 1984 and 2000.

In 2000, negative stream features were farther away from streamside landslides than in 1984. The 2000 streamside landslides show the same proximity distribution to the blue-line stream network seen in 1984.

CGS also analyzed the proximity of stream-disturbance features by length to areas of high and very high relative landslide potential. In 1984, the spatial correlation between elevated channel sediment and landslide potential was much higher than in 2000. Again, this was an expected result because sediment moved downstream, away from unstable hillslope sources. The downstream movement of elevated sediment resulted in aggradation in response reaches. Unlike stream disturbance, the proportion of streamside landslides that are closer to the larger landslides increased between 1984 and 2000. We believe this is due to the stabilization of the basin following the storm of 1975: by photo year 2000, streamside landslides more distant from unstable hillslopes were vegetated and temporarily stabilized. At the same time, proportionally more streamside landslides remained active or were newly generated in and near the more unstable slopes.

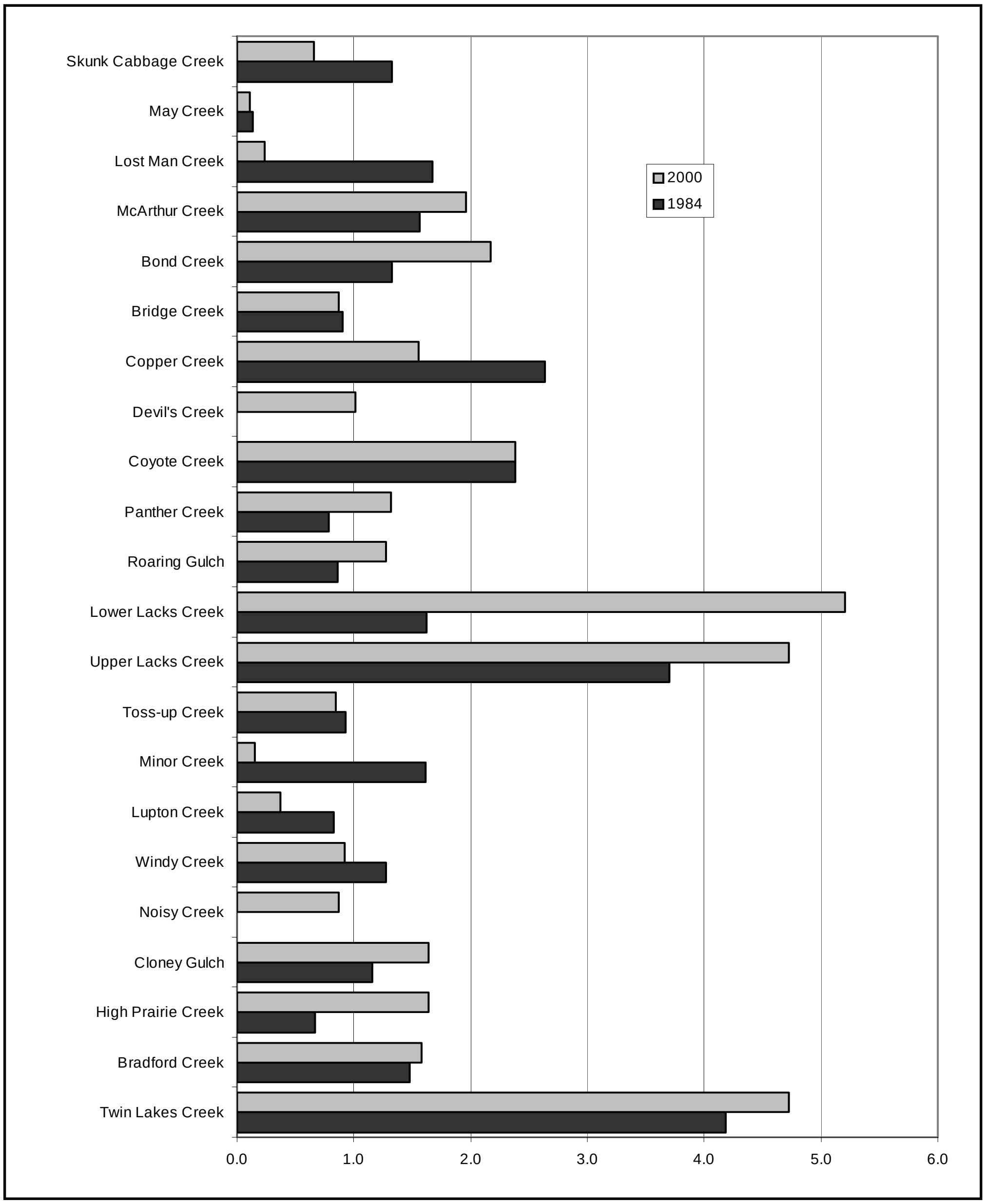

Figure III- 20. Number of active streamside landslides in 1984 and in 2000.

Normalized by (divided by) area of each planning watershed to create an index of 0-6 along the horizontal axis. Note the increase in active streamside landslides in Lacks Creek. Lacks and Twin Lakes Creeks had the highest density of active streamside landslides in 2000.

Table III- 11. Number and indices of streamside slides by basin, subbasins, and Planning Watersheds.

Basin, Subbasin, or Planning Watershed Unit of Analysis	Analysis Unit Area (sq. km.)	1984 # of Active Slides Along Streams	2000 # of Active Slides Along Streams	1984 Indexed* Active Slides	2000 Indexed* Active Slides	% Change 1984-2000
Redwood Creek basin	731.3	1,017	1,097	139	150	8
Estuary Subbasin	19.6	26	13	133	66	-50
Prairie Creek Subbasin	96.9	92	17	95	18	-82
Lost Man Creek	51.4	86	12	167	23	-86
May Creek	45.5	6	5	13	11	-17
Lower Redwood Subbasin	180.1	249	260	138	144	4
Bond Creek	33.2	44	72	133	217	64
Bridge Creek	60.9	55	53	90	87	-4
Copper Creek	40.6	107	63	264	155	-41
Devil's Creek	17.8	0	18	0	101	∞
McArthur Creek	27.6	43	54	156	196	26
Middle Redwood Subbasin	259.2	376	442	145	171	18
Coyote Creek	31.1	74	74	238	238	0
Lower Lacks Creek	24	39	125	163	521	221
Lupton Creek	32.6	27	12	83	37	-56
Minor Creek	40.3	65	6	161	15	-91
Panther Creek	39.4	31	52	79	132	68
Roaring Gulch	36	31	46	86	128	48
Toss-up Creek	35.3	33	30	93	85	-9
Upper Lacks Creek	20.5	76	97	371	473	28
Upper Redwood Subbasin	175.5	274	365	156	208	33
Bradford Creek	20.7	42	45	203	217	7
Cloney Gulch	42.1	24	34	57	81	42
High Prairie Creek	27.6	28	69	101	250	146
Noisy Creek	37.1	0	24	0	65	
Twin Lakes Creek	19.6	155	175	791	893	13
Windy Creek	28.4	25	18	88	63	-28

*Index = (# slides/analysis unit area) X 100

Table III- 12 was developed by CDF and CGS to show landslides and geomorphic features (as determined from review of aerial photos) and their proximity to watercourses. The presence of these features near watercourses is important, given their potential to deliver sediment to the stream channel, where the sediment has a potential to adversely affect salmonids and their habitat. The landslide and geomorphic features are divided up into a number of classes. Historically active landslide features (movement within the past 150 years) include earthflows, rock slides, debris slides and debris flows. All dormant landslides are reported as a combined category. Geomorphic features include disrupted ground, debris slide slopes, and inner gorges. Most features are reported in terms of area. However, if the feature width is less than 100 feet, the feature is mapped as a linear feature and reported as a length rather than in terms of area. Features that were mapped as linear features are generally much longer than wide and have a width of less than 100 feet. Where linear landslide features are found on both sides of the stream, they are counted both times for calculating the percentage of total blue line streams with linear landslide features adjacent. The spatial analysis is based on observation of feature-watercourse connectivity on aerial photos or on GIS analyzed intersections of features with the blue line streams from the United States Geological Survey topographic maps at a scale of 1:24,000. As used here, "watercourses" includes streams as well as fluvial features such as gullies that are hydrologically connected to the stream system.

The first numeric column in Table III- 12 lists the areas (acres) of historically active and dormant landslide features that were observed on aerial photos to be directly delivering sediment to watercourses, regardless of whether those watercourses appear on USGS 1:24,000 hydrography. The remaining numeric columns of the table look at the area (acres) or length (miles) of landslide and geomorphic features with respect to three distance ranges from each side of the blue line streams (0 to 179 feet, 180 to 660 feet, and greater than 660 feet) as captured in GIS from the 1:24,000 USGS hydrography. The areas and lengths of landslide and geomorphic features within 179 feet of the blue line streams are also calculated as: (1) a percentage of total areas within the entire Redwood Creek basin and its subbasins, and (2) a percentage of the total blue line stream length in the entire Redwood Creek basin and its subbasins. The feature area or length as a percentage was calculated only for the 0 to 179 feet distance to blue-line streams because this represents the area of highest sediment delivery likelihood.

Some hillslope features are relatively close to, or within specified distances of blue line streams. These hillslope features, including landslides (historically active and dormant) and selected geomorphic features are potential sources of sediment to streams. The closer the feature lies to a stream, the higher the likelihood of sediment from that feature reaching the stream network. The distance categories used are exclusive, i.e., slide areas or lengths reported in the 0-180 feet column are not repeated in the other columns. The >660 feet column includes landslide and geomorphic features that extend to the ridge top of the basin unit being analyzed.

A total of 43,971 acres of historically active and dormant landslides were mapped from air photos as having direct delivery to watercourses. This area represents 24% of the Redwood Creek basin area. However, not all of this 24% of the basin was simultaneously contributing sediment to the stream network. The results show that naturally unstable features (“landslides”) cover about a quarter of the bird’s-eye view of the basin and many of these landslides lie near streams. The historically active and dormant landslides might have higher rates of sediment delivery than stable lands for two reasons: mass movement and topographic irregularities enhancing fluvial erosion. Fluvial processes act through gully erosion, headward erosion, rilling, etc. Dormant slides might deliver sediment through fluvial erosion, including erosion of the toe area of the landslide.

An estimated 9,552 acres or 5.3% of the Redwood Creek basin area consists of area-based landslide and geomorphic features are located within 180 feet of blue-line streams. These landslide and geomorphic features have the potential to directly deliver sediment to the streams. Approximately 153 miles (about 29% of all blue line streams in the basin) of the blue line stream length in the Redwood Creek basin are adjacent to inner gorges, eroding banks, landslides or erosion prone geomorphic features. These are areas of likely high natural sediment delivery and should be considered sensitive areas and susceptible to excessive erosion from land use. However, the blue-line streams do not include all of the drainages in the basin. The actual drainage network of the Redwood Creek basin is much denser than the blue-line stream network depicted on USFS topographical maps at a scale of 1:24,000. Use of the blue-line stream network leads to the underestimation of the total drainage length and underestimation of the potential natural sediment input from landslides and selected geomorphic features that would be expected to yield higher volumes of sediment to the stream network.

Table III- 12. Proximity of landslide and selected geomorphic features to watercourses.[1]

Basin or Subbasin	Landslide and Selected Geomorphic Features[2]	Observed Direct Delivery to Water-courses in Aerial Photos (acres)	Feature Area or Length Within Given Distance to Blue Line Streams Based on GIS Analysis[3]				
			0-180 feet			180-660 feet (acres)	>660 feet (acres)
			Feature Area or Length	% of Basin or Subbasin Area	% of Basin or Subbasin Stream Length		
Redwood Creek Basin (180,688 acres)	Historically Active Landslides (total acres)	9,114	1,199	0.7%		3,114	5,757
	Earthflow (acres)	6,896	32	0.0%		54	82
	Rock Slide (acres)	1,552	243	0.1%		241	107
	Debris Slide (acres)	514	689	0.4%		2,177	4,736
	Debris Flow (acres)	152	235	0.1%		642	832
	Dormant Landslides (total acres)	34,856	4,631	2.6%		12,495	21,711
	Area-Based Geomorphic features (total acres)		3,722	2.1%		10,135	16,912
	Disrupted Ground (acres)		2,217	1.2%		6,238	11,862
	Debris Slide Slope (acres)		1,504	0.8%		3,897	5,049
	Linear Geomorphic Features (total miles)		153		29.3%		
	Eroding Banks (miles)		2		0.3%		
	Inner Gorge (miles)		151		29.0%		
	All Area-Based Features (total acres)	43,971	9,552	5.3%		25,745	44,380
Estuary Subbasin	Linear Geomorphic Features (total miles)		0		2.5%		
	All Area-Based Features (total acres)	0	41	1.2%		211	1,064

Basin or Subbasin	Landslide and Selected Geomorphic Features[2]	Observed Direct Delivery to Water-courses in Aerial Photos (acres)	Feature Area or Length Within Given Distance to Blue Line Streams Based on GIS Analysis[3]				
			0-180 feet			180-660 feet (acres)	>660 feet (acres)
			Feature Area or Length	% of Basin or Subbasin Area	% of Basin or Subbasin Stream Length		
Prairie Creek Subbasin	Linear Geomorphic Features (total miles)		6		8.0%		
	All Area-Based Features (total acres)	2,222	611	2.6%		1,685	2,496
Lower Redwood Creek Subbasin	Linear Geomorphic Features (total miles)		20		16.1%		
	All Area-Based Features (total acres)	7,573	1,857	4.2%		4,815	7,944
Middle Redwood Creek Subbasin	Linear Geomorphic Features (total miles)		38		20.5%		
	All Area-Based Features (total acres)	17,913	4,077	6.4%		10,510	17,771
Upper Redwood Creek Subbasin	Linear Geomorphic Features (total miles)		89		70.2%		
	All Area-Based Features (total acres)	16,263	2,965	6.8%		8,524	15,104

[1] This table and the underlying data and methods are complex. To ensure that you understand it and the assumptions behind it, read the accompanying text carefully.
[2] Refer to Plate 1 and California Geological Survey appendix.
[3] Blue line streams are those identified on USFS quad maps; they do not include all drainage systems within a basin and thus underestimate potential for sediment delivery.

Looking comparatively at the subbasins across the Redwood Creek basin, the Estuary, Prairie Creek, and Lower Redwood subbasins contain relatively less area of unstable landslide and geomorphic features proximate to streams. In contrast, the Middle and Upper Subbasins contain a relatively high area of these features close to streams. In the Upper Redwood Creek Subbasin, more than 70% of the blue-line stream miles have linear geomorphic features indicating potential hillslope instability within 180 feet. Thus, the Upper Subbasin is an area to exercise extreme caution during land-use activities adjacent to streams. Where this potential instability is realized, it may result in delivery of sediment to the stream system. As mentioned earlier, where linear features occur on both sides of a blue-line stream, their length is counted both times, while the stream length is counted only once.

Vegetation

Vegetation varies over the basin from Sitka spruce, red alder and grasslands in the Estuary Subbasin to old growth redwood forest along the lower portion of the drainage and Douglas-fir, intermixed with oak woodlands and hardwoods, to ponderosa and Jeffery pine stands along the upper elevations. Areas of grasslands are also found along the main ridge tops and south-facing slopes of the basin. Prior to the harvesting of timber within the Redwood Creek basin, 83% (150,000 of 181,000 acres of the drainage) supported mature coniferous forests. The remainder of the basin, approximately 17%, supported grasslands and oak woodlands. Redwood Creek drainage currently supports about 24,000 acres (13% of area) of old-growth coniferous forests. Most of the old growth forest is in publicly owned lands and managed by RNSP. By the year 2000, approximately 87% (130,700 acres) of the total forested area had been logged at least once.

Table III- 13 shows all vegetation cover types found within Redwood Creek listed from the largest to smallest area and by subbasins. This information was derived from 1998 multi-spectral scan information developed by the USFS remote sensing lab. The vegetation map layer is the source for CALVEG types. The minimum mapping size is 2.5 acres for contrasting vegetation types. Information on historical conditions is not available to compare changes in the types and condition of vegetation classes. More detailed vegetation information is presented in the Results and Analysis section and in Appendix F.

Just five vegetation types account for 90% (Table III- 13) of the vegetation in Redwood Creek. The most abundant type is Douglas fir, (*Pseudotsuga menziesii*) which covers 71,652 acres, or 40% of the basin. Redwood (Sequoia sempervirens) and redwood-Douglas-fir vegetation types cover a combined area of about

61,000 acres, accounting for 34% of the basin area. The other major vegetation types are annual grass/forbs, Oregon white oak (*Quercus garryana*), tanoak (*Lithocarpus densiflorus*), and red alder (*Ulnus rubra*).

Of the three commercial timber types approximately 18% (24,315 acres) is protected, in parklands, as old-growth forests. The mixture of redwood and Douglas-fir occurs within about 10 miles of the coast, usually in protected upland slopes up to approximately 2500-foot elevation. Associated coastal conifers within the Redwood-Douglas-fir type include grand fir (*Abies grandis*), Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*). The hardwoods, tanoak, red alder, and madrone (*Arbutus menziesii*) are often associated. California hazelnut (*Corylus cornuta var. californica*) also occurs as an understory shrub in this type. The remainder of the vegetation within the Redwood Creek drainage is comprised of 39 different and distinct vegetation types.

Hardwood trees species associated with disturbance and land use change are also found within Redwood Creek. Currently red alder covers 5,713 acres. Most of this area is located below the Bridge Creek area in the Lower Subbasin and generally on the west side of Redwood Creek. The heaviest concentrations of the tree are found in the areas of intense logging activity in the 1970s. Another hardwood species, which is associated with land use activity, is tanoak. Tanoak can exist under a forest canopy with low light levels throughout most of its life. Once released the suppressed trees exhibit remarkable growth and development. The association of tanoak with or without a Pacific madrone component is a very common type in the basin. This vegetation type covers 6,239 acres within Redwood Creek. The tree form of Oregon white oak (*Quercus garryana var. garryana*) becomes a local canopy dominant in woodlands and covers 7,752 acres. This species readily mixes with Black oak (*Quercus kelloggii*) in this area.

Areas of grasslands are found at various elevations in the basin. Annual grasslands occupy approximately 10,060 acres within the Redwood Creek basin. These areas become more extensive on private lands scattered throughout the area and intermix with agriculturally managed sites. On an acreage basis, the greatest amounts of grasslands are found on the Middle and Upper subbasins.

Only the area of barren rock (1,174 acres), water (99 acres) and dunes (20 acres) are not currently supporting some type of vegetation. The barren-rock areas are scattered around the basin, except for two large areas. The first larger area is the extensive gravel bars along Redwood Creek along the town of Orick and upstream above the Prairie Creek confluence. The second distinct area follows the new section of Highway 101, commonly referred to as the "bypass."

Generalized vegetation and land cover types have been developed based on the CALVEG information. Table III- 14 and Table III- 15 show various land cover types, by acres and percent of area, found within the Redwood Creek basin and each of the five subbasins. Conifer is the predominant cover type (141,669 acres or 79% of the basin area) on the basin and in each of the individual subbasins. The Prairie Creek subbasin has the highest percentage of conifer cover (95%), while the Estuary Subbasin has the lowest (33%). The hardwood cover type is second most common, covering 24,348 acres (14%) of the Redwood Creek basin. Almost half of the basin's hardwood cover type (11,861 acres) is found on the Middle Subbasin. The lowest level of the mixed cover type is found on the Prairie Creek subbasin, where it covers just 2% of the subbasin area. Agriculture, barren areas, shrub, developed areas, and water all constitute minor components of the cover at both the overall basin level and the subbasin level. More detailed information at the CalWater 2.2 planning watershed level is provided in each of the subbasin sections in Part IV.

Role of Riparian and Nearstream Forests

Riparian forests are defined as the area of land located immediately adjacent to streams, lakes, or other surface waters, and extending into floodplain and terraces. Riparian forests are dynamic environments that develop in response to disturbance. Flooding, fire, mass wasting, windfall, and disease are all natural disturbance processes that affect vegetation through succession (Naiman 1998).

The spatial extent of riparian areas varies laterally throughout the channel network and is strongly influenced by geomorphology (Naiman 1998). While the boundary (i.e., ecotone) of the riparian area and the adjoining uplands is not always well defined, it can exhibit strong differences in microclimate (Brosofoske et al. 1997).

Riparian areas differ from the uplands because of high levels of soil moisture, frequent flooding, and the unique assemblage of plant and animal communities found there. While representing only a fraction of the total basin, riparian forests typically support a broader array of plant and animal species than upland areas. This diversity is evident in the range of ecosystem functions that riparian areas provide. Riparian forest trees of the Redwood Creek basin include alder spp., big leaf maple, California bay, willow spp., redwood, and Douglas fir.

The term nearstream forest is used in this report to describe the forest area that includes both riparian forests and upland forests within close proximity to streams. The width of the nearstream forest zone varies according to stream size, geomorphic conditions, and other direct or indirect affects on streams. Overall, the nearstream forest species assemblage is typically more similar to adjacent upland forests. However, many of the same benefits from riparian forests are provided by or enhanced by the nearstream forest such as overstory shade, moderating air and water temperature, soil cohesion, and LWD loading. The LWD also helps a stream retain organic matter, and provides essential cover for salmonids (Murphy and Meehan 1991). Therefore, disruptions of riparian and near stream forest functions can have serious impacts to the aquatic habitat.

Land Management Impacts on Riparian Forests

Forest practices, agriculture, development and other land use have the potential to affect riparian processes and benefits to stream habitat. Prior to 1970 there was little or no protection given to riparian or nearstream forests. As a result, the riparian and nearstream forest zones on the North Coast tend to lack old mature forest stands and reflect the legacy of past forest practices. Benefits noted above from a properly functioning riparian and nearstream forest vegetation are impaired. A degree of protection of riparian zones, nearstream forests and aquatic habitat is currently provided, for example, through riparian stream buffer requirements of state Forest Practice Rules applied to non-federal lands and Northwest Forest Plan guidelines for federal lands.

Nearstream forest protection zones are important for several reasons. However, scientific investigations are still uncertain as to how wide and dense buffers need to be to maintain functions that benefit anadromous salmonid habitat. Nearstream forest protection zones based on one potential tree height are a common approach. However, studies in Caspar Creek (Mendocino County) suggest a larger area may needed (Reid and Hilton 1998).

Table III- 13. Acres of Redwood Creek basin vegetation types, by subbasin.

Vegetation Type	Entire Basin	Estuary Subbasin	Prairie Creek Subbasin	Lower Redwood Subbasin	Middle Redwood Subbasin	Upper Redwood Subbasin
Conifer Total	**141,669**	**1,075**	**24,173**	**39,037**	**46,766**	**30,618**
Douglas-Fir	71,652		51	2,057	44,352	25,192
Redwood	34,935	307	17,965	16,663		
Redwood - Douglas-Fir	26,033		4,034	19,567	2,389	43
Sitka Spruce - Redwood	2,958	639	1,569	750		
White Fir	2,308					2,308
Douglas-Fir - White Fir	2,065					2,065
Sitka Spruce - Grand Fir	386	77	309			
Mixed Conifer - Pine	351					351
Douglas-Fir - Pine	319				22	297
Sitka Spruce	297	52	245			
Ultramafic Mixed Conifer	192					192
Jeffrey Pine	157				3	154
Mixed Conifer - Fir	9					9
Mixed Conifer - Fir	6					6
Red Fir	1					1
Hardwood Total	**24,348**	**770**	**604**	**3,805**	**11,861**	**7,308**
Oregon White Oak	7,752			240	2,582	4,930
Tanoak (Madrone)	6,239			318	4,771	1,150
Red Alder	5,713	770	604	3,234	940	165
California Bay	2,498			13	2,078	407
Productive Mixed Hardwood	655				513	142
Canyon Live Oak	525				401	124

Vegetation Type	Entire Basin	Estuary Subbasin	Prairie Creek Subbasin	Lower Redwood Subbasin	Middle Redwood Subbasin	Upper Redwood Subbasin
California Black Oak	431				174	257
Tree Chinquapin	227				223	4
Willow	144				36	108
Bigleaf Maple (Dogwood)	77				63	14
Mixed Hardwoods	52				52	
Mixed Riparian Hardwood	35				28	7
Grassland Total	**10,156**	**799**	**387**	**1,244**	**4,102**	**3,624**
Annual Grass/Forbs	10,060	711	387	1,244	4,102	3,616
Wet Meadows	75	67				8
Perennial Grass	21	21				
Barren Total	**1,194**	**107**	**132**	**408**	**277**	**270**
Barren/Rock	1,174	87	132	408	277	270
Dune	20	20				
Shrub Total	**1,187**	**30**	**36**	**19**	**771**	**331**
Salal–California Huckleberry	560			5	539	16
Huckleberry Oak	288					288
Blueblossom Ceanothus	259			12	229	18
North Coastal Mixed Shrub	41		36	2	3	
Coyote Brush	30	30				
Scrub Oak	5					5
Riparian Scrub - Willow	4					4
Agriculture	366	341			25	
Developed	120	77	27	5	11	
Water	99	65				34

Table III- 14. Generalized cover type acres by basin and subbasin.

Cover Type	Entire Basin	Estuary Subbasin	Prairie Creek Subbasin	Lower Redwood Subbasin	Middle Redwood Subbasin	Upper Redwood Subbasin
Conifer	141,669	1,075	24,173	39,037	46,766	30,618
Hardwood	24,348	770	604	3,805	11,861	7,308
Grassland	10,156	799	387	1,244	4,102	3,624
Barren	1,194	107	132	408	277	270
Shrub	1,187	30	36	19	771	331
Agriculture	366	341			25	
Developed	120	77	27	5	11	
Water	99	65				34

Table III- 15. Generalized cover type by percentage of basin or subbasin area.

Cover Type	Entire Basin	Estuary Subbasin	Prairie Creek Subbasin	Lower Redwood Subbasin	Middle Redwood Subbasin	Upper Redwood Subbasin
Conifer	79	33	95	88	73	73
Hardwood	14	24	2	9	19	17
Grassland	6	24	2	3	6	9
Barren	<1	3	<1	<1	0	<1
Shrub	<1	<1	<1	<1	1	<1
Agriculture	<1	10	0	0	<1	0
Developed	<1	2	<1	<1	<1	0
Water	<1	2	0	0	0	<1

An analysis was conducted to assess the amount of vegetation cover found along the watercourses within Redwood Creek as a whole. The data used for this analysis were the vegetation data, discussed above, plus a 1:24,000 stream coverage developed by CDF from the USGS digital line graphs. Three different zones based upon different buffer widths were assessed. First a 50-foot buffer (i.e., going out 50 feet from each side of the stream) was used to assess what the minimum conditions may be based on the old Forest Practice Rules. The second buffer width used was a 150-foot zone to represent the current Forest Practice Rules for the protection of a fish-bearing stream. The final zone was a 90-meter (~300 feet) buffer based upon the approach taken in the Northwest Forest Plan.

Table III- 16 provides a comparison of acreage for each cover type found within each of the three buffer zones. Conifers and mixed conifer-hardwood forests comprise most of the cover type within all three buffer zones. The percentage of cover types generally matches what is found within the overall basin cover types.

Table III- 16. Vegetation cover type for the three buffer zones

Vegetation Cover Type	Acres and Percent by Buffer Zone					
	50 feet		150 feet		300 feet	
	Acres	Percent	Acres	Percent	Acres	Percent
Agriculture	4	0.1	24	0.1	61	0.2
Barren	184	3.2	430	2.3	574	1.6
Conifer	2,497	43.1	7,839	42.5	15,366	42.4
Hardwood	779	13.4	2,519	13.7	5,084	14.0
Grassland	132	2.3	454	2.5	1,035	2.9
Mixed Conifer/Hardwood	2,140	36.9	6,997	37.9	13,741	37.9
Shrub	40	0.7	126	0.7	287	0.8
Urban	2	0.0	7	0.0	23	0.1
Water	22	0.4	56	0.3	77	0.2
Total	5,800	100.0	18,452	100.0	36,248	100.0

Basin wide assessment of the vegetation size class components for each of the three buffer zones was also completed and is shown in Table III- 17. Most all of the largest diameter trees are located in the RNSP. Overall trees in the size class 3 (12- 24 inches DBH) occupy the greatest amount of the area (over 47%) within the buffer zones.

Table III- 17. Vegetation size classes for three buffer zone widths.

Vegetation Size Class	Tree Diameter Class	Acres and Percent of Area by Buffer Zone					
		50 feet		150 feet		300 feet	
		Acres	Percent	Acres	Percent	Acres	Percent
0	Sapling	0	0.0	2	0.0	9	0.0
1	<6 inches	87	1.6	286	1.6	602	1.8
2	6 to 11 inches	873	16.1	2,894	16.7	5,863	17.2
3	12 to 24 inches	2,579	47.6	8,261	47.6	16,268	47.6
4	24 to 40 inches	881	16.3	2,806	16.2	5,483	16.0
5	>40 inches	994	18.4	3,099	17.9	5,950	17.4

Tree canopy closure comparisons of the three buffer zones (50 ft. 150 ft. and 300 m.) based on a percentage of the area in each canopy closure (density) class also were performed (Table III- 18). Canopy closure and canopy density are terms used to describe the amount of shade provided by trees. Overall, each buffer zone along the watercourses has approximately 53% of its area in greater than 70% canopy closure range. In contrast, approximately 33% of the watercourse length for each buffer width is less than 50% in shade canopy. For the three different buffer zone widths the percentage of canopy closure did not vary by more than two percent within the seventy, 80 and 90% density classes. For the lower closure classes the amount of variation between the buffer zones widths was even less. This analysis does not differentiate between understory shade provide by small conifers and hardwoods and overstory shade provided by mature conifers.

A similar analysis shows canopy density within 150 feet of watercourses at the basin, subbasin and planning watershed scales (Table III- 19). These data show patches of canopy in both high and low canopy densities. In the Lower Subbasin 26% of the area within 150 feet of all watercourses had ≤30% shade canopy and 66% of the area had ≥70% canopy. In the Middle Subbasin 35% of the area within 150 feet of watercourses had ≤30% shade canopy and 45% of the area had ≥70% canopy. In the Upper Subbasin, 41% of the area within 150 feet of watercourses had ≤30% shade canopy and 40% of the area had ≥70% shade canopy. The relatively large areas of low density canopy allows sunlight to reach nearstream areas and potentially increase water temperatures.

Table III- 18. Canopy density classes for three buffer zone widths.

Density Class	Canopy Closure Class	Acres and Percent of Area by Buffer Zone					
		50 feet		150 feet		300 feet	
		Acres	Percent	Acres	Percent	Acres	Percent
1	10-20%	130	2.4	392	2.3	786	2.3
2	20-30%	767	14.2	2,516	14.5	4,869	14.3
3	30-40%	731	13.5	2,418	13.9	4,821	14.1
4	40-50%	190	3.5	563	3.3	1,061	3.1
5	50-60%	325	6.1	1,016	5.8	1,995	5.8
6	60-70%	365	6.7	1,135	6.6	2,151	6.3
7	70-80%	626	11.6	2,185	12.6	4,469	13.1
8	80-90%	886	16.4	2,645	15.2	5,012	14.6
9	90-100%	1,394	25.6	4,476	25.8	9,001	26.4
Total		**5,414**	**100**	**17,346**	**100**	**34,165**	**100**

Table III- 19. Vegetation density of the 150 foot watercourse buffer zone for the basin, subbasins, and CalWater Planning Watersheds within Redwood Creek.

Redwood Creek, Sub-basins, and Planning Watersheds	Acres by Percent Canopy Density Class									
	0	10	20	30	40	50	60	70	80	90
REDWOOD CREEK BASIN	**34**	**392**	**2,561**	**2,439**	**572**	**1,051**	**1,141**	**2,184**	**2,685**	**4,504**
Estuary Sub-basin	**34**	**0**	**20**	**20**	**19**	**11**	**1**	**52**	**46**	**35**
Skunk Cabbage Creek	34	0	20	20	19	11	1	52	46	35
Prairie Creek Sub-basin	**0**	**8**	**154**	**108**	**22**	**203**	**55**	**486**	**766**	**729**
Lost Man Creek	0	4	116	92	11	111	33	265	224	378
May Creek	0	4	38	16	11	92	22	221	542	351
Lower Redwood Creek Sub-basin	**0**	**42**	**570**	**439**	**100**	**199**	**46**	**586**	**856**	**1,232**
Bond Creek	0	6	61	28	1	20	2	73	167	203
Bridge Creek	0	1	220	154	30	43	11	272	331	463
Copper Creek	0	17	170	204	48	102	11	120	164	262
Devil's Creek	0	4	47	41	5	6	9	6	63	250
McArthur Creek	0	14	72	12	16	28	13	115	131	54
Middle Redwood Creek Sub-basin	**0**	**135**	**887**	**1,183**	**297**	**405**	**616**	**607**	**481**	**1,723**
Coyote Creek	0	22	202	123	34	30	48	49	78	93
Lower Lacks Creek	0	8	27	18	84	52	119	84	16	316
Lupton Creek	0	10	56	211	0	30	19	79	85	169
Minor Creek	0	17	178	46	19	82	104	142	77	221
Panther Creek	0	18	196	183	23	23	32	37	71	328
Roaring Gulch	0	32	128	319	26	46	26	104	93	294
Toss Up Creek	0	25	70	262	51	50	55	85	42	182
Upper Lacks Creek	0	3	30	21	60	92	213	27	19	120
Upper Redwood Creek Sub-basin	**0**	**207**	**930**	**689**	**134**	**233**	**423**	**453**	**536**	**785**
Bradford Creek	0	27	165	71	22	27	58	137	111	112
Cloney Gulch	0	57	171	48	16	35	36	35	75	48
High Prairie Creek	0	50	195	170	35	50	98	105	112	148
Noisy Creek	0	8	162	93	12	28	47	58	98	145
Twin Lakes Creek	0	56	198	207	47	55	129	71	111	175
Windy Creek	0	9	39	100	2	38	55	47	29	157

* Acres located along the estuary subbasin. These 34 acres do not have any canopy.

In a related study of riparian vegetation on Redwood Creek, Urner and Madej (1998) used multiple series of aerial photos, from 1948 to 1997, in combination with fieldwork to assess changes to riparian composition and density along the mainstem of Redwood Creek and major tributaries. They were particularly interested in changes resulting from timber harvest and floods, distribution of conifers and exotic species in the riparian stand understory, and long-term implications for shading and large woody debris recruitment. They reported a dramatic decrease in uncut conifer riparian zones since 1948. In the later part of the period they examined, they noted that riparian cover was increasing, though it was dominated by hardwoods, such as alder, rather than the redwood and Douglas-fir that comprised the original riparian stands prior to the advent of timber harvest in the basin. Table III- 20 and Table III- 21 present findings for uncut, hardwood-dominated, and sparse cover vegetation characteristics. Urner and Madej used a variable buffer width that was based on average tree height. This was implemented as 165-foot buffer to represent riparian areas above highway 299 and a 240-foot buffer for riparian areas below highway 299.

Table III- 20. Changes in the amount of stream length that is bordered by open or sparse canopy, 1948-1997 (Urner and Madej 1998).

Year	Left Length Total (m)	Right length Total (m)	Average Length (m)	Total Length (m)	Percent of Stream Length	Number of Openings
1997	761	1,566	75	2,327	1%	30
1992	2,229	4,940	163	7,169	4%	45
1978	5,233	12,994	147	18,227	9%	123
1965	17,878	17,548	250	35,426	18%	142
1958	13,463	13,719	325	27,182	14%	84
1948	1,187	4,234	330	5,421	3%	15

Table III- 21. Riparian characteristics, by percent of area, along Redwood Creek, 1948-1997.

Year	Harvest Type				Vegetation			Density		
	CC Old	CC Young	Select	Uncut	Conifer	Grass	HDW	Dense	MOD	Sparse
1997	10	68	7	14	42	3	55	53	44	3
1992	0	76	9	15	41	6	54	53	44	4
1978	0	74	9	16	52	7	41	36	55	9
1965	0	53	19	28	71	6	22	31	51	18
1958	0	34	16	49	73	5	21	49	38	14
1948	0	9	5	86	68	6	27	78	19	3

Given the differences in methods, such as date and source of data, it is difficult to compare the NCWAP stream buffer analysis with the work of Urner and Madej (1998). However, the NCWAP analysis indicates that in 1998, the 50-foot buffer width was 13.4% hardwood dominated (by area), 43.1% conifer dominated and 36.9% mixed conifer/hardwood dominated, for a total of 80% of the buffer area with a significant conifer component. However, the present size of the conifers and their ability to provide shade is much less than the larger trees that were cut during timer harvests. In addition, where Urner and Madej found 58% of the stream length to be hardwood dominated, is in part due to different methods. For example, the Urner and Madej numbers are for along Redwood Creek, while the NCWAP numbers are for all streams in the Redwood Creek basin identified in a hydrography coverage that corresponds to the streams found on a 1:24,000 scale USGS topographic map. There is also a difference in the data source and the resulting interpretation of stand conditions. The NCWAP vegetation data is based on interpretation of satellite imagery, using 30-meter pixels and a 2-acre minimum mapping unit, while the Urner and Madej study was based on aerial photos. The differences in spatial scales can influence the amount of hardwood component in the forest stands that were mapped as conifer.

In addition, both studies describe a different characteristic of the riparian forest. The similarity in the vegetation composition at different buffer widths suggests that in moist watersheds like Redwood Creek the transition from the riparian zone to upland areas is a gradual one, and that it is not easily detected using the regional vegetation maps.

The Urner and Madej study is unpublished, the results preliminary, but if we consider it a valid approach, then it tells us something about what has happened to the riparian forests over time. Their data show that riparian forests were greatly impacted by timber harvesting in the 1950s and 1960s. Since the implementation of the Forest Practice Rules began in the 1970s, there has been a further decline in conifer-dominated riparian stands (i.e., from 52% of riparian area in 1989 to 41% in 1992 and 42% in 1997).

Table III- 20 shows that the total length of stream bordered by open and sparse canopy increased dramatically in the 1950s, going from a total length of 5,421 feet in 1948 to 27,182 feet in 1958. It reached a peak of 35,426 feet in the 1960s and then started to recover. By 1997, the amount of stream length with open or sparse canopy had decreased to 2,327, or below the level recorded in the 1948 photo series. Also, the area of dense riparian canopy increased from 36% in 1978 to 53% in 1997 (Table III- 21). The study clearly shows that the recovery of riparian forests has resulted in stands that have a much greater hardwood component than was known prior to timber harvesting in the basin (e.g., 27% hardwood in 1948 versus 55% hardwood in 1997).

Riparian Vegetation Along Sample Stream Reaches

Additional vegetation assessment was completed for the stream reach information collected by the Department of Fish and Game. Digital vegetation information was utilized to determine the area and vegetation type, size class, and canopy density for the 66 separate fish bearing stream reaches (located mostly in the Middle Subbasin tributaries and mainstem) surveyed by DFG (Table III- 22). A buffer zone of 150 feet along each side of the stream reach was developed to determine specific vegetation information. The 150 foot buffer zone was used because it corresponds to the required watercourse and lake protection zones (WLPZ) outlined in the current Forest Practice Rules. The vegetation information was obtained from the CALVEG types satellite imagery. The minimum mapping size is 2.5 acres for contrasting vegetation types. The vegetation layers were then “clipped” to the GIS shape files for the stream reach assessment. Acres of cover type, percent canopy closure, and tree diameter class were then calculated utilizing ArcView GIS.

Table III- 22. Vegetation attributes within 150-feet of fish bearing streams.

Cover Type	Acres	Percent of Area	Canopy Density Class	Acres	Percent of Area	Diameter Size Class*	Acres	Percent of Area
Agriculture	0.5	0.3	0-9%	17.8	10.0	Non-stocked or Seedling	17.9	10.1
Barren	11.1	6.3	10-19%	7.2	4.1	< 6 inches	1	0.6
Conifer	47.1	26.6	20-29%	26.3	14.8	6 to 11 inches	44.1	24.9
Hardwood	31.5	17.8	30-39%	26.6	15.0	12 to 24 inches	72.7	41.0
Grassland	4.7	2.7	40-49%	7.8	4.4	24 to 40 inches	31.5	17.8
Mixed Conifer/Hardwood	80.9	45.6	50-59%	11.7	6.6	> 40 inches	10.2	5.7
Shrub	1.5	0.8	60-69%	10.5	5.9			
			70-79%	18.4	10.4			
			80-89%	18.3	10.3			
			90-100%	32.8	18.5			

The total buffer area for the DFG-sampled stream reaches is 177 acres. Fifty-five percent of the 150 foot buffer area along fish bearing reaches had less than 60% canopy cover. In addition, a similar comparison for cover types indicates that the CDFG stream survey reaches have a significantly lower percentage of conifers and higher percentage of mixed conifer/hardwood than stream buffers for the basin as a whole. Comparing the density and size classes of the buffer areas along the DFG sample reaches to the same factors along all Redwood Creek streams indicates that the 150 foot buffer areas along the sample reaches have relatively less area in the higher size classes, with over 75% of the area composed of trees less than 24 inches in diameter. Thirty-five percent of the anadromous reach length was composed of trees less than 12 inches DBH. These data indicate that the forest within 150 feet of fish bearing stream reaches are mainly composed of small sized trees and they are not capable of providing all the benefits needed to maintain desirable riparian and aquatic habitat conditions.

The importance of the shift toward hardwood-dominated riparian stands, as indicated by the work of Urner and Madej (1998) in particular, has implications for both forest ecology and land management. Redwood Creek along with many North Coast streams are deficient in the amount of instream LWD and have water temperatures above desirable levels for salmonid production. One of the main mechanisms for reducing water temperatures and increasing LWD recruitment to streams in the future is to promote the development of large conifers in the riparian and nearstream forest zone. In some cases this may require more active management of forest stands currently dominated by hardwood in order to increase their conifer component. However, it is not well understood how much LWD is needed.

Fire History and Fire Hazard

Large uncontrolled wildland fires pose a number of risks to streams and watersheds. These fires can remove vegetation whose foliage protects soils from raindrop impact and whose roots hold soils in place. Thus, the loss of vegetation due to fire can result in significantly increased erosion and delivery of sediment to streams. Wildland fire associated erosion can be further exacerbated when conditions result in the creation of hydrophobic soils. Loss of vegetation and formation of hydrophobic soils also can result in changes in the rate (faster delivery over a shorter period) at which precipitation is delivered to streams and in the process of delivery (overland flow versus subsurface flow). The resulting "flashier" hydrograph can result in higher flow and/or greater levels of flooding for a given amount of precipitation. These changes in sediment delivery and flow can have adverse impacts on streams and fish habitat. In some instances, fires have been reported to cause pulses of nutrients to be mobilized and transported to the stream system, causing temporary eutrophication. Additionally, where high severity fires occur in the stream zones themselves and cause loss of canopy cover in the riparian corridor, there can be a rise in stream water temperatures until vegetation cover and shading regrow. Fires also may provide some benefits to stream ecosystems and fish. Burnt vegetation is a source of carbon and nitrogen that enters streams after fires. This influx of nutrients can increase the primary productivity in nutrient poor stream systems leading to an increase in insect production and salmonid food supply.

Suppression of large wildfires can result in adverse impacts on wetlands, riparian areas, or stream channels. Intense heat from catastrophic fires could remove upland vegetation and create patches of bare soil. Heavy rainfall could erode the soil and cause sediment to move into riparian areas and stream channels. Post-fire rehabilitation efforts are typically undertaken to reduce the potential for surface erosion and sediment delivery. Cutting fire lines for suppression efforts would directly disturb soil and vegetation. Generally fire lines are constructed along ridge tops and away from stream channels and wet areas. This location, coupled with post-fire stabilization such as installing water bars, seeding with native grasses and forbs, and spreading with hay, help to minimize erosion and sediment delivery to watercourses.

However, fire has long been used as a land management tool within Redwood Creek. Forests were burned by the Native Americans on a frequent basis to reduce the fuel loading as an aid to hunting. Fire is utilized as a management tool by the lumber industry. When using steam donkeys, forests were burned prior to yarding. Generally these areas were burned after the large timber was felled and the bark was removed. Once this was done burning was utilized to remove the significant amount of logging debris and bark that was in the unit. Removal of this debris made the yarding of the logs much easier but resulted in an increase in sediment generation from the burned unit.

Fire is used today as part of modern silvicultural practices. Burning of a clear-cut unit is utilized for the preparation of the area for planting and regeneration of the site. Burning prescriptions outline the use of light ground fires to reduce the fine fuels but retain the larger more coarse debris for its wildlife benefits and erosion control properties. Redwood National Park also utilizes prescribed fire as part of its management plan.

Within recorded history, fires have been a common part of Redwood Creek. A total of 20,763 acres have been burned within the drainage since 1950 (Table III- 23). Due to the difference in reporting methods, the number of fires and the acres burned for the National Park Service (NPS) includes the prescribed fires that the Park conducts on an annual basis. Acres burned for other jurisdictions do not include prescribed fire acres. Some of these burned areas in the Park reflect grassland areas, which have been burned multiple times to control unwanted vegetation. Since 1980 there have been 65 recorded burns within the National Park totaling 7,293 acres. Most of these are along the grassland ridges of the Bald Hills area

Table III- 23. Acres burned and the number of reported fires by responsible agency since 1950.

Agency	Number of Fires	Total Acres Burned
CDF	7	3,591
NPS	106	15,317
USFS	11	1,067
Total	**124**	**20,763**

Wetlands and riparian areas tend to be less susceptible to fire than upland vegetation types and are usually not directly affected by unplanned fires to any significant degree. These areas typically are not greatly affected by wildland fires. Wet areas and riparian zones do not burn well due to the high moisture content of the vegetation and soils.

Prescribed fire use within the Redwood Creek basin could reduce adverse impacts to watercourses and wet areas. Regular use of prescribed fire could reduce fuels so that catastrophic fires are less likely to occur. Watercourses and riparian areas would not be as adversely affected by prescribed fire as by an uncontrolled wildfire. Prescribed fires generally do not burn as hot as an uncontrolled wildfire. These cooler fires would not damage the soil organic layer to the effect seen with catastrophic wildfire. Prescribed fire burns do not require the extensive network of constructed fire lines found in use with a large wildfire. These aspects of prescribed fires alone would reduce impacts to the watercourses and wet areas compared to catastrophic wildfires.

Fire Hazard and Fuel Rankings

The breakdown of acres by fuel rank for Redwood Creek and its component subbasins is shown in Table III- 24 and Figure III- 21. Taken as a whole, Redwood Creek presents a significant fire hazard, where roughly 112,000 acres (62% of the land base) is in either the high or very high fuel rank. Most of these areas are dominated by conifer vegetation (sometimes with an associated hardwood component in the overstory) where the combination of surface and ladder fuels in conjunction with slope steepness indicate expected high intensity fires, with surface fire flame lengths greater than 8 feet, and in forested types, high incidence of crown fire for fires burning under the assumed weather and fuel moisture conditions used in the analysis. In addition, 67,000 acres (37% of the basin area) in the moderate fuel rank. Most of these areas are dominated either by grasslands or hardwood forests and woodlands. Fuel rank maps and tables of fuel ranks at the subbasin scale and planning watershed level are provided in Part IV of this report.

Table III- 24. Fuel ranks summary for Redwood Creek, subbasins, and Planning Watersheds.

Area of Analysis	Fuel Rank								Total Acres
	Moderate		High		Very High		Not Mapped		
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	
Redwood Creek basin	67,186	37	101,757	56	10,764	6	1,101	1	180,808
Estuary Subbasin	920	27	1,670	49	378	11	467	14	3,435
Prairie Creek Subbasin	3,869	15	20,267	80	955	4	277	1	25,368
Lower Redwood Creek subbasin	17,134	38	24,672	55	2,533	6	168	<1	44,507
Middle Redwood Creek Subbasin	29,675	46	31,121	49	3,220	5	110	<1	64,126
Upper Redwood Creek Subbasin	15,588	36	24,027	55	3,678	8	80	<1	43,373

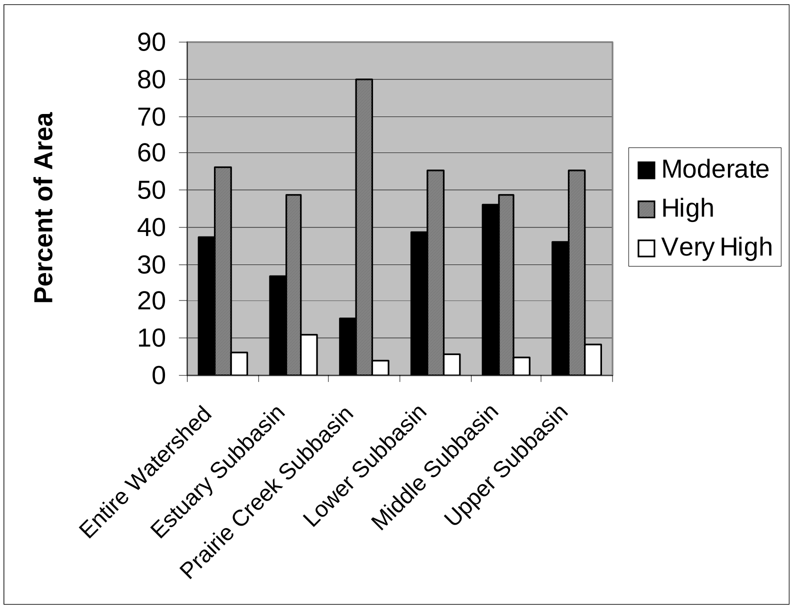

Figure III- 21. Fuel rankings for Redwood Creek basin and subbasins.

The individual subbasins, with the exception of Prairie Creek, show a relatively similar distribution of fuel ranks reflecting the specific vegetation and fuel assemblages present in the localized areas. In Part IV of the report, there is a fuels map for each subbasin. The estuary subbasin has the largest area in the not mapped category, owing to the agricultural area found there. The areas of very high rank are relatively large and contiguous in this subbasin as compared to the other subbasins. The Prairie Creek subbasin is dominated by areas in the high rank, with 80% of the area falling into that class. An additional 4% of the subbasin is modeled as having a very high fuel rank. However, high fuel rank does not directly translate into high likelihood for wildfires. The severe fire weather conditions assumed by the CDF fuel rank model used in this analysis are not typical for the Prairie Creek Subbasin or Estuary Subbasin. The large old growth redwoods are fire resistant and many have endured for centuries to over one thousand years. In addition, these subbasins exhibit high moisture content in soils and in the vegetation, and a cool coastal climate. Large fire growth is unlikely, given the conditions in the Prairie Creek Subbasin (L. Arguello, RNSP, personal communication).

The Lower Subbasin is dominated by areas in the high rank, with a spattering of small areas in the very high rank along the eastern border of the unit. The Middle Subbasin is almost evenly split between moderate and high rank areas, with again, small discontinuous zones of very high rank scattered throughout the unit. Finally, the Upper Subbasin shows a similar distribution to the Middle Subbasin, though with a slightly greater concentration of very high rank areas and less of the moderate rank areas typical of the Middle Subbasin's westerly and lower portions.

Land Use

Pre-European Settlement

Native Americans made extensive use of Redwood Creek, especially along the main channel of Redwood and Prairie Creeks. Wide-ranging villages were located along the flood plain near the mouth of the ocean. The Yurok People occupied approximately 300,000 acres (Lara 1996) covering the area from the mouth of Little River through the lower portion of Redwood Creek and north to Wilson Creek and inland to Bluff Creek along the Klamath River. Waterman (1923) recorded no fewer that five villages in this area of Redwood Creek during his work on the Yurok Tribe. The rich forests of this region were teeming with wildlife and the streams were full of fish. Fire was also used as a land management tool. Forests were burned on a frequent basis to reduce the fuel loading as an aid to hunting. Although the Yurok People did not cut down redwood trees, a fallen redwood tree or portions of the tree were well utilized. Uses of the redwood tree included: sticks for cooking and drying various fish, for drying meat such as elk or sea lion, construction material for houses or sweat lodges, gill net floats, net needles, drum handles, baby baskets, storage baskets, women's work dresses, chairs, pillows, and the indispensable canoe.

Chilula people inhabited the lower and central portion of Redwood Creek. Chilula villages were located on or near lower Redwood Creek from the inland edge of the redwood belt to a few miles up stream of Minor Creek. Eighteen village sites were recorded as belonging to these people. All but one of these sites was located on the eastern side of the creek (Kroeber 1976) in order to take advantage of the of the increased sunlight.

A third group of Native Americans that inhabited Redwood Creek were the Whilkut people. They occupied upper Redwood Creek area upstream of the Chilula to the headwaters and portions of the Mad River and Grouse Creek drainages.

European Settlement

European settlement of the Orick area was first recorded in the 1850s. During January 1851, a small gold rush broke out over the beach sand at Gold Bluff. Miners, seeking to develop the area north of Redwood Creek, in the area of the "bluffs" and Majors Creek, first settled here. The alluvial plain in and around Orick was cleared of the extensive Sitka spruce stands, hardwood trees, and thick brush and was converted to farm and grazing land. This converted area accounts for less than one percent of the total basin area. The upper areas of Redwood Creek were becoming utilized and populated during this same time period by miners and settlers. The initial use of hardwoods in this area was for fuel wood, fence posts, and tanbark. Bark from the tanoak tree, was used for the tanning of hides.

Historic cattle ranching and sheep farming utilized the native meadows, grasslands, and oak woodlands. Cattle were moved into the Redwood Creek area and by 1860 extensive herds were located along the Bald Hills and Upper Redwood Valley. After 1865 the sheep and wool industry became the leading agricultural enterprise in the eastern portion of the valley, away from the dense stands of timber. Excellent stands of native grasses provided year-round grazing and were well suited for sheep grazing. Wool produced in this area of Humboldt County was considered to be the best grown on the Pacific Coast and brought the highest prices on the open market (Green 1980).

Up until 1940 there was an estimated 15,000 to 20,000 sheep within the Bald Hills and Redwood Creek area (Stover, pers. com). With this large number of animals within a relatively small area one can only expect intense impacts from this enterprise. The only land base suitable for grazing was the natural grasslands and oak woodlands. These two areas amount to approximately 32,000 acres of suitable rangeland. These figures would indicate that there were approximately 1 to 2 sheep per acre. This level is well above the recommendation of no more that one animal per four acres. This ratio can be even as high as one sheep for 20 acres on low quality rangeland (Stoddart, Smith and Box 1975). Once the carrying capacity of the range is exceeded and the area is overgrazed, adverse effects typically result: reduced forage production, creation of bare and unstable topsoil, loss of top soil, increased erosion, creation of gullies, invasion of the site by non-native plants, increase in the percentage of annual plants and reduction in the number of plant species present. Historic overgrazing of the Redwood Creek land base could have lead to the incipient stages of erosion in the basin. While this topic is beyond the scope of the NCWAP program, it may warrant further study.

Land Ownership

Prior to 1968 most of the Redwood Creek drainage was held in private ownership. Timber companies or large family ranches owned most of this land base. During this time timber harvesting was the dominant land use. In the early 1920s, the Save-the-Redwoods League purchased approximately 14,000 acres, creating a sanctuary of old growth coast redwood in the Prairie Creek basin which became part of the Redwood State Park system.

Redwood National Park was created in 1968. Ten years later Congress added more land that included logged-over portions of Redwood Creek in the Lower Subbasin. Timber production was no longer the principal land use in the lower part of the drainage. Recreation and preservation of natural resource values became the main management goals in the park lands.

Currently, 43% of the entire basin is within public ownership (Table III- 25 and Figure III- 22). Privately held lands account for 56% of the ownership (101,142 acres) within the Redwood Creek basin. The Redwood Creek Landowners Association is comprised of ten private ownerships (Landowners Association 2000) ranging from small to large industrial tracts, which own and manage lands within Redwood Creek. This collective ownership accounts for more that 80% of the privately owned property in the basin. Eight large ownerships of larger than 3,000 acres each account for 90% of this total. Some of these members have managed land within the basin for fifty years or longer. These landowners conduct a mix of land uses, including ranching and timber management.

Table III- 25. Current acres and percentage of area by ownership within Redwood Creek.

Landowner Class	Ownership Acres	Basin (%)	Federal Ownership (%)
National Park	66,696	36.9%	92.7%
State Park	6,620	3.7%	
BLM	3,599	2.0%	5.0%
USFS (Six Rivers)	2,537	1.4%	2.3%
Private	101,142	56.0%	
Total	180,594	100.0%	100.0%

Source: Redwood National Park

These current ownership figures represent a consolidation of the ownership patterns which existed during the beginning of the 20th century. The 1911 "Denny's Official County Map" showing property ownership of Humboldt County includes the Redwood Creek area and reveals a much more fragmented land ownership pattern. Land sections were divided up into multiple ownerships with each section containing as many as six ownership names such as Hammond Lumber Company, B.L. Lyons, Hill – Davis Company, Collins, Russ and Sons, Solomon, Merryman Fruit Land and Lumber, Thomas & Bair, Gold Bluff Mining & Lumber, Warren Timber Company, Trinity National Forest, C H Wright and J D Tilley, and many more. Northern Mountain Power Company could also be included in this partial list because of their power line that bisected Redwood Creek. This power line was located within the same area as the present day right of way. As the demand for forest products increased by 1950 and timber operations became the principal land use within Redwood Creek, companies began to increase their land base. Smaller companies and individual holdings were bought up or the timber rights were acquired by the larger more viable operations. As a result of this ownership consolidation almost all of the privately held land became subject to forest management and timber harvests operations.

As the demand for forest products increased in the 1940s and 1950s, timber operations became the principal land use within the basin and the larger companies increased their land base. Smaller companies and individual holdings were bought up or the timber rights were acquired. As a result of this ownership consolidation, almost all of the privately held forest land became subject to forest management and timber harvests operations.

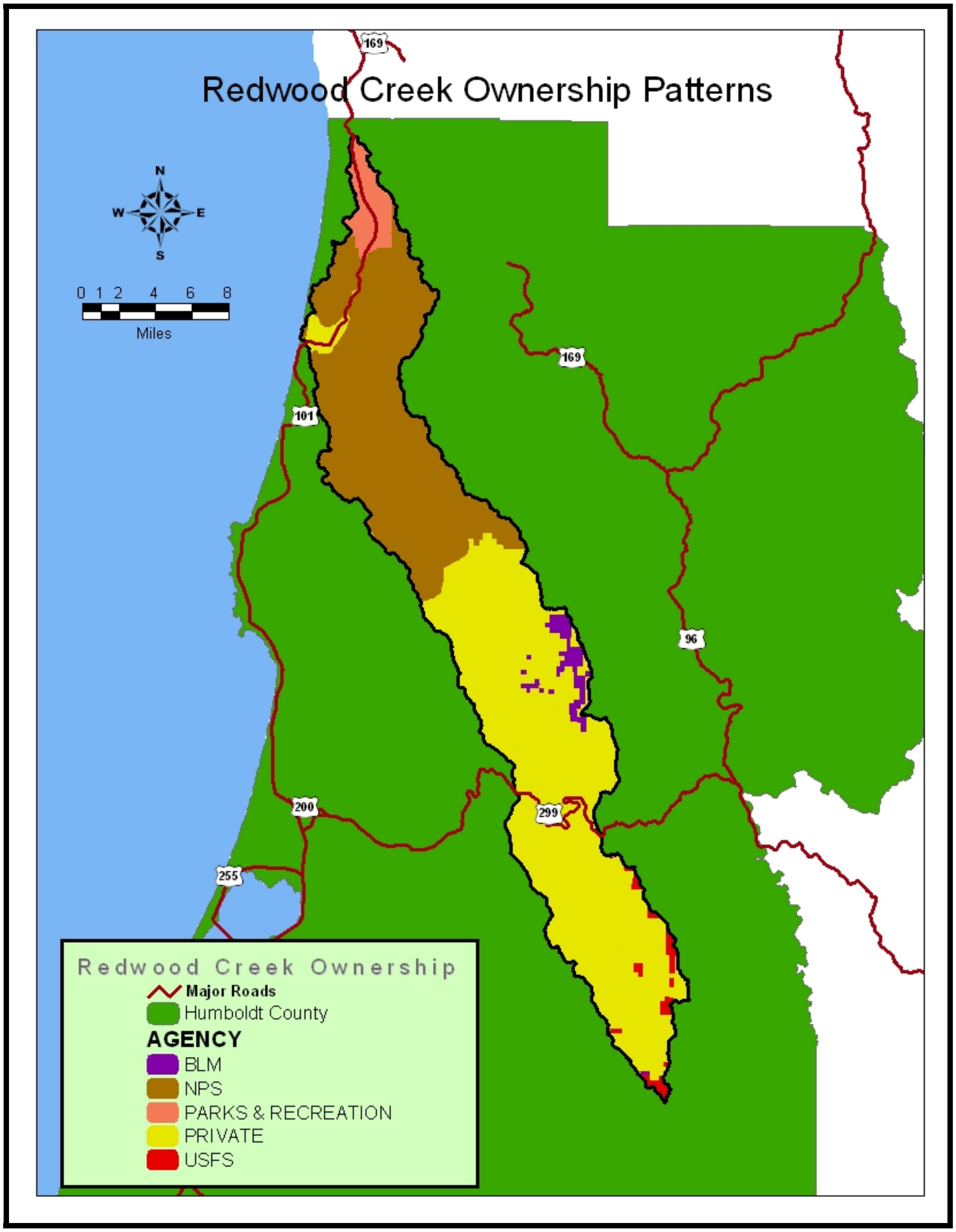

Figure III- 22. Redwood Creek ownership map, 2001.

Forest Management and Timber Harvesting

Multiple years of aerial photos were examined to assess historical forest management on the Redwood Creek basin. More recent harvesting activity was documented from timber harvesting plan (THP) documents and captured in GIS. More detailed information of timber harvest is presented in Part II and in Appendix F.

Timber harvest has been the dominant land use in the private lands of the Redwood Creek basin. Initial timber harvests are visible on the 1942 aerial photos. This early logging was conducted with steam donkeys and cable systems as evident from the telltale yarding patterns in the photos. Some early tractor logging started in the late 1930s, but it did not become highly utilized until after World War II. The post-war years and associated housing boom created an increase in the demand for Douglas-fir logs. This boom led to an increase in logging within the middle and upper portions of Redwood Creek. During the period from 1949 to 1954, 19% of the area was logged (Best 1984). The harvest practices of this era resulted in a significant amount of area that grew back in extensive tanoak stands, which are present. These almost pure tanoak stands, which have a low to negative harvest value depending upon highly variable wood chip markets, are being harvested and utilized on an experimental basis. Once the stands are cut, the areas are replanted to native Douglas-fir to reestablish high-timber-value tree species.

Aerial photos from the 1940s period indicate that the yarding pattern was down the slope and drainage. Overall ground disturbance was also increased due to the tractor's ability to construct large "layouts" in a relativity short amount of time. Layouts are large "cushions" of pushed up soil and debris that help to keep large trees from breaking when they hit the ground after being cut. Tractor-constructed layouts observed in the 1940s photos were often 300 feet long and 20 feet wide. The harvesting practices of the day clearly resulted in high levels of soil disturbance with high potential to generate and deliver sediment to stream systems.

Modern cable yarding methods did not become widely utilized within Redwood Creek until around 1972 when Arcata Redwood Company brought in the first highlead system. Introduction of cable yarding systems along with the newly legislated Forest Practices Act of 1973 modified timber yarding methods. There was an increase in ridge top landings and mid-slope road construction.

By 1948, 5% of the Redwood Creek basin (excluding Prairie Creek Subbasin) had been harvested. The most active period of harvesting was between 1962 and 1978, when 32% of the basin was harvested in 16 years. By 1978, 81% (approximately 121,000 acres) of the coniferous forests of the basin had been logged and approximately 1,240 miles of roads and 5,600 miles of skid trails were constructed to remove timber from the forest (Best 1995). Much of this work was done prior to rules of the Forest Practice Act of 1973.

By the year 2000, an estimated total of 130,680 acres within the Redwood Creek basin (72% of the landscape or 87% of the coniferous forest) has been cut on a first entry harvest basis. An additional 30,000 acres in the Middle and Upper subbasins have undergone a second or third entry harvest. Table III- 26 and Table III- 27 reflect the cumulative area of timber harvesting within Redwood Creek.

Table III- 26. Cumulative first entry harvest in the Redwood Creek basin.

Year	Cumulative percent of basin area harvested
As of 1948	5*
1948-1954	21
1954-1962	35
1962-1978	67
1978-2000	72

*Excluding Prairie Creek Subbasin.

Table III- 27. Timber harvest estimates by subbasin, 1950-2000, including acres with multiple harvests.

Subbasin or Planning Watershed	Harvest Acres by Period							
	1950 to 1964	1965 to 1974	1975 to 1983	1984 to 1992	1992 to 2000	Total Harvested	Total Acres	Percent Harvested
Entire Redwood Creek basin	70,319	35,291	20,809	20,493	13,868	160,780	180,701	89.0
Estuary Subbasin	1,249	84	137	0	0	1,470	3,433	42.8
Prairie Creek Subbasin	11,236	1,387	919	0	0	13,542	25,305	53.5
Lower Subbasin	12,470	13,436	4,308	0	0	30,214	44,505	67.9
Middle Subbasin	32,406	11,991	12,616	13,999	10,011	81,023	64,122	126.3
Upper Subbasin	12,958	8,393	2,829	6,494	3,857	34,531	43,336	79.7

Due to the extensive parklands in the other subbasins, the Middle and Upper subbasins were the site of virtually all the post-1978 harvests. Figure III- 23 shows the number of harvest plans and the acres harvested per year for the period of 1978 to 2001 in the Upper and Middle subbasins. A data table for this series may be found in Appendix F. Harvest operations peaked during the years of 1986 to 1989, with a high of 40 harvest plans covering 3,746 acres in 1988. The overall harvest trend indicates a steady decline both in the number of plans and the acres harvested per year, particularly in the more recent years.

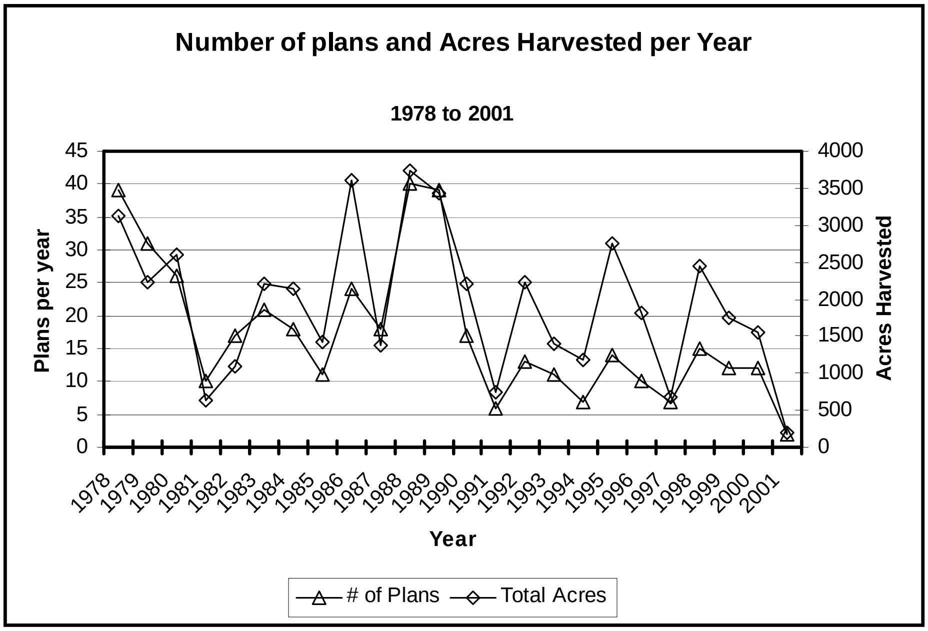

Figure III- 23. Numbers of timber harvest plans per year and acres harvested for the Middle and Upper subbasins, 1978 though 2001.

An average of approximately 1,940 acres were harvested annually in the 24-year period from 1978 to 2001. This represents about 1.8% of the combined subbasins being harvested annually. This would also reflect approximately 1.07% of the entire Redwood Creek basin being harvested annually since the Park expansion in 1978. Looking on a decadal basis, 1980-1989 saw an annual average of about 22 THPs and 2,227 acres harvested for the two subbasins, or about 2.1% of the area per year (Table III- 28). The decade of 1990-1999 saw an average of about 11 THPs and 1,720 acres harvested per year, or about 1.6% of the area of the two subbasins. The last two years, 2000-2001, show a significant reduction in harvesting activity relative to the previous decade, with an average of 2 THPs and 869 acres harvested per year.

Table III- 28. Average annual number of timber harvesting plans and plan acres per decade or period, 1980-1999, Middle and Upper subbasins.

Decade or Period	Average # of Plans/Year	Average # of Acres/Year	Average # of Acres/Plan
1980-89	22.4	2,227	99
1990-99	11.2	1,720	154
2000-2001	7.0	869	124

This harvest rate decline may be due to various factors, including the decline of available timber, changing market conditions or changes in management objectives. The spike in the acres cut in the late 1980s was mostly due to an active timber market. The trends also show an increase in the average size (acres-wise) of THPs. This trend has been seen elsewhere in the state. It is at least in part due to the high cost of THP preparation. By making THPs larger, the average cost of THP preparation per acre of harvest area can be significantly reduced.

Analysis of the yarding method, decade of harvest and slope class was conducted for the Middle and Upper subbasins utilizing GIS. These two subbasins are the areas where intensive land management activities such as timber harvest are still ongoing. Overall the amount of tractor yarding on the steeper slope classes has declined as a percentage of the acres yarded. During the decade of the 1970s, 34.9% of the slopes over 65% were yarded by cable systems. In the decade of the 1990s, cable yarding increased to 53.7% of the harvest acres on slopes over 65%. An increase in the use of cable systems and helicopter yarding on slopes less than 65% during the decade of the 1980s and 1990s also was noted. Based on the slope stability information developed by CGS, landslide potential is quite high on slopes greater than 35% for much of the basin. Timber harvest and road construction on these steeper and highly unstable slopes should involve careful on-site evaluation by a registered geologist. Management techniques (such as less intensive silvicultural prescriptions, cable or helicopter yarding, engineered road fills) should be selected accordingly to minimize slope failure risks to an acceptable level, or the area should be avoided.

Roads

There are approximately 2,000 miles of roads within Redwood Creek basin. Redwood National Park has estimated that about 50 miles of roads are located within the inner gorge of watercourses. Only major highways and most county roads are paved. The remainder of the roads within the drainage are surfaced with either native material, gravel or rock from a local source. Detailed summaries of road attributes by subbasin are presented in Part III of this report.

The vast majority of the roads in the basin were constructed during the initial timber harvest period of the 1950s. Most private road construction was for the purpose of timber harvesting. This road system was identified as a major source of sediment delivered to stream channels. With evolving changes in Forest Practice Regulations since the early 1970s, new harvest-related road construction has had to meet increasingly higher standards. These regulations cover construction activities such as operations on steep slopes, road alignment, road grades, erosion control, watercourse crossings, culvert instillation, winter period operations, and road maintenance. New construction undertaken by Caltrans for a new freeway by-pass accounted for elevated amounts of runoff and sediment production by the time the project was finished in 1992. Impacts of particular concern occurred during a heavy rainstorm in October 1989.

Road density information in Cederholm et al. (1981) suggest that fine sediment increases in basins with more that three miles of road per square mile of area. Currently, Redwood Creek has approximately 4.8 miles of road per square mile for the entire basin. This number drops to 2.15 miles of road per square mile of area within the Prairie Creek and Lower subbasins. The USFS and BLM ownerships in Redwood Creek have 4.8 miles of road per square mile of ownership. Private lands in both the Middle and Upper subbasins average over 8 miles of roads per square mile of landscape. Many of these roads were built prior to modern road construction standards, and unless upgraded, have potential for erosion and sediment delivery to streams.

The road-decommissioning program within the National Park has treated or removed 214 miles of roads since the program began in 1978. Road assessment for the entire Redwood Creek basin has been completed or is nearing completion. Assessment work in Lupton Creek, Noisy Creek, Pardee Creek, Toss Up Creek, and Roaring Gulch planning watersheds has been funded. With the funding and implementation assessment program, roughly 90% of the private lands in Redwood Creek will have been inventoried. The Redwood Creek landowners' road assessment project is specifically intended to provide a prioritized plan for reducing the effects of roads on stream channels. Some landowners have already taken action to upgrade many of their roads and watercourse crossings.

Water Quality

Water Column Chemistry

In general, the existing thirty years of water chemistry data characterizes Redwood Creek as a moderately hard water, moderately oligotrophic stream, with adequate water quality to support salmonid populations. The data are within optimal ranges defined as Basin Plan objectives. Nothing can be concluded about the quality of water from the upper portion of the basin due to a lack of sampling sites, except that water quality in the mainstem (near the confluence with Minon Creek) is good. Dissolved oxygen and pH values do not change much from one subbasin to another. Conductivity in Prairie Creek was slightly lower in the 1970s compared with the rest of the basin. Nutrients (nitrogen and phosphorus) in the basin are low.

The statewide Surface Water Ambient Monitoring Program (SWAMP) collected thirteen samples from Redwood Creek during 2001-2003 near the town of Orick, CA. SWAMP samples were analyzed for DO, pH, conductivity, temperature, turbidity, alkalinity, ammonia, nitrogen, phosphorus, total organic carbon, chlorophyll, metals, pesticides, and herbicides. The USGS and USEPA collected water quality data during 1958-1988. Their data did not show levels of concern to water quality for salmonids or human consumption.

Because of heightened interest in this basin, we are fortunate to have 30 years of water chemistry data to monitor changes over time.

Water Temperature

Two metrics were used to evaluate summer water temperature suitability for salmonids of Redwood Creek. The first metric is the maximum weekly average temperature (MWAT), which is the upper temperature recommended for a species life stage or a threshold that should not be exceeded over any seven-day period (Armour 1991). The second metric is the seasonal maximum or the highest temperature observed during the hottest part of the year.

Seasonal maximum or peak temperature data indicate temporary or short-term exposure to extreme conditions. It is generally accepted that a threshold temperature exists that fish can withstand for short consecutive period of hours before damage is caused by stress (Armour 1991). The instantaneous seasonal maximum that may lead to salmonid lethality is >75°F (RWQCB 2000).

For sites throughout the basin, the MWATs calculated from continuous summer temperature data from 1994 to 2001 are borderline or exceed the "fully suitable" range for optimal salmonid production (Table III- 29and Figure III- 24). Temperatures in Redwood Creek basin show maximum MWATs for the period of record along the mainstem ranging from 67-72ºF and tributaries in the 54-68ºF range. It is interesting to note that the MWAT was reached during the same week across the basin. Temperature data from 1974 in Woods (1975) lists three tributaries (Lost Man, Little Lost Man, and Panther Creeks) with MWATs ranging from 57-64ºF. These measurements were taken with less accurate continuous recording equipment compared to those in use today. The data from 1974 should be considered as descriptive and are included to illustrate the complete record of temperature data gathered for Redwood Creek. However, the stream may have been more exposed to sunlight because of removal of shade canopy during timber harvests giving validity to the high temperature of Lost Man Creek in 1974.

The mainstem reaches, especially in the Upper and Middle subbasins, experience the highest MWAT temperatures perhaps due to wide aggraded channels with little to no canopy cover and a NW/SE aspect. Throughout the basin, cold water tributaries help to ameliorate increases in, and in some cases, lower mainstem temperatures. Overall, the headwaters area of Redwood Creek and Prairie Creek subbasin are the coolest perhaps due to cold water inputs from tributaries with tall streamside trees and steep inner gorges which provide shading over the channel.

In 1980 and 1981, Anderson (1988) measured maximum temperatures of tributaries and mainstem Redwood Creek on an hourly basis. These measurements may not have captured the seasonal maximum temperature. However, peak temperatures recorded ranged between 54 and 79°F and tributaries averaged 6 degrees cooler than the mainstem. From 1994-1998, peak temperatures recorded in tributaries ranged from 63-72°F and peak temperatures in the mainstem ranged from 68-81°F (Ozaki et al. 1999). Temperatures recorded from continuous monitors exceeded the critical lethal temperature threshold of 75°F every summer from 1994 to 1998 at three of the six mainstem Redwood Creek monitoring locations (Figure III- 25). A few tributaries to the mainstem also approached or exceeded the lethal peak temperature limit. Figure III-32 shows a map of temperature monitoring sites.

Continuous and spot temperature monitoring data reflect the temperature at a point of the stream. Spatial area is not associated with the data other than the point monitored. Additional temperature monitoring sites along each stream need to be established to obtain more complete and meaningful temperature regime information. Continuous monitoring during the warm summer months should be continued at current sites and expanded to cover more tributary and mainstem locations. The establishment of trend lines from these data will assist in future studies and help evaluate effects of management efforts.

Table III- 29. Maximum MWATs and seasonal maximum temperatures for stations in the Redwood Creek basin from 1974 to 2001.

Site ID	Site	Subbasin	Period of Record	Max MWAT (ºF)	Seasonal Maximum (ºF)
*3012	*Redwood Creek Estuary[5]	Estuary	1997-98	68	70
10, Little Lost Man	Little Lost Man3	Prairie	1974	57	
20, Lost Man	Lost Man3	Prairie	1974	64	
20, Lmc	Lost Man1	Prairie	2001	58	61
30, Ldc	Larry Dam Creek1	Prairie	2000, 01	57	58
3015	Prairie Creek at Streelow Crk[5]	Prairie	1997, 1999	59	61
3016, prw	Prairie Creek at Wolf Bridge [5, 1]	Prairie	1997-98, 01	60	63
3013, RwLow	*RedCrk upstm Prairie Creek [5, 1]	Lower	1997-99, 2001	67	76
40, Tmcd	Tom McDonald Creek1	Lower	2001	58	60
*3014, RwTtg	*RedCk upstm Tom McD Ck [5, 1]	Lower	1997-99, 2001	70	76
3002, Bri	Bridge Creek [5, 1]	Lower	1996-2001	61	67
824	Coyote Creek[5]	Middle	1994	61	63
50	Panther[3]	Middle	1974	66	
984	Panther mouth[5]	Middle	1998	58	61
2019	Upper Panther Creek[5]	Middle	1994-95	57	59
3004, Lac	Lacks Creek [5, 1]	Middle	1997-2001	67	73
1144	Upper Lacks Creek [5]	Middle	1998	61	65
*3011	*RedCrk upstm Lacks Creek[5]	Middle	1997-98	72	80
1118	Beaver Creek[5]	Middle	1997-98	62	66
1119, Mill	Mill Creek [5, 1]	Middle	1997-98, 2001	61	64
1120	Molasses Creek [5]	Middle	1997-98	63	70
1121	Moon Creek [5]	Middle	1998	68	79
*3006, 1145, Min	Minor Creek [5, 1]	Middle	1997-99, 2001	65	77
1123	Minor Creek Trib [5]	Middle	1998	59	63
1124	Upper Minor Creek [5]	Middle	1997-98	61	64
1125	Sweathouse Creek [5]	Middle	1998	62	65
957	Lupton Creek [5]	Middle	1997-98	59	62
*3008, RwOkn	*O'Kane gaging station RedCrk upstm Lupton Creek [5, 1]	Upper	1997-99,2001	71	80
608	High Prairie Creek [5]	Upper	1998	56	57
614	Upper High Prairie Creek [5]	Upper	1998	56	57
*3007, RwMin	*RedCrk upstm Minon Creek[5]	Upper	1997-99	65	71
611	Minon Creek mainstem [5]	Upper	1998	62	65
612	Upper Minon trib [5]	Upper	1998	54	47
613	Upper Minon Creek [5]	Upper	1998	54	47
5041901	Lake Prairie Creek[6]	Upper	1996-99	60	65
5043201	Pardee Creek[6]	Upper	1996-99	58	59

Data sources: 1RNSP (2001), 3Woods (1975), 5Lewis T. et al. (2000), 6Simpson (2000).

* Indicates locations on mainstem Redwood Creek. Site ID numbers correspond to locations in Figure III- 25. See Appendix C for a map of all monitoring locations.

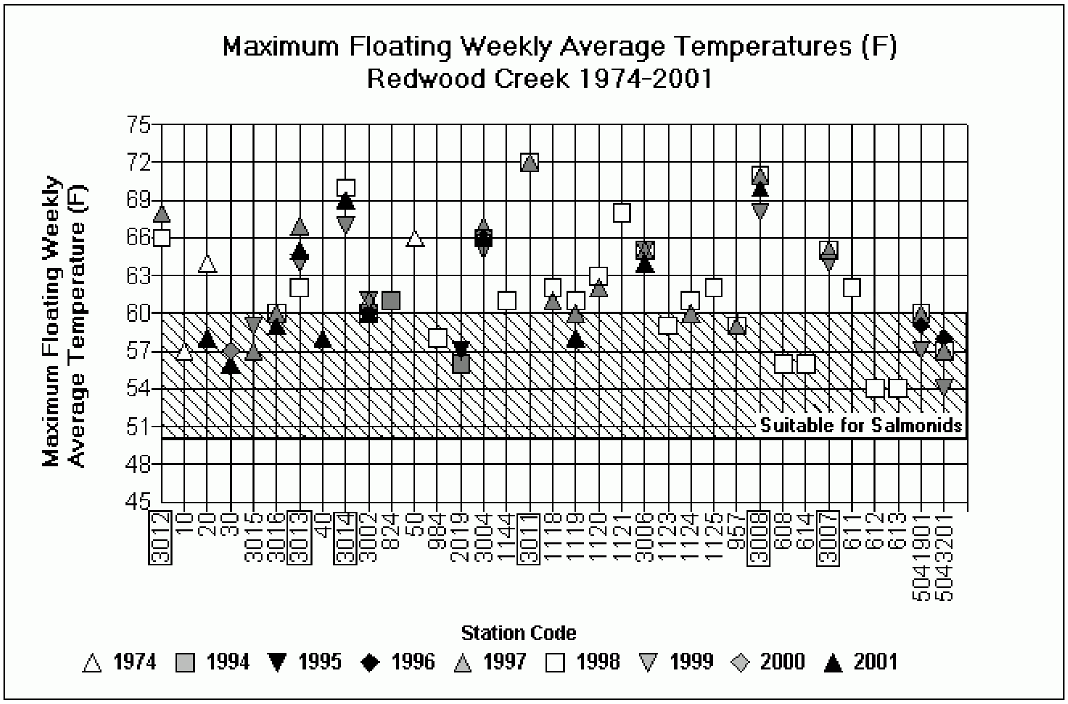

Figure III- 24. MWATs for all stations in the Redwood Creek basin, 1994 to 2001.

Suitability range (50-60°F) highlighted in figure corresponds to the EMDS "fully suitable" range for MWAT data. Data sources: RNSP (2001), Lewis et al. (2000), Simpson (2000), Woods (1975). See and Figure III- 25 for station locations.

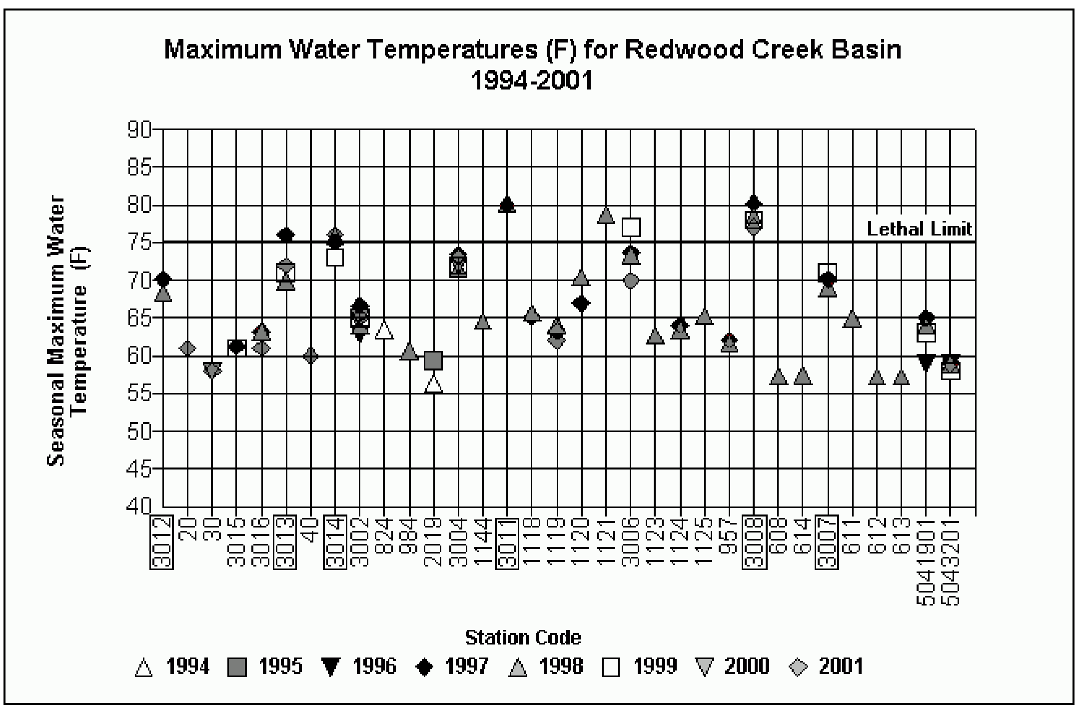

Figure III- 25. Seasonal maximum temperatures for all stations in Redwood Creek basin, 1994 to 2001.

Sources: RNSP (2001), Lewis et al. (2000), Simpson (2000), Woods (1975). Lethal limit (75°F) highlighted in figure corresponds to seasonal maximum limit. Data sources: RNSP (2001), Lewis et al. (2000), Simpson (2000), Woods (1975). See Table 29 and Figure 26 for station locations.

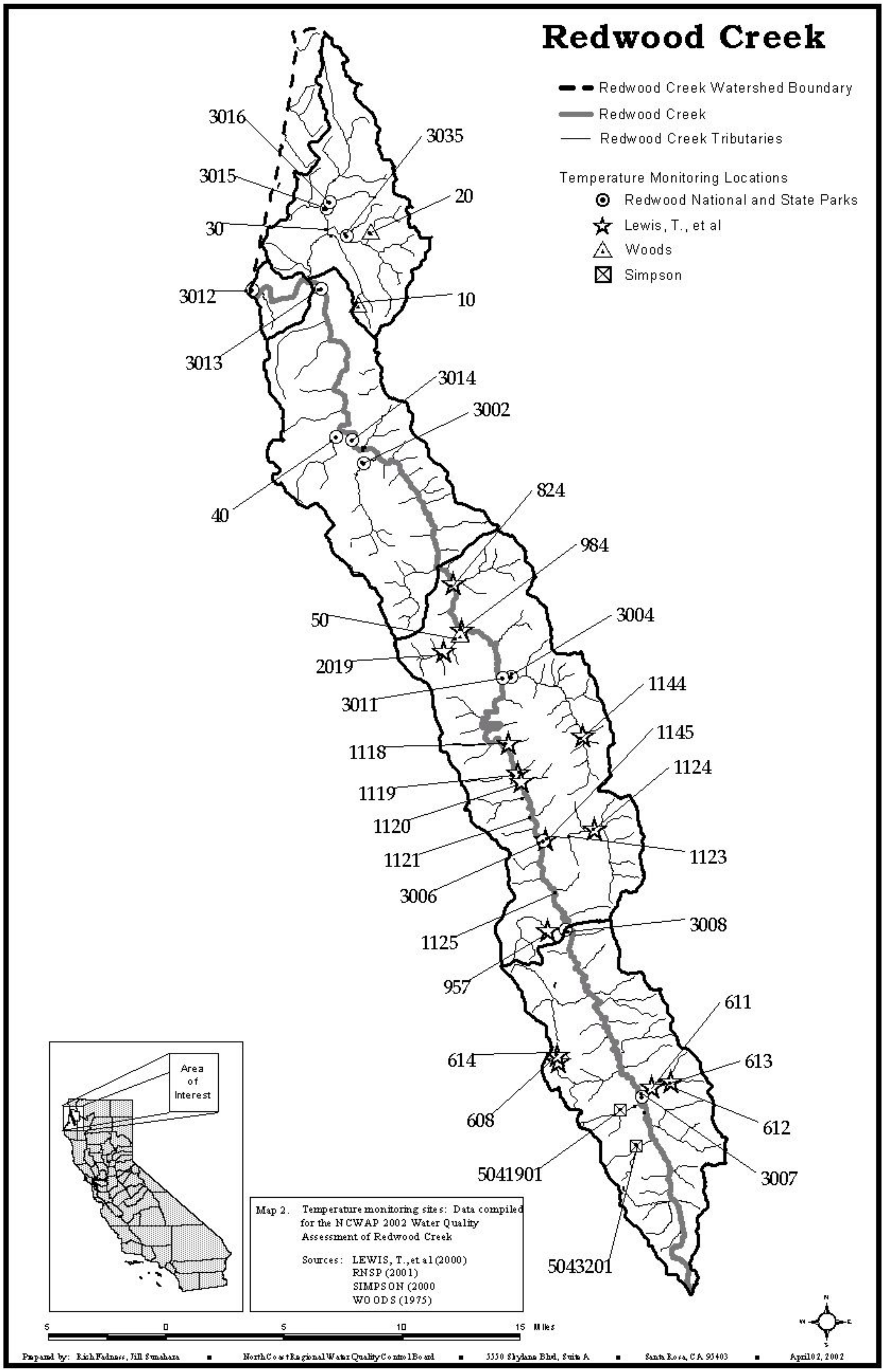

Figure III- 26. Location of temperature monitoring sites.

In-Channel Sediment

In-channel sediment is particularly important to examine for Redwood Creek since the basin is listed as sediment impaired under Section 303(d) of the federal Clean Water Act, and hence falls under jurisdiction of the state and federal TMDL programs. Data for sediment in the Redwood Creek basin are available from the RNSP and USGS for pebble counts, sediment cores, and suspended sediment at stream gauges since 1973. See Appendix C for sediment sampling locations and data from all sources. RNSP and USGS conducted pebble count surveys and calculated D50 values at four sites on mainstem Redwood Creek from 1979 to 1995 (Figure III- 27). These values are directly comparable to the US EPA minimum target for D50 at >37mm. The data are plotted in by site and year. Particle size distribution data from pebble counts used to calculate the D50 are in Tables 10-14 in Appendix C. Mainstem Redwood Creek did not meet the mean particle size target considered suitable for salmonid habitat at the confluence with Miller and Harry Weir creeks for the period monitored. Initially particle size met TMDL targets at Lupton Creek, but did not after 1981. Mean particle sizes increased over the study period to suitable levels in Redwood Creek at the confluence with Panther Creek.

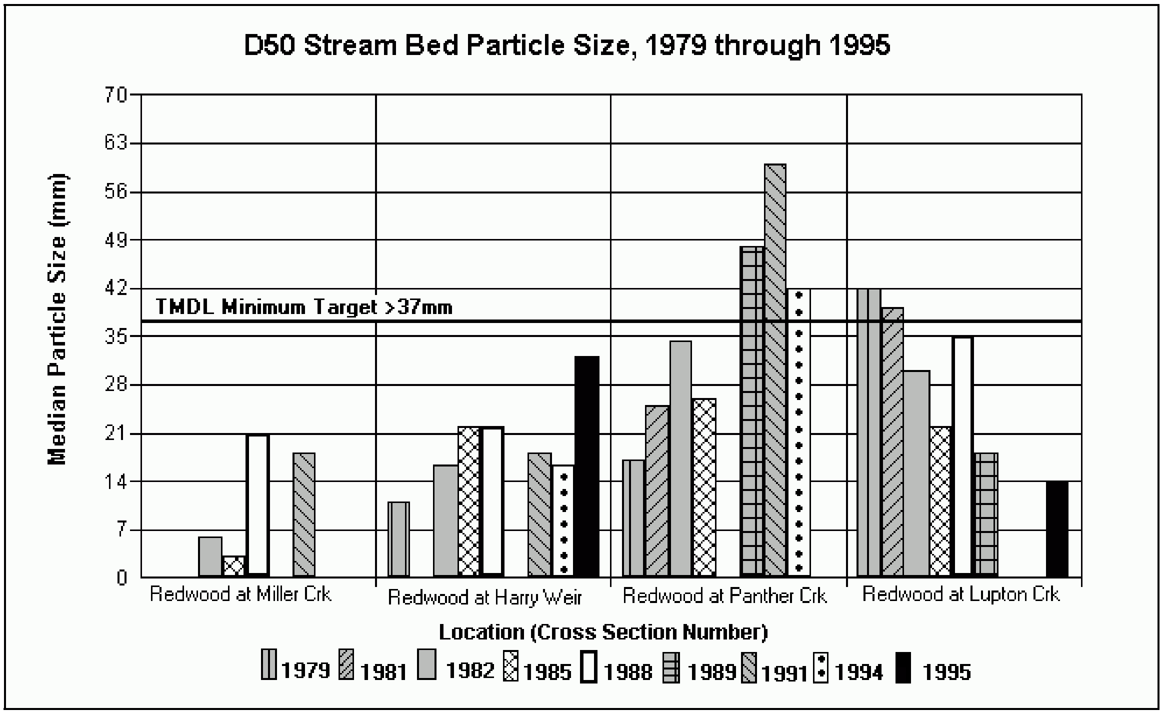

Figure III- 27. Median surface particle size in-channel substrate data from mainstem Redwood Creek, 1979 to 1995.

TMDL minimum target of >37mm is defined in the US EPA sediment TMDL for Redwood Creek (US EPA 1998).
Data from RNSP 2001.

The amount of fine materials present in the streambed are important to because small particle sizes may negatively impact young anadromous salmonids and their food supply. Fine sediment can reduce water flow though salmonid redds causing developing fish to suffocate or be exposed to high levels of metabolic wastes. Small streambed materials are more mobile and present opportunities for redd destruction. There is also a threat of capping of the redds by fine sediments, thus preventing young fry from emerging. Small streambed material in the mainstem may contribute to decreasing salmonid populations in conjunction with other limiting factors. Existing data for percent of fine subsurface material in the <0.85 and <6.5mm fractions are comparable to numeric TMDL targets derived from sampling methods which include core samples from a McNeil type sampler sieved wet, with fines measured by volumetric displacement. See Valentine (1995) for a description of the McNeil sampling and analysis method. A discrepancy exists between the requirements of the US EPA approved TMDL for Redwood Creek and the Technical Support Document written by the NCRWQCB, on which the US EPA TMDL was based. The US EPA document states that subsurface sediment samples should be sieved dry, however the numeric targets derived in the Technical Support Document were based on the wet sieved method and volumetric displacement. The percent of fine materials in subsurface sediment samples sieved wet are not comparable to samples that are dried and measured gravimetrically, unless a conversion factor is empirically derived from the geologic formation through which the stream flows. The discrepancy between the two analysis methods has yet to be resolved between the two agencies. Consequently, streambed sediment data analyzed gravimetrically are not comparable to existing TMDL targets. These data were not discussed in this assessment but are included in Appendix C.

The RNSP and USGS collected McNeil sediment core samples from five mainstem locations and eight tributaries between 1975 and 1995 using similar methods of collection and dry sieving the samples. These data are not comparable to the existing TMDL targets due to the method of analysis of the samples. Data from a 1974 study by Woods (1975), analyzed volumetrically, indicated that the percentage of fine sediments present in the <0.85mm size class exceeded TMDL targets for three tributaries to Redwood Creek. According to RNSP staff, the percentage of fine sediments tends to be higher in the lower basin (EPA 1998). It appears that fine sediment is moving through the system in waves, but without current and standardized streambed sediment data comparable to existing numeric targets, it is difficult to assess the status and impact of in-channel sediment on salmonid habitat in the basin.

Suspended Sediments and Turbidity

High turbidity levels in Redwood Creek are believed to occur more frequently and persist longer than in the past. Chronic turbidity and elevated levels of suspended sediments affect the ability of sight-oriented juvenile salmonids to locate food and may cause gill abrasions. A suppressed feeding ability may reduce the growth rate of juvenile fish and impair completion of successful smoltification and ultimately reduce survival rates upon entering the sea. Chronic turbidity may also reduce the reproductive cycle and growth of some aquatic invertebrates that serve as prey species for anadromous salmonids

It was shown that land use is responsible for increases in suspended sediment concentrations in managed areas within the Redwood Creek basin (Nolan and Janda 1995). Nolan and Janda (1995) found that suspended sediment discharge was roughly ten times greater from timber harvested terrain compared to unharvested terrain. Additionally, Klein (2001) found that the number of consecutive days that exceeded a turbidity target of 27 mg/l was four to five times greater in planning watersheds managed for timber harvest (Panther and Lacks creeks) when compared to unmanaged planning watersheds (Prairie and Little Lost Man creeks). While some of the differences may be explained by inherent sediment producing characteristics between the planning watersheds, the main factor for the higher turbidity levels in Lacks and Panther creeks is likely due to timber harvest and related management activities (Klein 2001).

Anadromous Salmonid Fishery Resources

Redwood Creek basin supports anadromous populations of fall run Chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), winter and summer runs of steelhead trout (O. mykiss), coast cutthroat trout (O. clarki clarki), and other valuable fisheries resources (Table III- 30). Although a recent estimate of the size of anadromous salmonid populations of the Redwood Creek basin has yet to be determined, a review of past fisheries studies, anecdotal information and data collected for this assessment indicates that the present populations are less abundant and less widely distributed compared to their historic presence (Hallock et al. 1952; Briggs 1953; USFWS 1960; Anderson 1988; Brown 1988; Busby et al. 1994; Van Kirk 1994; McEwan and Jackson 1996; NMFS 1998; McElhany et al. 2000; CDFG 2002). However, Redwood Creek's anadromous salmonid stocks should be viewed as critically valuable natural resources and increasing the abundance, diversity and distribution of these stocks are vital steps towards the restoration of viable salmonid populations to California.

There are approximately 135 miles of stream habitat accessible to anadromous salmonid in the Redwood Creek basin. The mainstem Redwood Creek provides approximately 65 miles and tributaries provide approximately 60 miles of stream of accessible habitat (Table III- 31).

Table III- 30. Fishery resources of the Redwood Creek basin.

Common Name	Scientific Name
Anadromous	
coho salmon	*Oncorhynchus kisutch*
Chinook salmon	*Oncorhynchus tshawytscha*
steelhead trout	*Oncorhynchus mykiss*
sea run coastal cutthroat trout	*Oncorhynchus clarki clarki*
Eulachon	*Thaleichthys pacificus*
Pacific lamprey	*Lampetra tridentata*
Freshwater	
rainbow trout	*Oncorhynchus mykiss irideus*
coastal cutthroat trout	*Oncorhynchus clarki clarki*
Coast range sculpin	*Cottus aluticus*
Humboldt sucker	*Catastomus occidentalis humboldtianus*
prickly sculpin	*Cottus asper*
Pacific brook lamprey	*Lampetra pacifica*
Three-spine stickleback	*Gasterosteus aculeatus*
Marine or Estuarine Dependent	
tidewater goby	*Eucyclogobius newberryi*
Pacific herring	*Clupea pallasi*
saddleback gunnel	*Pholis ornata*
surf smelt	*Hypomesus pretiosus*
night smelt	*Spirnchus starksi*
shiner surfperch	*Cymatogaster aggregata*
staghorn sculpin	*Leptocottus armatus*
starry flounder	*Platicthys stellatus*
Amphibians	
Pacific giant salamander	*Dicamptodon tenebrosus*
tailed Frog	*Ascaphus truei*
red-legged frog	*Rana aurora*
foothill yellow-legged frog	*Rana boylei*

Table III- 31. Number of stream miles accessible to anadromous salmonids in each of the Redwood Creek subbasins.

Subbasin	Redwood Creek Mainstem Miles Accessible to Anadromous Salmonids	Tributary Miles Accessible to Anadromous Salmonids
Estuary	3.5	1.5
Prairie Creek	0	24
Lower	19	9.5
Middle	24	19
Upper	19	5.5
Total	**65.5**	**59.5**

Streams in the Prairie Creek Subbasin provide anadromous salmonids the largest amount of tributary habitat of all the subbasins. The remainder of anadromous fish bearing tributary habitat is distributed between approximately 46 named tributary streams located in the Lower, Middle and Upper subbasins (Brown 1988) (Table III- 32). The steep channel gradient restricts access to only the lower reaches of most tributary streams in the Lower, Middle and Upper subbasins. The majority of suitable tributary habitat is found in only ten streams including Bridge, Emerald, and Tom McDonald creeks of the Lower Subbasin, Lacks, Minor, Coyote, Panther, and Wiregrass creeks of the Middle Subbasin, and Minon and Bradford creeks of the Upper Subbasin. Other tributary streams are still important as they cumulatively provide important habitat for anadromous populations and also contribute important water flows into Redwood Creek. In addition, resident populations of rainbow and coastal cutthroat trout exist in many tributaries above barriers to anadromous salmonids.

Table III- 32. Anadromous salmonid distribution in the Redwood Creek basin.

Subbasin and Streams	Steelhead	Cutthroat	Chinook	Coho
Estuary Subbasin Streams				
Redwood Creek	x	x	x	x
Strawberry Creek	x	x		x
Prairie Creek Subbasin Streams				
Prairie Creek	x	x	x	x
Skunk Cabbage Creek	x	x		x
Little Lost Man Creek	x	x	x	x
Lost Man Creek	x	x	x	x
Streelow Creek	x	x		x
May Creek	x	x		x
Godwood Creek	x	x	x	x
Boyes Creek	x	x	x	x
Brown Creek	x	x	x	x
Lower Redwood Creek Subbasin Streams				
Hayes Creek	x	x		
McArthur Creek	x	x		x
Elam Creek	x	x		
Bond Creek	x	x		
Cloquet Creek	x	x		
Miller Creek	x			
Forty Four Creek	x	x		
Tom McDonald Creek	x	x	x	x
Harry Wier (Emerald) Creek	x	x		x
Bridge Creek	x	x	x	x
Dolason Creek	x			
Copper Creek	x			
Devils Creek	x			
Redwood Creek	x	x	x	x
Middle Redwood Creek Subbasin Streams				
Coyote Creek	x	x		x
Panther Creek	x	x		x
Garrett Creek	x			
Lacks Creek	x	x	x	x
Karen Creek	x			x
Roaring Gulch	x			
Garcia Creek	x			
Cashmere Creek	x			
Beaver Creek	x			
Pilchuck Creek	x			x
Mill Creek	x			
Molasses Creek	x			
Toss-up Creek	x			
Wiregrass Creek	x			
Minor Creek	x		x	x
Loin Creek	x			
Santa Fe Creek	x			
Sweathouse Creek	x			
Captain Creek	x			
Lupton Creek	x			
Redwood Creek	x	x	x	x
Upper Redwood Creek Subbasin Streams				
Windy Creek	x			
Jena Creek	x			
Noisy Creek	x			
Squirrel Trail Creek	x			
Emmy Lou Creek	x			
Cut-off Meander	x			
Six Rivers Creek	x			
Gunrack Creek	x			
Simion Creek	x			
High Prairie Creek	x	x		
Minon Creek	x			
Lake Prairie Creek	x			
Upper Panther/Bradford Creek	x			
Pardee Creek	x			
Snowcamp/Smokehouse/ Twin Lakes	x			
Redwood Creek	x	x	x	x

From the long-term perspective, anadromous salmonids of Redwood Creek, show declines from historic numbers and in distribution across the basin. In 1960, the U.S. Fish and Wildlife Service estimated spawner escapement of 5,000 Chinook, 2,000 coho, and 10,000 steelhead (Figure III-34) (USFWS 1960). These estimates were made based on data collected from other streams and applied to Redwood Creek. They were meant to provide a general magnitude of anadromous salmonid runs are not indicative of larger runs of prior years (USFWS 1960; CDFG 1965; and RNSP 2000) The data needed to determine if populations are continuing to decline, have stabilized, or are on the rise across the basin are not available.

The decline in anadromous salmonids populations is not unique to Redwood Creek. For example, in 1984-85 the statewide total of natural coho salmon spawners was estimated at 6 to 15% of the level of the 1940s (CDFG 2002). In addition, coho and Chinook populations drastically declined in the Eel River according to adult salmon counts at Benbow Dam, South Fork Eel River (CDFG 2002).

In response to California's declining wild populations, Chinook, coho, and steelhead are listed as "threatened" under the Federal Endangered Species Act (FESA). In 2002, the California Fish and Game Commission found that North Coast coho salmon warranted listing as threatened, as defined under the California Endangered Species Act (CESA). In addition, several other plant and animal species living in the Redwood Creek basin receive special status protection under the FESA and CESA including coastal cutthroat trout, which is considered a California species of special concern by the Department of Fish and Game (Appendix D).

Freshwater and estuarine habitat degradation and has been identified as a leading factor in the decline of Redwood Creek's anadromous salmonids (Ricks 1982; Larson 1982; Hofstra 1983; Anderson 1988; Brown 1988; Madej 1991; and CDF&G 2002). Widespread declines of summer steelhead, sea run coastal cutthroat, coho and Chinook salmon is likely linked to their sensitivity to degradation of specific habitat components necessary to complete the freshwater and/or estuarine phase of their life cycle. Because steelhead tolerate a wider range of habitat conditions than the other anadromous species, they are more widely distributed in the basin and have persisted in streams where other species have declined or are now rarely observed.

Similar to most north coast streams, there has been neither basin-wide quantitative assessment nor coordinated long term monitoring of all Redwood Creek's anadromous salmonid stocks. There are recent population data such as downstream migrant studies and spawning surveys available for select streams. However these data are inconclusive because they lack of consistent effort across the study areas, or have not been ongoing for sufficient time to establish trends, and may require optimal environmental conditions to conduct observations. Coordinated studies such as downstream migrant trapping, spawner surveys, and other population assessment techniques may soon provide the level of information needed to make quantitative assessments of the current status and trends of Redwood Creek's anadromous salmonid populations.

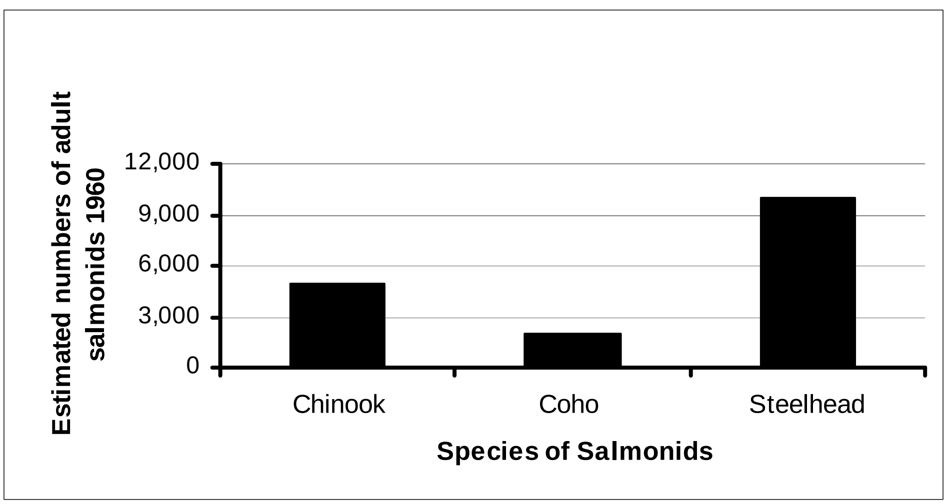

Figure III- 28. U.S. Fish and Wildlife Service estimates of adult salmonid populations in the Redwood Creek basin, 1960.

Historical Fishery Information

Historically, the salmon, steelhead, cutthroat trout, and other fishery resources of Redwood Creek were important food supply to Native Americans. The Chilula Tribe residing along Redwood Creek were reliant upon abundant runs of salmon, winter steelhead, summer steelhead, trout and lamprey (Van Kirk 1994). Beginning in the mid 1800s, the fishery resources of Redwood Creek provided sport and commercial fishing opportunities for early settlers and visitors to Humboldt County. In the late 1800s and early 1900s Chinook salmon of 50 to 60 pounds and occasionally 70-80 pounds were caught in the estuary. Coastal cutthroat in the four to six pound range were also caught (Meyer 1994). The abundant salmon, steelhead, and coast cutthroat trout made the estuary a favorite location for trolling by boat or fishing from shore.

Past accounts of large fish runs and catches were not limited to the estuary. References to large fall and winter salmon and steelhead runs and excellent coastal cutthroat fishing in spring and summer are presented in Van Kirk (1994). According to interviews with people who have lived for many years or generations in the Redwood Creek basin, a common theme occurred: large numbers of salmonids were present until the flood of 1964. Migrating salmon were described as “sounding like horses in the creek” or were so numerous that the kids felt like they were “swimming on top of fish” (Van Kirk 1994). A grandfather of a longtime resident said in the early 1900s: “there were so many fish in Redwood Creek that you could walk across the creek on their backs”. Another long time resident of middle Redwood Creek described how there use to be a “real good summer steelhead run”, which came in Redwood Creek soon after snowmelt in late February and early March. He mentioned “these fish used Lacks and Minor Creeks” and said “there are still a few, but not nearly as many as there used to be”(Van Kirk 1994). Another anecdote from a 1920 article in American Angler gave the following description of summer steelhead in upper Redwood Creek: “Every pool has ten to twenty five, and they run from twenty to thirty-six inches. Some of the pools were up to 20 feet deep” (Gerstrung 2001 Draft).

During spring and summer of the late 1800s to early 1900s, the sport fishing effort in Redwood Creek shifted to coastal cutthroat trout. Coastal cutthroat trout were referred to as “speckled beauties” (Van Kirk 1994). An excerpt from an article in the Arcata Union (July, 1910) reads “a magnificent lot of trout” were taken by two men. They caught “their limit of 25 pounds of speckled beauties every day for three days on Redwood Creek” (Van Kirk 94). Prairie Creek and the estuary also were popular areas to fish for the coastal cutthroat, but by 1925, the quality of the coastal cutthroat fishery had declined. Both the fish size and catches were smaller compared to the earlier days.

Local residents and visitors looked to hatchery production as a way to supplement the coast cutthroat fishery. A writer for the Arcata Union paper described the need for hatchery programs to assist in fish production in an July 1926 article: “The program of refilling the streams with fish was commenced following discovery recently that the Humboldt streams were ceasing to be a prolific source of fishing (for coastal cutthroat) and that anglers from the bay region lured north by the former fishing paradise were returning disappointed. If enough eggs can be obtained at the new hatchery, the streams of northern California will be kept well stocked. This would aid greatly in attracting tourist as the streams in this part of the state do not go dry in the summer time” (Van Kirk 94). In response to this decline in fish, a hatchery was established at Prairie Creek in 1927. Even with the enhancement attempts by the Prairie Creek Hatchery, the coastal cutthroat fishery never recovered to its former popularity or population levels.

There is also reference to what may be chum salmon caught in Redwood Creek (Van Kirk 1994) and infrequently observed pink salmon in Prairie Creek (CDFG 1952). Other interesting bits of anecdotal history by local residents provided in Van Kirk (1994) are stories of abundant crayfish populations prior to 1964, which are now rarely observed in Redwood Creek (D. Anderson, RNSP, personal communication). The decline of crayfish in Redwood Creek has never been investigated. Van Kirk (1994) also notes that Redwood Creek once supported large eulachon runs. For example, in April of 1973, an unusually large run of eulachon occurred for two to three days. Residents proclaimed “You could grab them out with your hands” (Van Kirk 1994).

Anecdotal physical descriptions of the Redwood Creek basin are more limited than fish related accounts. According to several longtime residents, Redwood Creek stream temperatures used to be much colder. One stated: “The water in Redwood used to be like ice, but warmed up after logging along the Creek.” Another resident added that the kids would "freeze" when they swam and that today the water is warmer because the creek is more "filled up" (Van Kirk 1994). Residents also expressed their views of how the creek had become shallower and how there "aren't as many holes as there used to be." Several people interviewed told of a "15-20 foot" hole at the mouth of Prairie Creek that is no longer present. Residents also commented on how canopy has diminished. One stated: "Redwood used to have a thick canopy" (Van Kirk 94).

Two CDFG reports provide descriptions of past conditions. In 1951, DFG collected salmonids by beach seine from Redwood Creek for a three-state fingerling marking program (Hallock et al. 1952). During fish collection efforts, it was noted that Redwood Creek was an "excellent silver salmon stream", but it "was not seined extensively because in the few places where they could be reached by road, the pools were so deep as to make netting impractical" (Hallock et al. 1952). Fisk et al. (1966) stated that the 1964 flood and associated hillslope and streambank erosion left Redwood Creek in a "severely damaged condition" and without much suitable anadromous salmonid habitat.

In summary, valuable historical information of the Redwood Creek fisheries was published in the Arcata Union Newspaper, which is presented along with interviews of long time residents and other anecdotal accounts in Van Kirk (1994). These anecdotal accounts describe the presence of large populations of salmon, summer and winter steelhead, and coastal cutthroat of Redwood Creek. Also, the economic importance of a viable fishery to local residents and significant revenues to the economy of Orick is noted. Information provided in CDFG reports substantiate many of the anecdotal accounts. Table III- 33 provides an additional brief summary of historical events.

Table III- 33. Historical events affecting fishery resources of Redwood Creek.

Year	Event
Pre-European Settlement	Yurok, Chilula and Whilkut people occupied Redwood Creek region.
1850s	Settlement of Orick with first white settlers. Conversion of spruce, redwood and hardwood forests for farm and grazing land.
1860s	Introduction of cattle and sheep into Redwood Creek region.
1920s	Establishment of Prairie Creek Redwood State Park. Save the Redwoods League purchases 14,000 acres of sanctuary old growth forests.
1927	Hatchery established on Prairie Creek (Prairie Creek Hatchery) for collection of coastal cutthroat trout, steelhead, and salmon eggs.
1936	Hatchery moved to its location on Lost Man Creek just upstream of its confluence with Prairie Creek.
1040s	Post WWII. Large scale logging with the use of tractors and gasoline-powered chainsaws.
1950	January cold spell with heavy snowfall followed by heavy rains caused Redwood Creek to overflow its banks and the residents of Orick had to flee their homes. Approximately 3 feet of water was reported in the center of town with up to 6 feet at the southern approach (Van Kirk 1994).
1955	December 22, 1955 flood carried a peak discharge of 50,000 cubic feet per second (cfs).
1964	December 22, 1964 flood had a peak discharge of 50,500 cfs on. Caused tremendous damage to the town of Orick and deposited tremendous sediment loads in middle and lower portions of Redwood Creek. Although peak discharge of the 1964 flood was only slightly higher than flood of 1955 on Redwood Creek, the total volume and damage to stream banks and hillslopes is considered the most damaging event of the century in the North Coast region (Harden et al. 1978).
1965	On January 22 the Arcata Union reports that silt and debris clog streams. "The recent flood was extremely damaging to wildlife" according to Captain Walter L. Gray of the Department of Fish and Game. "We know the loss of fish life was much greater than in 1955." "Many large fish were found in pastures buried in silt." "Streams were damaged by siltation, logging debris, and erosion. To make matters more complex, heavy runoff in many small tributaries have created deltas at the mouth which will go dry during periods of low water and will prevent fish from migrating"(Van Kirk 1994).
1968	Establishment of Redwood National Park. Completion of flood control levees along the lower 3.4 miles of Redwood Creek.
1973	New forest practice law established to improve protection of water quality, timber productivity, and other forest values.
1975	March 18, 1975 flood had a peak discharge of 50,200 cfs on and continued to deposit large sediment loads throughout Redwood Creek.
1978	Expansion of Redwood National Park.
1989	Construction of 101 By-Pass and related large sediment delivery to Prairie Creek basin.
1992	Closure of Prairie Creek Hatchery due to insufficient funding sources
1996	Flood re-charges upper basin with sediment.
1997	Coho salmon of the Southern Oregon/Northern California ESU listed "threatened" under the Federal Endangered Species Act.
1998	Total Maximum Daily Load allocation for sediment established for the Redwood Creek basin by EPA.
1999	Chinook Salmon of the California Coastal ESU listed as "threatened" under the Federal Endangered Species Act.
2000	Steelhead of the Northern California ESU listed as "threatened" under the Federal Endangered Species Act.
2002	Coho salmon warranted listing as threatened, as defined under the California Endangered Species Act.

Prairie Creek Hatchery

The Prairie Creek Hatchery is located just north of the town of Orick and operated from 1927 until 1993. Throughout its years in operation, the hatchery propagated Chinook, coho, steelhead, rainbow trout, and coastal cutthroat trout. The fish were released mostly in the Redwood Creek basin and other Humboldt County streams. The hatchery was originally intended to supplement the declining coastal cutthroat sportfishery.

Total adult fish counts returning to Prairie Creek were not made during the first fifty years of hatchery operations. The hatchery operations consisted of collecting the desired number of salmonid eggs for each year and then focused on hatching and releasing fry. Fish were only collected to meet demand for eggs from the early portion of the run. Late running fish were allowed to freely pass through the facility uncounted. The hatchery likely increased the numbers of coho and steelhead returning to Lost Man Creek. The coastal cutthroat fishery, for which the hatchery was originally intended, never returned to its former strength or popularity noted from the early 1900s (Van Kirk 1994). A more detailed summary of the Prairie Creek Hatchery operations is presented in the Prairie Creek Subbasin section below. Hatchery production records from 1927 to 1993 are presented in Appendix D, Attachment 3.

Anadromous Salmonid Status and Life History Notes

Chinook, coho, steelhead, and coastal cutthroat utilize an anadromous life history strategy. The term anadromous refers to fish that are born in freshwater, migrate to the ocean as juveniles, where they grow and mature before returning as adults to freshwater streams to spawn. Chinook, coho, steelhead and coastal cutthroat all have specific habitat requirements, but the general anadromous salmonid life history pattern includes adult upstream migrations from the sea, spawning, egg incubation, fry emergence, juvenile rearing, and downstream migration through estuaries to the sea where salmon reside until maturation and upstream migrations. Steelhead and coastal cutthroats may re-enter streams after a brief ocean residence and return to sea with out spawning.

Viable populations of anadromous salmonids exhibit a diversity of behavioral adaptations in terms of upstream and downstream migration timing and juvenile rearing strategies. Historically, large, protracted spawning runs and diverse instream rearing strategies were the best insurance for survival in environments as dynamic as freshwater streams, estuaries, and the Pacific Ocean. Today's salmonid populations are reduced in numbers, appear less diverse in run timing, and therefore are more vulnerable than past populations to short term habitat perturbations, such as effects from floods and droughts, and other stochastic events in both the freshwater and marine environments.

A summary of the life history strategies, historic and current status of anadromous salmonid population of Redwood Creek is provided below. Further information on fisheries and habitat status of Redwood Creek is provided in each subbasin section.

Chinook salmon

Redwood Creek supports a fall run of Chinook salmon. Chinook salmon, also referred to as "king salmon," is the largest of the Pacific salmonid species. Due to declining wild populations, Chinook salmon of Redwood Creek of the Coastal California Evolutionary Significant Unit (ESU) were listed as threatened under the Federal Endangered Species Act in 1999. The Coastal California ESU includes all naturally spawned populations of Chinook salmon from rivers and streams south of the Klamath River to the Russian River. The estimated distribution of Chinook salmon of Redwood Creek is presented in Figure III- 29.

In 1960, the U.S Fish and Wildlife service estimated 5,000 adult Chinook populated Redwood Creek. The USFWS also estimated that the available Chinook salmon spawning areas in the basin would accommodate approximately 5,400 redds (USFWS 1960). This estimate suggests that it would require over 10,000 Chinook salmon to fully utilize the available spawning habitat of the Redwood Creek basin. In 1979, the adult spawning population of Redwood Creek was estimated at 1,850 adults (Ridenhour and Hofstra 1994 Draft). The 1979 number was based on the number of juveniles estimated from the estuary population in early July 1980 (Ridenhour and Hofstra 1994 Draft).

The Chinook of Redwood Creek typically begin spawning migrations soon after fall rains breech the lagoon. The majority of spawning occurs from November through January and generally peaks in December). The best historical spawning areas are Prairie Creek, the middle reach of Redwood Creek including Lacks and Minor Creeks, and the upper reach of Redwood Creek (USFWS 1960). According to anecdotal accounts, the lower reach of Redwood Creek also is used for spawning during low flow years and when the river mouth opens late in the season (Van Kirk 1994).

Spawning occurs in gravel and cobble areas where females dig depressions or pits into the substrate by rapid beats of the tail fin. While the eggs are released into the pit, a male fertilizes them. Then the female will cover the fertilized eggs as she digs another pit just upstream, and the process continues until a mound called a redd is constructed containing one or more pits with eggs. It is important that water flows are sufficient through the redds because the developing embryos need dissolved oxygen for respiration and flow to remove metabolic wastes or they will die. As the newly hatched fry emerge from the redds in late winter or early spring they must find their way up through the spaces between the gravel and cobble substrate of the redd, which may be a distance of foot or more. It is important that the redd does not contain much fine sediment. Too much fine sediment can stop the water flow needed to sustain the fry or fill the passage spaces between the substrate leading to the stream above and trap the young salmon in the redd. Redd construction, egg incubation and fry emergence are similar for all anadromous salmonids.

Juvenile Chinook may begin seaward migrations soon after emerging from their redds or rear for some time in their natal stream. The peak downstream migration period is generally from mid April to early May (Sparkman 2000; 2001; 2002; 2003). Water temperatures in the mainstem Redwood Creek generally become too warm for rearing during the summer months so downstream migrations are usually completed by July. A few juvenile Chinook have been observed rearing in tributary streams during the summer months. The majority of the basin's juvenile Chinook arrive in the estuary/lagoon May to July where they may rear for weeks to months before entering the sea (Anderson 2000 and 2001and Wilzbach 2001). Rearing in the estuary allows Chinook to achieve important growth before entering the sea. However, estimates of only 7 to 15% of the Chinook population survives in the lagoon from July to September (Anderson 2000 and 2001). Juvenile Chinook use of the estuary/lagoon is discussed below.

An alternative to estuarine rearing for juvenile Chinook is summer stream rearing. There is evidence of over-summering Chinook in the basin, as 21 yearlings (in 2001) were collected in trapping efforts (Sparkman 2001). In addition juvenile Chinook were observed in Bridge and Tom McDonald Creeks during surveys in 2001 (D. McCann 2002 personal communications). In 2002 juvenile Chinook were observed in Coyote Creek and 70 were observed in Lacks Creek (B. Reisberger 2003 personal communications). These juvenile Chinook were rearing over summer and if they survive, may enter the ocean in late fall or the following year as yearlings. Over-summer stream rearing may be another important behavioral adaptation to maintain juvenile life history diversity for Chinook of Redwood Creek.

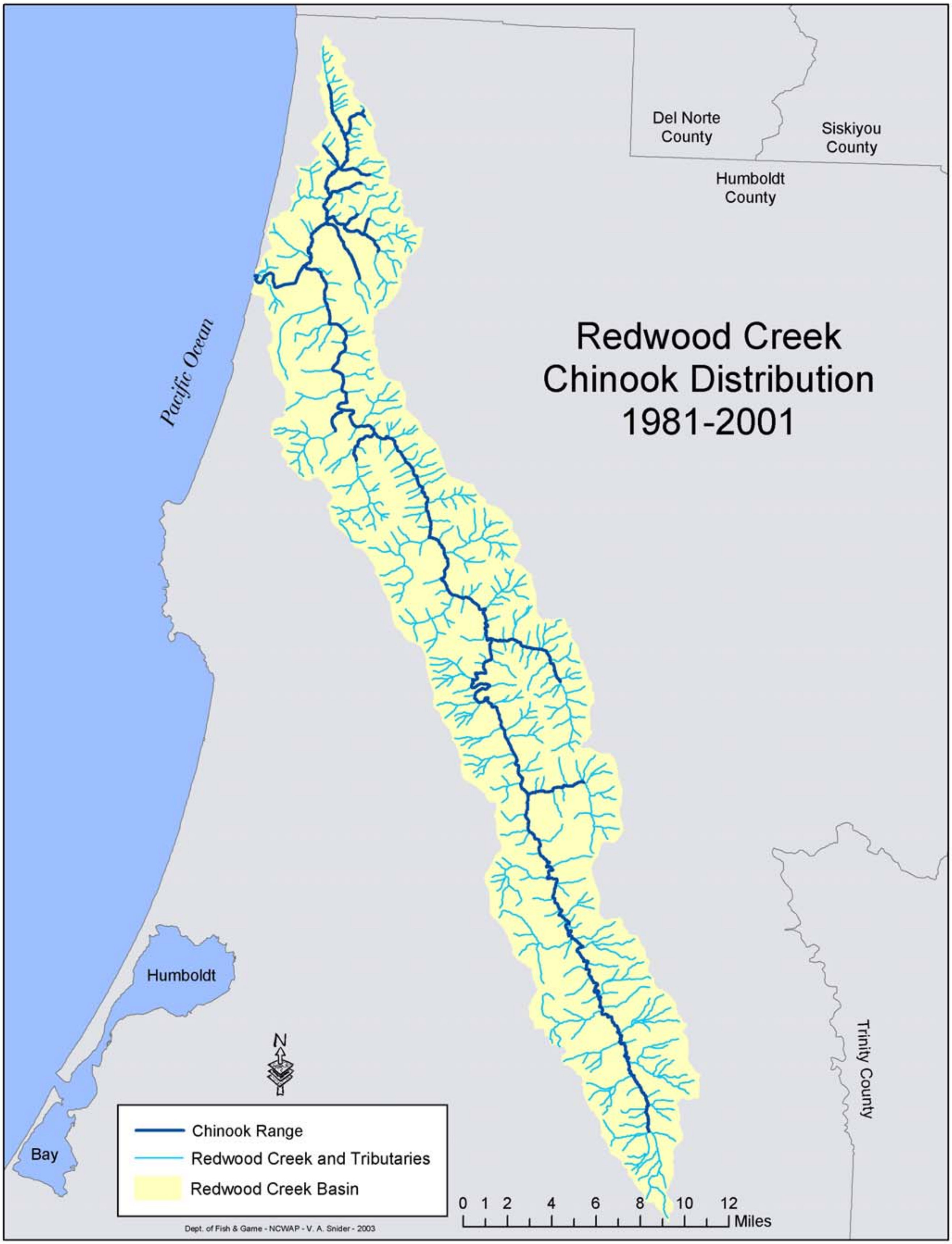

Figure III- 29. Stream habitat used by Chinook salmon for migration routes, spawning and juvenile rearing in the Redwood Creek basin. Adapted from Cal EPA and RNSP.

Chinook Downstream Migrant Trapping Studies and Spawner and Redd Surveys

Annual downstream migrant studies (March –August) of juvenile Chinook in Redwood Creek began in 2000. The studies use a rotary screw trap, located on Redwood Creek mainstem just below the confluence with Toss Up Creek, near river mile (RM) 37. These trapping efforts provide estimates of juvenile Chinook numbers produced from approximately 28 miles of mainstem Redwood Creek and eleven miles of tributary stream habitat located above the trap site. However, it is likely that the majority of spawning occurs in the mainstem reach.

The results from the trapping data indicate spawning success in the upper 1/3 of the Redwood Creek Basin during 2000-2002 but relatively low counts of juveniles were recorded in 2003 (Figure III- 30). The low counts of Chinook YOY in 2003 may be due to few adults returning to spawn or it may be due to redd scour associated with river flows that peaked at 23,000 cfs (at Orick) on December 28, 2003, after the majority of spawning was completed for that brood year. The moderately high flows may have buried or scoured the redds, leading to egg mortality. Spawning gravels located in aggraded stream reaches are highly mobile and redds built in such sites are at risk to scour from high flows (Meehan 1991) washing eggs and developing embryos from the protective gravel nests.

In addition, spawner and redd counts were conducted during December 2000 through February, 2001, along approximately twenty-seven miles of Redwood Creek located between the confluence of Lacks Creek (RM 28) in the Middle Subbasin and Minon Creek (RM 55) in the Upper Subbasin. A total of 208 redds, 413 live Chinook, 129 Chinook carcasses, and 2 live coho salmon was reported. One hundred thirty-eight redds (11.3 redds/mile) were observed in a 10 mile mainstem reach below the screw trap and 95 redds (5.3 redds/mile) were observed in an 18 mile reach above the trap. One survey in lower Lacks Creek found seven redds and one adult Chinook carcass (M. Farro 2002 personal communications). Optimal stream conditions were noted for counting redds, stream visibility was excellent, and crews were able to survey in a consistent manner. Adequate rainfall and ideal stream flows were present in 2000/2001 from the onset of the spawning season through fry emergence and into the early stages of the Chinook life cycle. The good flow conditions should have produced a high yield of eggs to fry (M. Farro personal communications).

Combined results from the downstream migrant studies and redd counts (collected from above the trap) were used to estimate survival of Chinook eggs to fry under good flow conditions. Using the 2000/2001 spawner survey data of 5.3 redds per mile, and assuming one female per redd, over the potential 28 miles of main stem habitat available, 148 females may have spawned above the screw trap in the 2000/2001 season. Assuming a 1:1.25 ratio of female to males provides an estimate of 172 males and a total of approximately 310 Chinook spawners above the screw trap based on redd counts.

Assuming 4000 eggs per female (M. Farro personal communication) and an escapement estimate of 148 females above the screw trap, approximately 64% (95 % CI range of 57-71%) of eggs survived to produce 378,000 (± 42,721) fry captured at the screw trap in 2001(more details can be found in Appendix D). This estimate assumes no mortality from time of emergence to capture at the trap. Once incubation is complete, Bjornn and Reiser (1991) reported that in laboratory studies, Chinook have difficulty emerging from gravel substrates when fine sediments exceeded 30% by volume and over 90% of swim-up fry emerged when less than 10% fine sediments were present. These escapement and egg to fry estimates should be used with caution but do provide insight into the magnitude of the run size into the upper reach of Redwood Creek and egg to fry survival for the 2000/2001 season.

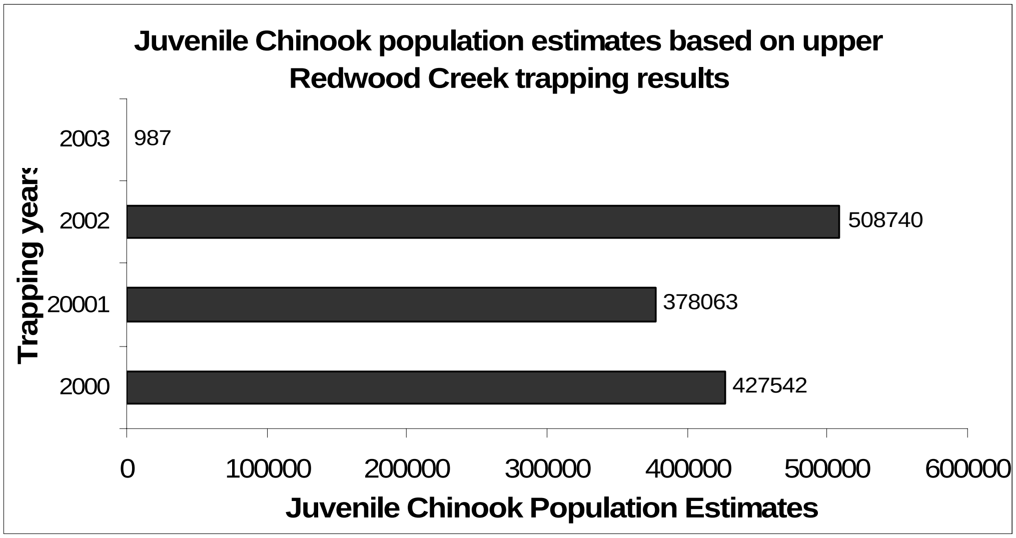

Figure III- 30. Yearly juvenile Chinook population estimates based on trapping results on Redwood Creek, 2000 to 2003.

From Sparkman 2000, 2001, 2002, and 2003. The 2000 effort trapped 123,633 young-of-the-year (YOY) Chinook and produced a population estimate of 427,542 ± 37,446 YOY. An additional 21 yearling Chinook were also captured (Sparkman 2001). In 2001, 120,692 juvenile Chinook salmon were trapped yielding a population estimate of 378,063 ± 42,721 YOY. The 2002 YOY population estimate is approximately 500,000 ± 23,000. However, the 2003 population estimate of YOY Chinook was only 987 ± 98.

A second rotary screw trap was operated by the Humboldt State University Cooperative Fishery Research Unit in 2001. The trap was located in the lower basin just downstream of the confluence with Prairie Creek (approximately three miles from the mouth of Redwood Creek) and approximately 30 miles from the middle Redwood Creek screw trap. This lower trap sampled fish moving downstream from both Prairie and Redwood creeks. A total of 21,383 YOY Chinook was captured with the trap. Population estimates could not be determined due to low mark recaptures during every week of trap operation (Wilzbach 2001). Trapping efficiencies were low due to the wide and shallow conditions of the channel, that allowed fish to escape capture by the trap.

A review of these trapping data suggests the majority of YOY Chinook move rather quickly downstream in May and do not grow much during the time they spend between the two trap locations. Peak YOY Chinook catches occurred during late May both screw traps (Figure III- 31). A second peak occurred in mid-June at the middle trap site, but this was not observed at the lower trap. The average size of juvenile Chinook captured at the lower trap was only slightly greater than those trapped approximately 30 miles upstream (Figure III- 32). Inspection of these data reveals that most YOY Chinook range from 40 mm (April) to 60 mm FL (July) at time of capture at both trap sites.

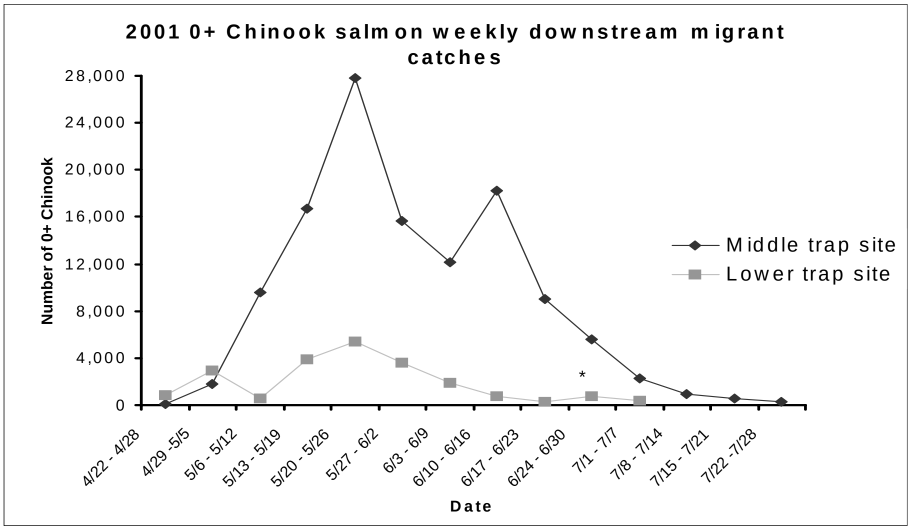

Figure III- 31. Temporal pattern of 0+ Chinook catches.

In middle Redwood Creek, trap located just downstream of Toss Up Creek and lower Redwood Creek (trap located just downstream of Prairie Creek) for the Summer of 2001. *Trapping on the lower trap ended July 4, 2001. (Adapted from Sparkman 2001 and Wilzbach 2001).

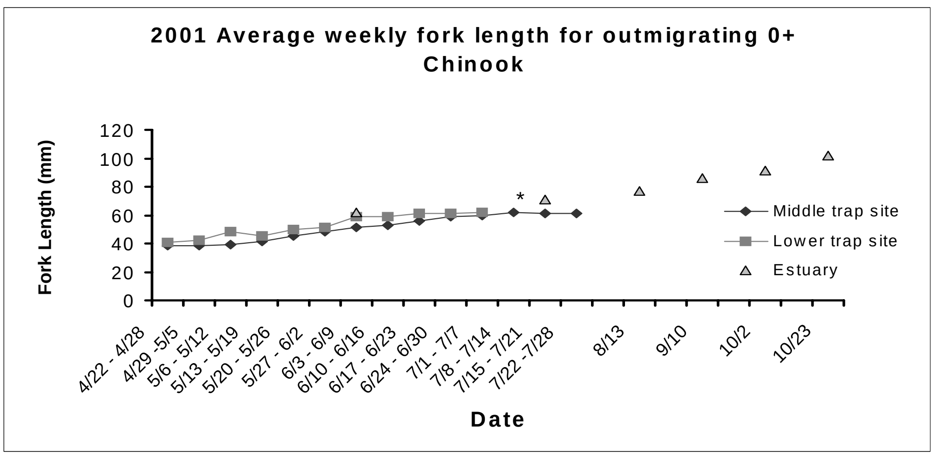

Figure III- 32. Average weekly fork lengths for 0+ Chinook.

In middle Redwood Creek (trap located just downstream of Toss Up Creek), lower Redwood Creek (trap located just downstream of Prairie Creek) and Estuary for the summer of 2001 (Adapted from Sparkman 2001 and Wilzbach 2001). *Trapping on the lower trap ended July 4, 2001. Average size of juvenile Chinook captured in the estuary is also provided.

Juvenile Chinook in the Estuary

Generally, estuaries are critical nursery habitat for juvenile Chinook for streams like Redwood Creek with temporally short mainstem rearing patterns. Estuaries provide a relatively sheltered, food rich environment where juveniles achieve important growth before entering the sea. Nicholas and Hankin (1988) reported that a great majority of Chinook returning to spawn in Oregon streams were greater than 100 mm when they entered the ocean as juveniles. In order to obtain the larger size, Chinook from many streams rear in estuaries and enter the ocean in late August through November (Reimers 1973, Nicholas and Hankin 1988, and Cannata and Hassler 1995). Ocean conditions also play an important role in determining the survival rate of juvenile salmonid smolts upon their first encounter with the marine environment however, it is generally accepted that larger juveniles have a survival advantage over smaller juveniles upon entering the sea.

The majority of juvenile Chinook arrive in the estuary from April to July. A review of two years of estuary sampling indicates an average size range of juvenile Chinook captured by beach seine is approximately 62-72 mm FL in early June before the sand bar closes the creek mouth and 70 -75 mm FL in mid-July after the mouth has closed (Table III- 34). The average size of these fish is below the desirable size for high survival rates upon ocean entry so they may remain in the estuary/lagoon to achieve further growth. The small size of juvenile Chinook arriving to the estuary may be due to the relatively short time spent migrating from spawning gravels to the estuary and/or low food availability in Redwood Creek.

It appears that in order for Redwood Creek Chinook to achieve 100 mm or greater size upon ocean entry, they must rear and grow in either riverine or estuarine habitats during the summer and early fall seasons. However, juvenile Chinook mortality rates are high in the lagoon under present conditions and only a small percentage of juveniles rearing in the lagoon survive to achieve the size of 100 mm. Estimates of 7 to 15% survival have been produced from studies conducted July to September in the lagoon during the summers of 2000 and 2001 (Table III- 34) (Anderson 2000 and 2001). The number that survive until fall rains breech the lagoon is likely even less.

Table III- 34. Comparison of Chinook fork length (FL) and population estimates.

Redwood Creek Screw Trap near Toss Up Creek- Spring/Summer 2000				**Redwood Creek Estuary - Summer/Fall 2000**				
Date	**Population est.**	**95% CI**	**Ave FL**	**Date**	**Mouth**	**Population est.**	**95% CI**	**Ave FL**
April	140,265	± 100,033	41.5	June 5,6,8	Open	55,640	37,930 - 73,360	72
May	109,903	± 30,597	51.2	July 17,18,20	Closed	18,350	490 – 38,840	74
June	159,297	± 29,142	59.3	Sept 11,12	Closed	2,910	1,960 – 3,860	94
July/Aug	18,075	± 4,200	66.5	Oct. 26	Closed	na*	na	111
Total:	**427,542**	**± 37,446**				**76,900**		
Redwood Creek Screw Trap near Toss Up Creek - Spring/Summer 2001				**Redwood Creek Estuary - Summer/Fall 2001**				
Date	**Population est.**	**95% CI**	**Ave FL**	**Date**	**Mouth**	**Population est.**	**95% CI**	**Ave FL**
4/22 - 5/5	48,220	na *	38.7	June 4	Open	58,633	± 19,531	62
5/6 - 6/2	260,400	na	44.1	July 16	Closed	34,259	± 27,032	71
6/3 - 6/30	62,553	na	53.8	Aug 13	Closed	3,616	± 3,035	77
7/1 - 8/4	6,890	na	60	Sept. 10	Closed	2,288	± 2,485	86
				Oct. 2	Closed	na	na	91
				Oct 23	Closed	na	na	102
Total:	**378,063**	**±42,721**				**175,696**	**±52,083**	

Collected from Redwood Creek screw trap (near Toss Up Creek) and by beach seine collections from the estuary/lagoon, 2000 and 2001. Ninety-five percent confidence intervals (95% CI) are included for population estimates (Anderson 2000 and 2001; Sparkman 2000 and 2001). * na= not available

Coho Salmon

Coho salmon (also known as silver salmon) of Redwood Creek typically exhibit a three-year life cycle, spending one year in freshwater streams and two years in the ocean before returning to spawn. However, each year 4 to 28% of the spawning run may be composed of 2-year old males called grilles (Shapovalov and Taft 1954). Most juvenile coho spend one year in streams before migrating to sea, but a proportion (estimates of 17%) of the juvenile coho population of Prairie Creek have been observed stream rearing for two years (Bell 2001 and W. Duffy personal communications 2001). These fish may not have achieved large enough size to migrate to sea as yearlings. Studies found that these were significantly smaller than other juvenile coho of the same age during their first winter in freshwater. Could this be a sign of habitat deficiencies? During their second winter and as outmigrants, these age 2+ coho were on average larger than age 1+ coho (Bell 2001). Coho that enter the ocean at age 2+ have returned to spawn as four year old adults (T. Weseloh, Cal Trout, personal communication).

Because coho spend a year or more in freshwater streams, they depend upon complex channels with woody debris, cool water, good shade canopy, and sufficient food to sustain them through their fry and juvenile stages. In addition to complex mainstem habitat, secondary channel habitats such as alcoves and backwater pools with large woody debris cover are highly preferred habitat conditions for juvenile coho salmon (CDFG 1991).

Coho populations in Redwood Creek, like in other California watersheds, have declined in numbers and distribution compared to their historic presence (CDFG 2002). Moyle et al. (1995) estimated that in the mid 1990s, 5,000 wild coho salmon (no hatchery influence) spawned in California each year. This is a dramatic decline from statewide estimates from the 1940s, which estimated there were anywhere from 200,000 to one million adult coho in California (Calif. Advisory Committee on Salmon and Steelhead Trout 1988).

In 1951, Redwood Creek was considered an excellent "silver salmon" stream by Hallock et al. (1952) and was considered a good release site for marked fish as part of a salmon fingerling marking program. As a result, over 10,000 marked young-of-the-year (YOY) coho were released (May through July 1951) into deep pools located on lower Redwood Creek (Hallock et al. 1952). Recent stream surveys (CDFG 2001 and 2002) failed to detect juvenile coho in the same area as Hallock considered excellent coho habitat in 1951.

The coho population of 1960 was estimated at 2,000 spawning adults (U.S. Fish and Wildlife 1960). This estimate was derived from data collected on other streams and applied to Redwood Creek and was meant to provide only the general magnitude of coho runs of the late 1950s. This estimate is not indicative of the larger runs of prior years (USFWS 1960; CDFG 1965; RNSP 2000). Coho of Redwood Creek belong to the Southern Oregon-Northern California (SONC) Coho Evolutionary Significant Unit (ESU).

In response to declining populations in California, coho of the SONC coho ESU were listed in 1997 as "threatened" under the Federal Endangered Species Act. In 2002, the California Fish and Game Commission found that in the region of Redwood Creek, coho salmon warranted listing as threatened, as defined under the California Endangered Species Act (CDFG 2002). The Department of Fish and Game has formed a coho recovery team that will aid the Department in planning recovery and implementing a recovery strategy for coho salmon north of San Francisco.

The Prairie Creek basin provides some of the most important coho habitat in the Redwood Creek basin. Outside of the Prairie Creek drainage, coho have recently been found in the lower and middle reaches of Redwood Creek and Tom McDonald Creek, Bridge Creek, McArthur Creek, Coyote Creek, Minor, Lacks, Panther, Karen, Strawberry, and Pilchuck Creek (Figure III- 33) (Anderson 1988; Brown 1988; Neillands 1990; PCFWWRA 1995; DFG 2001 surveys; DFG 2002; and RNSP unpublished data). However, electro-fishing conducted in the summer of 2001 did not produce any coho in Bridge, Coyote, Karen, and Pilchuck Creeks, nor in any other tributaries surveyed in the middle or upper portions of the basin (see Appendix D, Attachment 1). In addition, no coho were reported from the upper 1/3 of the Redwood Creek basin during downstream migrant studies conducted during 2000, 2001, and 2002 (Sparkman 2001 and personal communications 2002).

Current adult coho population estimates are not available for the Redwood Creek basin, but recent counts were collected from a weir located on Prairie Creek just above the confluence of Streelow Creek. The adult counts for 1995-96 and 1996-97 were only 115 and 124 coho salmon respectively (Roelofs and Klatte 1996 and 1997). These counts reflect approximately 14 of the 22.5 miles of habitat accessible to coho salmon in the Prairie Creek basin. A 1997 population estimate of 24,588 out migrating juvenile coho was made for the portion of the Prairie Creek basin above Streelow Creek (Klatte and Roelofs 1997).

Weekly downstream migrant trapping just below Prairie Creek data show peak migration of age 1+ coho occurred in mid May in 2001(Figure III- 34) and their average size ranged approximately between 105 and 115 mm FL (Figure III- 35) (Wilzbach 2001). The trapping effort had low capture efficiency, but likely reflects the low numbers of age 1+ coho salmon produced from the Redwood Creek basin. A smaller number of YOY coho were also captured from the trap. Several juvenile coho have been collected in the estuary (1,390 ± 630 in year 2000) and a few have resided in the lagoon over summer (Anderson 2000). Coho salmon redd and carcass counts from Prairie Creek 1983-2002 are provided in the Prairie Creek Subbasin section of this report.

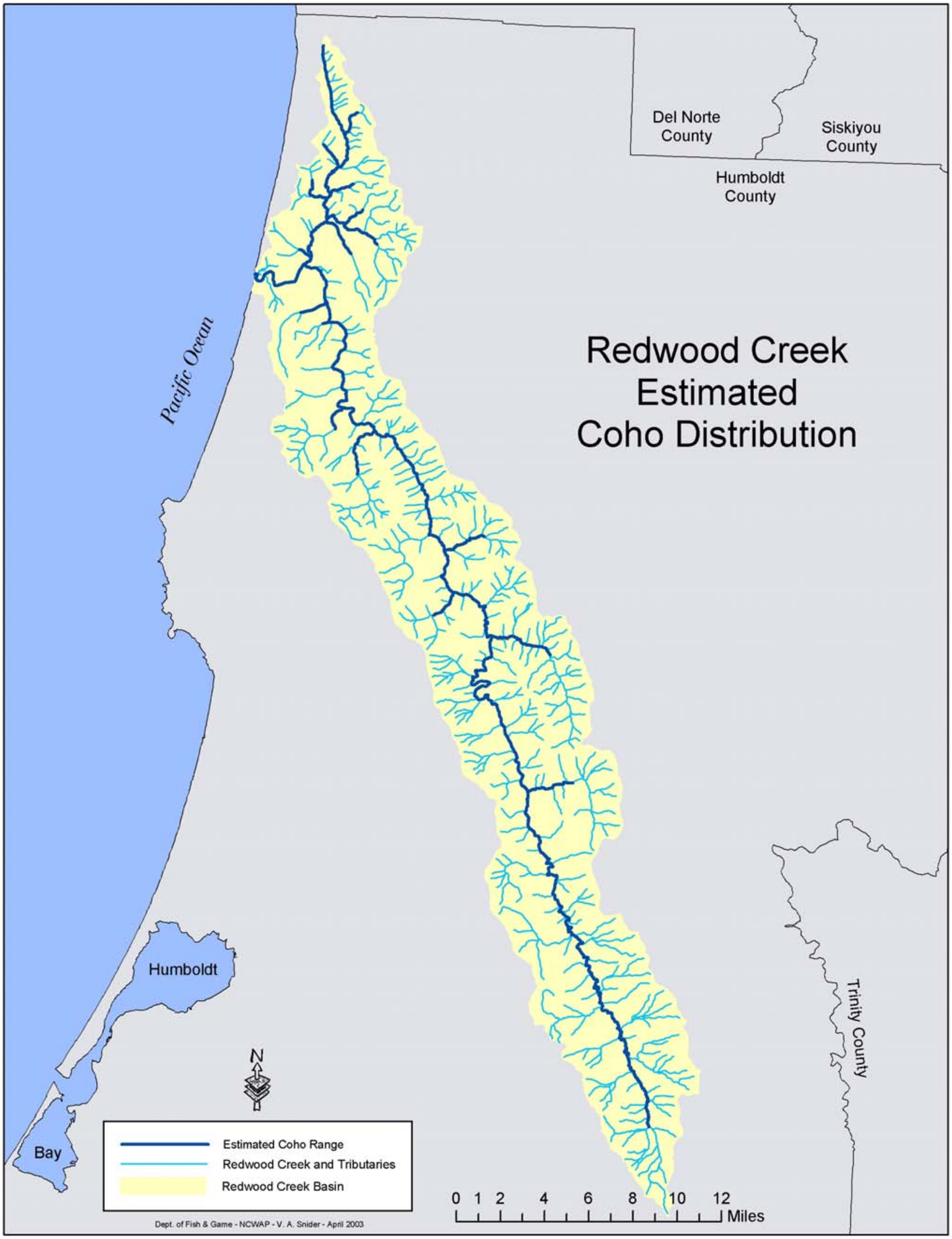

Figure III- 33. Estimated stream habitat used by coho salmon for migration routes, spawning and juvenile rearing in the Redwood Creek basin. Adapted from Cal EPA and RNSP.

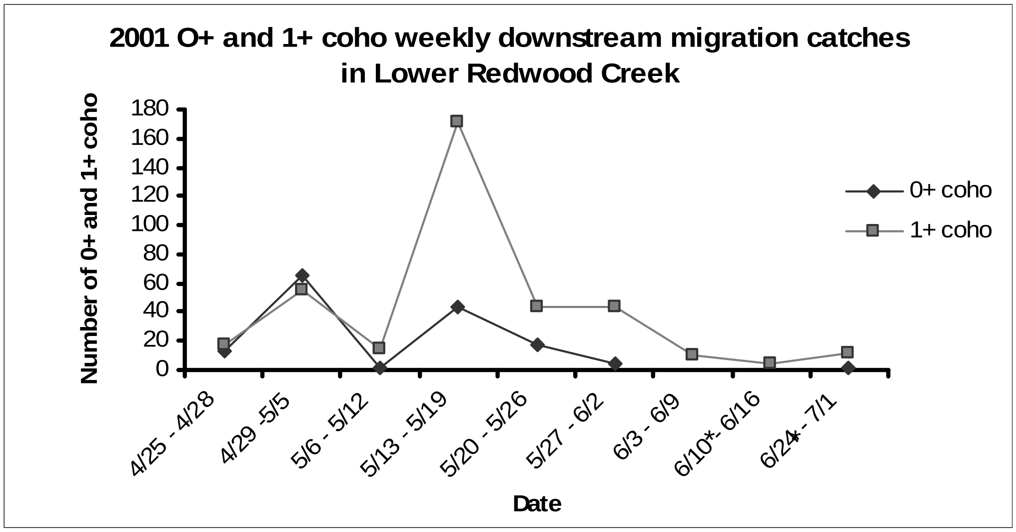

Figure III- 34. Weekly catches of 0+ and 1+ Coho in the lower Redwood Creek area, (Trap Located Just Downstream of Prairie Creek), 2001 (Wilzbach 2001).

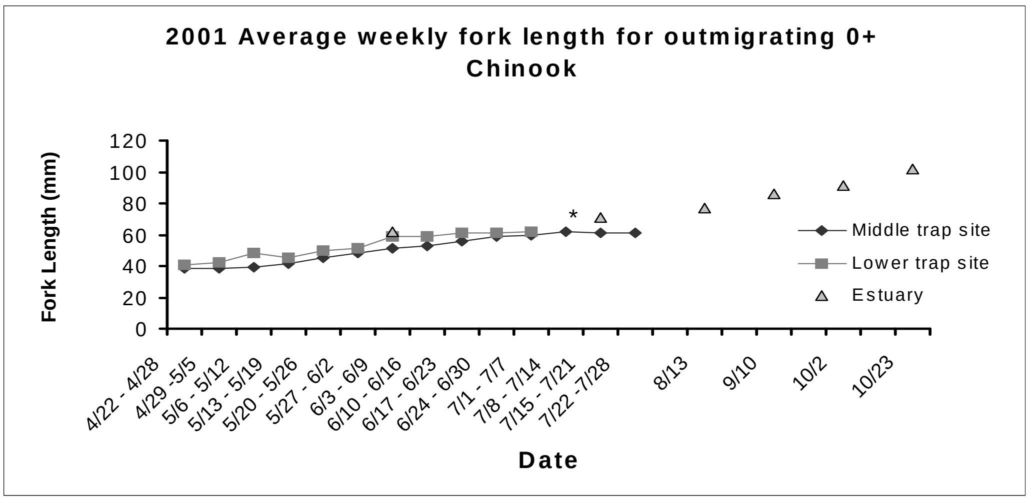

Figure III- 35. Average weekly fork lengths for age 0+ and 1 + Coho in the lower Redwood Creek area, (Trap Located Just Downstream of Prairie Creek), 2001 (Wilzbach 2001).

Steelhead

Redwood Creek supports two distinct runs of steelhead, a winter run, and a summer run. In addition, "half-pounder" steelhead, which may range in size from approximately 10 to 18 inches, return after a short period of ocean rearing.

A map showing the distribution of steelhead in Redwood Creek basin is presented in Figure III- 36. Although steelhead numbers have likely decreased from historic levels, their decline in numbers and distribution is not as significant as coho or sea run coastal cutthroat in the Redwood Creek basin. A map showing the distribution of steelhead in Redwood Creek basin is presented in Figure III- 36. This difference may be attributed to their ability to tolerate a broader range of habitat conditions compared to coho or coastal cutthroat, which share similar juvenile rearing strategies. Coho and coastal cutthroat are more sensitive to high water temperature and exhibit a greater affinity for complex habitat than steelhead (Rosenfeld et al. 2000). The summer run steelhead is considered a distinct stock and is discussed separately below.

Steelhead typically spend one to three years in inland waters before migrating to the ocean. Peak migration to the ocean occurs during March through May. Steelhead typically live in the ocean from one to four years before returning to freshwater streams to spawn. In contrast to all anadromous Pacific salmon, steelhead may not die after spawning. Incidence of repeat spawning by steelhead ranges from about 17.6% for small coastal streams to 63.6% for spring run of the Sacramento River system (Hopelain 1998). Steelhead may repeat spawning migrations as many as four times (Barnhart 1986 and Hopelain 1998).

The U.S Fish and Wildlife service estimated a run of approximately 10,000 steelhead populated Redwood Creek in 1960 (USFW 1960). This number was derived from data collected on other streams and applied to Redwood Creek. It was meant to provide only the general magnitude of steelhead runs of the late 1950s and is not indicative of the much larger runs of prior years (USFWS 1960; CDFG 1965; RNSP 2000). A review of available information suggests that the present populations of steelhead are less abundant compared to historic population levels and may be less abundant than the USFWS estimates of 1960.

Steelhead of Redwood Creek are included in the Northern California Evolutionary Significant Unit (ESU), which was listed as "threatened" in 2000 under the Federal Endangered Species Act. The Northern California ESU is defined as a distinctive group of steelhead that occupies coastal river watersheds from Redwood Creek south to the Gualala River. A rough estimate of the total adult steelhead population for California is 250,000 adults, less than half the population thirty years ago (McEwan and Jackson 1996). The major factor for the decline is freshwater habitat loss and degradation including inadequate stream flow, blocked access to historic spawning and rearing grounds, and human activities that generate and deliver sediment into watercourses (McEwan and Jackson 1996).

Steelhead were observed in 57 of 111 Redwood Creek tributaries surveyed for fish presence in 1980–1981 (Brown 1988). Steelhead also was the most widely distributed and numerous salmonid species observed in the Redwood Creek basin in the summer 2001 CDFG electrofishing surveys. Young of the year (YOY) trout was the most abundant age class found in all streams during 2001 surveys. The presence of YOY indicates successful spawning likely occurred in those streams. Alternatively, YOY may have moved into the area from other sites, or drifted downstream from above anadromous barriers. There were a number of streams (Panther Creek, Garrett Creek, Mill Creek, Molasses Creek, Minon Creek, and Lost Man Creek) in which the percentage of 1+ steelhead was relatively high (>25% of the total steelhead count) (DFG surveys 2001). The presence of 1+ and older steelhead may indicate a positive measure of steelhead habitat suitability. The absence or very low numbers of 1+ and older may indicate a habitat deficiency or habitat factor limiting the advancement of YOY to yearlings. Attachment 2 in Appendix D shows the results from electrofishing surveys in Redwood Creek. It is important to note that these qualitative surveys provide only a qualitative estimate of distribution, year class strength and population structure.

A portion of the basin's steelhead population was sampled by a rotary screw trap during the spring to early summer seasons of 2000 to 2003 (Sparkman 2000, 2001, 2002, 2003). The trap was located on Redwood Creek, just downstream of the confluence with Toss Up Creek, and is the same trap described in the previous discussion of Chinook salmon. These data were used to estimate the numbers of age 1+ and 2+ steelhead moving downstream from approximately twenty-eight miles of mainstem Redwood Creek and eleven miles of tributary stream habitat of accessible habitat in the upper 1/3 of the Redwood Creek basin (Table III- 35 and Figure III- 37).

The results from the rotary screw trap data should be interpreted differently for steelhead compared to Chinook. This difference is primarily because the great majority of juvenile Chinook caught at the trap are undergoing seaward migrations where as not all juvenile steelhead are necessarily migrating to the sea. Steelhead exhibit diverse juvenile life history patterns, which may include upstream and downstream movements within the mainstem and tributary streams. In addition to seaward migrations, movements are often due to a density dependant response, behavior adaptations, or a change in environmental conditions. The estimates of age 1+ steelhead are likely influenced by these factors, while the age 2+ steelhead are more likely to be migrating towards the sea. Many downstream moving steelhead will take up summer residence in the estuary.

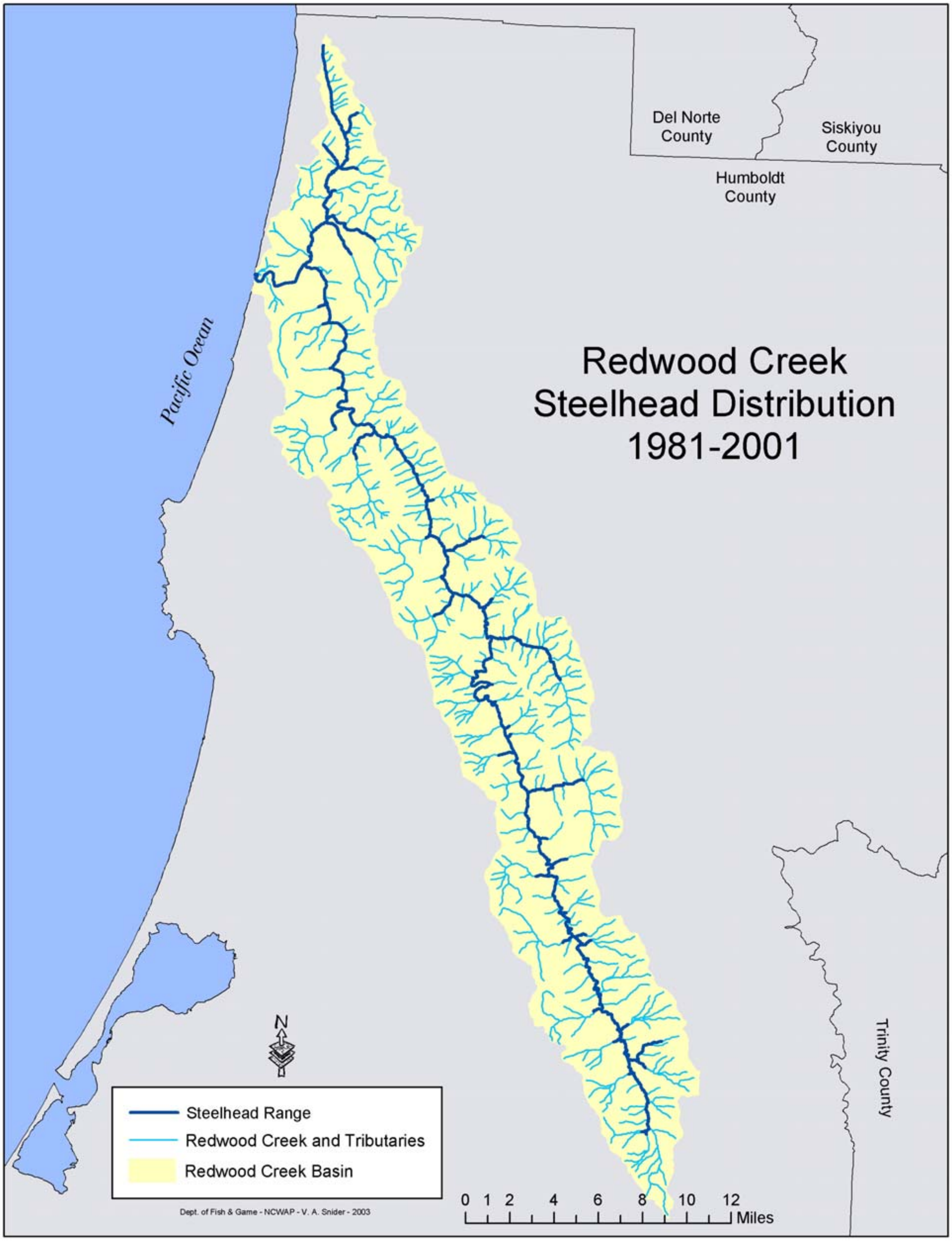

Figure III- 36. Stream habitat used by steelhead for migration routes, spawning and juvenile rearing in the Redwood Creek basin. Adapted from Cal EPA and RNSP.

Table III- 35. Number of captures and population estimates for juvenile steelhead and average fork lengths (FL) collected from Redwood Creek screw trap near Toss Up Creek (adapted from Sparkman 2000, 2001, 2002).

Date	# of 1+ Steelhead	Population Estimate	Ave FL (mm)	# of 2+ Steelhead	Population Estimate	Ave FL (mm)
Redwood Creek Screw Trap - Spring/Summer 2000						
4/5 - 4/29	9,159	11,062	79.9	341	2,171	169.1
4/30 - 5/27	5,550	30,262	88.4	247	1,360	165.4
5/28 - 7/1	3,256	24,996	100.8	71	678	150.1
7/2 - 7/29	188	1841	109	59	429	155.7
7/30 - 8/5	30	168	107.3	18	102	157.1
Total:	**12,263**	**68,328**	**92.4**	**736**	**4,740**	**164.4**
Redwood Creek Screw Trap - Spring/Summer 2001						
3/27 -3/31	1,298	2,789	83	107	703	154.5
4/1 - 4/28	6,816	16,153	86.4	461	3,603	156.5
4/29 - 5/26	4,507	15,338	93.6	376	3,290	151.8
5/27 - 6/30	2,037	15,016	98	287	4,483	138
7/1 - 8/4	117	1359	87	129	590	153.7
Total:	**14,775**	**50,654**	**91.9**	**1,360**	**12,669**	**151.2**
Redwood Creek Screw Trap - Spring/Summer 2002*						
Totals	12,217	28,501 +/- 6.3%	86.7mm	1,589	7,370 +14.7%	147.5mm

*Only total numbers of steelhead were available for 2002.

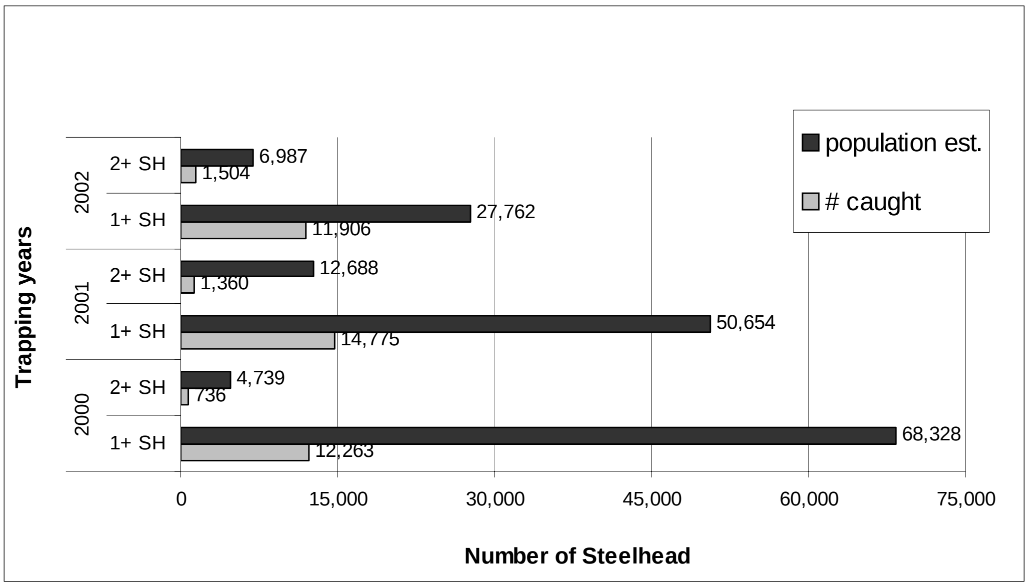

Figure III- 37. Yearly juvenile steelhead population estimates, 2000-2002. Adapted from trapping results on Redwood Creek (Sparkman 2000, 2001, and 2002).

An important juvenile rearing strategy used by steelhead, including Redwood Creek stocks utilizes the estuary/lagoon. Juvenile steelhead are known to rear in estuaries/lagoons for several months to one year or more before entering the ocean (Anderson 1988; Ridenhour and Hofstra 1994; Cannata 1998). Estuarine-reared juvenile salmonids often achieve growth rates greater than achieved in small streams because estuary/lagoon ecosystems usually provide an abundant amount of living space and are food rich environments. Like the juvenile Chinook, a high level of mortality occurs to the steelhead rearing in the Redwood Creek lagoon during summer and early fall (Table III- 36).

Table III- 36. Juvenile steelhead population estimates and average fork lengths.

Date	Mouth	Population est.	Ave FL
Steelhead population data Redwood Creek Estuary - Summer/Fall 2000			
5-June	OPEN	12,780	126
July 17,18,20	CLOSED	8,950	202
Sept 11,12	CLOSED	4,270	220
26-Oct	CLOSED	not available	
Steelhead population data Redwood Creek Estuary - Summer/Fall 2001			
4-Jun	OPEN	38,456	113
16-Jul	CLOSED	34,259	89
13-Aug	CLOSED	4,612	81
10-Sep	CLOSED	9,348	126
2-Oct	CLOSED	not available	118
23-Oct	CLOSED	not available	147

LF = Fork Length.
Collected from Redwood Creek estuary/lagoon 2000 and 2001 (Anderson 2000 and 2001).

Summer Steelhead

Summer steelhead migrate into freshwater streams from spring through early summer (Barnhart 1986). Currently, only 20 streams in Northern California are populated with summer steelhead including Redwood Creek (Gerstrung 2001 draft). These streams must provide cool, deep pools of sufficient size and complexity to support adults over the low flows and high water temperatures of summer and early fall seasons. The summer steelhead population of Redwood Creek is likely the most threatened by extirpation of all salmonids in the Redwood Creek basin.

Summer steelhead enter fresh water sexually immature and consequently must wait several months before spawning. They rely on the remaining high spring flows to allow passage upstream where they hold in deep pools over the summer and fall. The majority of adult summer steelhead of the Eel River Basin utilize pools from 10 to 20 feet deep for over summer habitat (Scott Harris, CDFG, Personal Communication). Similar conditions were once abundant in Redwood Creek. In addition to deep pools summer steelhead prefer water temperatures less than 66ºF (19ºC) (Baigun et al. 2000) and ample cover such as large rootwads, underwater ledges, caverns, and bubble curtains, which fish seek when disturbed. Spawning summer steelhead may be somewhat spatially and temporally segregated from winter steelhead. Generally, summer steelhead spawn December through February in smaller tributaries or in the headwaters of larger systems, further upstream than winter steelhead (Barnhart 1986).

Little is known about historical abundances of the Redwood Creek summer steelhead population because quantitative records date back only the two or three decades (Anderson 1993). But, there is a considerable amount of evidence depicting a relatively large historic population. Native Americans depended on summer steelhead of Redwood Creek for subsistence, and they were frequently harvested before the fall salmon runs, supplementing the harvest of big game (Moyle et al. 1995). Sport fisherman used to enjoy the abundance of Redwood Creek summer steelhead runs in the late 1800's to early 1900's. Interviews with long-time residents of Redwood Creek gave testimony to "real good" summer steelhead runs in the past. "There are still a few, but not nearly as many as there used to be" (Van Kirk 1994). A 1920 article in American Angler gave the following description of summer steelhead in upper Redwood Creek: "Every pool has ten to twenty five, and they run from twenty to thirty-six inches. Some of the pools were up to 20 feet deep" (Gerstrung 2001 Draft).

Today, Redwood Creek supports a small population of summer steelhead. Average numbers of fish observed during summer snorkel surveys performed from 1981 to 2000 are typically between 15 to 40 fish (Figure III-38). Counts have ranged from a high of 44 adults in 1984 and 1985 to a low of three adults in 2000 (Gerstrung 2001 draft). However, snorkel surveys have not been conducted over the same areas each year, which may contribute to the variability in these numbers. In the 1990s, the majority of the observations were made on Redwood Creek mainstem from the confluence of Lacks Creek upstream to Bradford Creek. Deeper, more numerous pools are located in this reach of Redwood Creek.

Summer steelhead are known to depend on deep and cool pools as habitat during summer months and fall months. Under present conditions, ambient water temperatures in Redwood Creek range from 68-80.6ºF (20-27ºC). Deep, stratified, cool pools may be necessary to provide summer refugia for adult summer steelhead (Nielsen et al. 1994, Ozaki et al. 1999). Fewer than 25 suitable pools have been observed in the 12-mile reach between Stover Creek and Chezem dam (Weseloh 1993). The lack of deep, complex pools reduces the suitability of Redwood Creek for summer steelhead.

The decline of summer steelhead illustrates how temporary loss of a critical habitat element such as adult over-summer habitat, may have long-term adverse impacts to survival of a stock. The large scale reduction of deep pools that occurred from excessive sedimentation during the 1964 flood likely had a dramatic adverse impact on the summer steelhead population of Redwood Creek. As a result, the current breeding population may be less than the minimum size needed to sustain a viable population (Meffe 1986), placing summer steelhead of Redwood Creek at a high risk of extinction (Nehlsen 1991). If habitat conditions improve in Redwood Creek, then the summer steelhead population may increase in size.

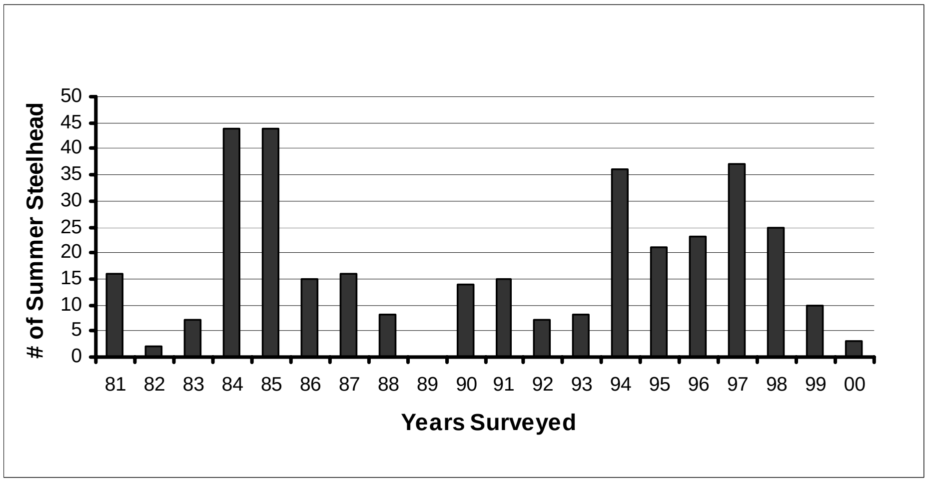

Figure III- 38. Summer steelhead dive counts on Redwood Creek, 1981-2000.

Adult summer steelhead numbers represent steelhead greater than sixteen inches in length. Survey efforts varied year to year. Full surveys (Hayes Creek upstream to Bradford Creek) were completed in 1987 and 1993 through 1998; three-fourths (Hayes Creek upstream to Highway 299 bridge) in 1981; and half surveys (Hayes Creek to Lacks Creek) were completed in 1983-1986, 1988-1992, and 1999 through 2000. In 1984 and 1985 adults and half-pounders were not counted separately; the adults were most numerous [Gerstrung 2001 (Draft)].

Coastal Cutthroat Trout

Coastal cutthroat trout range from the lower Eel River north to the southeastern portions of Alaska. Redwood Creek supports anadromous and resident forms of coastal cutthroats. Anadromous forms are often called sea run coastal cutthroat. However little is known about their use of ocean waters or their migratory habits (Gurstung 1996).

Coastal cutthroat trout are found in the estuary, Prairie Creek, Redwood Creek, and several tributaries throughout the basin (Brown 1988; Gerstrung 1996; and B. Michaels, Green Diamond, personal communication). The majority of the known anadromous population resides in the Prairie Creek drainage where nearly all tributaries support sea run coastal cutthroat (Gerstrung 1996). Historic records indicate that coastal cutthroats up to four pounds were commonly caught by sportfishers in the estuary (Snyder 1908 and Van Kirk 1994), but fish of that size are rarely observed from samples collected recently (D. Anderson, RNSP, personal communications 2002). Snyder (1907) described Redwood Creek as “fairly swarming” with coastal cutthroats. Today, coastal cutthroat trout are listed as a species of special concern in California and are also a candidate species for federal listing. “The coastal cutthroat has been compared to the “canary in the gold mine” because it is one of the first species to suffer from environmental degradation” (Gurstung 1996).

Coastal cutthroats exhibit a wide range of life history characteristics. In Northern California, coastal cutthroat begin migrations to spawning streams in August through October, following the first substantial rainfall. Ripe or nearly ripe females have been observed September through April, indicating a protracted spawning period (Moyle et al. 1995). They generally spawn in smaller tributaries or further upstream than steelhead trout and coho salmon where their offspring rear without competition from most other salmonids species (Pauly et al. 1989). Anadromous female cutthroat seldom spawn before the age of four years old and are capable of repeat spawning in subsequent years. Coastal cutthroat typically live from 4-7 years (Moyle et al. 1995). However, the mortality rates are generally high after the initial spawn. Most anadromous cutthroat trout juveniles migrate in spring to the ocean at age two, but seldom overwinter at sea; rather they return to rivers in the fall or winter of the same year (Trotter 1989). Many coastal cutthroat may reside in the estuary year round and many are likely long-term residents in streams.

Resident coastal cutthroats may utilize a potamodromous life history strategy. That is, they may use the estuary or larger streams for primary residence and ascend small streams for spawning. Resident coast cutthroat populations also occur above anadromous reaches of the tributaries to Redwood Creek throughout the basin (Ridenhour and Hofstra 1994; Brown 1988; and B. Michaels personal communication 2002). Little is known about the status of resident coastal cutthroats of the Redwood Creek basin.

In the late 1800s and into the early 1900s Redwood Creek and Prairie Creek the coastal cutthroat populations were harvested by many local and visiting sport anglers (Snyder 1907, Dewitt 1954, USDI 1960, Van Kirk 1994). As one local angler said "coastal cutthroat trout were abundant" and in some years, there were as many coastal cutthroat trout migrants as steelhead (Gerstrung 1996). The coastal cutthroats provided a popular summer fishery which attracted anglers from San Francisco and other areas. However, the fisheries popularity and the daily limit of 25 pounds were more than adequate to reduce populations. By 1925, the coastal cutthroats of lower Redwood Creek and Prairie Creek were over harvested. The number of visiting anglers coming to fish Redwood Creek also declined which affected the local economy (Van Kirk 1994).

In response to the decline in the fishery and the public's desire to supplement declining stocks, the Prairie Creek Hatchery was constructed in 1927. The facility's goals were to collect coastal cutthroat eggs for hatchery propagation and release fry back into the basin. The egg taking and stocking proved unsuccessful in restoring the cutthroat fishery. While their populations continued to decline slowly, it was not until later that coastal cutthroat populations in Redwood Creek crashed in response to detrimental habitat changes during the mid 1960s (Gerstrung 1996).

In the summer of 2001, five tributaries of Prairie Creek were sampled by electro-fishing for presence of fish species by CDFG survey crews. Coastal cutthroat were present in four of the tributaries, but they were few in numbers. The anadromous reaches of fifteen tributaries located in the Middle and Upper subbasins were also electro-fished by CDFG field crews. Only Panther Creek yielded a few coastal cutthroat. Dive surveys along the mainstem of Redwood Creek from 1991 to 1996 averaged 0.5 fish / kilometer (Gerstrung 1996). Dive counts increased in 1999 and 2000 from previous levels (Figure III- 39). Almost 85% of the cutthroat observed in 1999 and 2000 in mainstem Redwood Creek were counted between the confluences of Hayes Creek upstream to Coyote Creek.

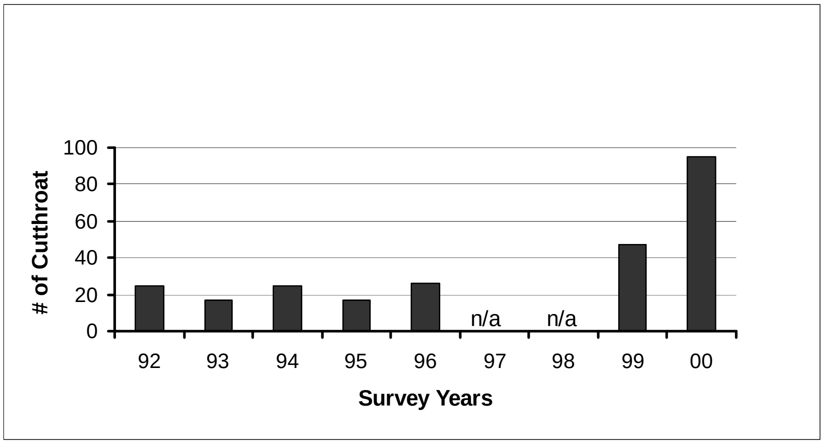

Figure III- 39. Number of coastal cutthroat trout observed during summer steelhead snorkel surveys on Redwood Creek mainstem, 1992-2000.

Surveys were typically from the confluence of Hayes Creek upstream to Lacks Creek. Most of the coastal cutthroat trout observed were adults. Counts of coastal cutthroat were not made in 1997-98.

Basin Issues, Integrated Analysis, and Cumulative Effects

A major challenge in watershed assessment is integrating a large amount of information from multiple sources and disciplines in a fashion that allows the exploration and understanding of the interrelationships among watershed process, land use activities, socio-economics, and watershed conditions. This included public participation in two workshops and scoping meetings to help develop a set of basin issues of concern to help guide the assessment process.

Previous portions of this Basin Profile largely focused on individual disciplines of watershed science. Building on the preceding materials, this section strives to make interdisciplinary evaluations of the biological, physical, and socio-economic interactions and their cumulative effects upon watershed processes that influence the Redwood Creek basin. Assessing cumulative watershed environmental effects is both a practical challenge and a legal requirement for some land use activities under the California Environmental Quality Act (CEQA) and the National Environmental Policy Act (NEPA) (Henly 1993).

The NCWAP integrated interdisciplinary analysis in a number of ways. This work contributes to the identification of cumulative environmental impacts on watersheds. The NCWAP developed data tables intended to help identify and highlight relationships across a number of important assessment factors. The NCWAP refers to these as “integrated analysis” tables. Key relationships examined are those among land use, landslides, relative landslide potential, and instream fish habitat. In addition, the Ecosystem Management Decision Support (EMDS) models help to evaluate stream conditions, upland conditions, and potential basin risks (such as sediment production) by looking at factors both past and present.

The integrated analysis also includes discussions of basin issues. The analyses here summarize and integrate key issues and findings presented in this report at the basin level with subbasin comparisons. The subbasin section of this report (Part IV) presents analysis at the level of subbasin and planning watersheds.

Redwood Creek General Issues and Summary Findings

Public scoping meetings, two workshops with Redwood Creek basin residents and constituents, and analyses of the NCWAP assessment data developed this working list of general issues, comments and/or concerns. The issues are grouped by common themes and are addressed through the following findings, synthesis, answers to assessment questions, and management recommendations.

Salmonid populations have declined from historic levels, prompting listings under the state and federal ESAs:

- Redwood Creek’s anadromous salmonid stocks should be viewed as critically valuable natural resources;
- Present anadromous salmonid populations are less abundant and less widely distributed compared to their historic presence in the Redwood Creek Basin;
- Increasing the abundance, diversity and distribution of Redwood Creek’s salmonid stocks are vital steps towards the restoration of viable salmonid populations to California;
- The capacity for salmonids to increase in abundance and distribution is in part limited by the reproductive potential of existing stocks;
- The presence of salmonid stocks does not mean that efforts to protect habitat conditions should be relaxed;
- Sport and commercial fish harvests have played a role in the reduction of numbers of Redwood Creek’s salmonid populations;
- Given improving aquatic habitat conditions, it will likely take several generations before salmonid populations rebound to viable levels.

Impairments to freshwater and estuarine habitat needed to complete salmonid freshwater life cycles have been identified as a leading factors in the decline of Redwood Creek's anadromous salmonids:

- Many of the adverse changes to stream habitat conditions have been exacerbated by winter floods and summer droughts;
- Primary causes for stream habitat deficiencies can often be traced back to land management actions that increase erosion, or activities that alter characteristics of near stream forests;
- Warm water temperature in mainstem Redwood Creek limits salmonid production in most of the Upper Subbasin and all of the Middle and Lower subbasins;
- Many tributaries across the basin have cool water temperatures but often lack the combination of structural components that create the habitat diversity and complexity needed by salmonids to support viable populations;
- A significant factor affecting salmonid production is the large reduction in area and habitat quality of the estuary/lagoon;
- The present habitat problems observed in most streams of the basin are often related to excessive sediment in stream channels and/or the lack of a large conifer contributions from nearstream forests;
- Excessive sediments inputs can result in several adverse and long lasting impacts to salmonid habitat including impaired spawning habitat, a decrease in channel diversity, a reduction in the numbers and depths of pools, stream bank erosion, widened channels, and riparian vegetation becomes less affective at providing shade over the water needed to moderate water temperature;
- The negative impacts from excessive sediments are in some cases exacerbated by the general lack of instream large wood debris (LWD);
- More LWD is needed in many stream channels to help with channel maintenance processes including formation of pools and sediment routing, providing shelter for fish, and to provide nutrient inputs;
- As a result of timber harvests and stream bank erosion, there is a low potential for near term LWD input to several anadromous reaches in the basin.

Natural geologic instability contributes to sediment inputs to the basin's stream network:

- The Redwood Creek Basin is situated in a tectonically active and geologically complex area. Most of the bedrock is relatively weak, easily weathered and naturally susceptible to erosion;
- The region experiences a high level of seismic activity and major earthquakes have occurred along the Cascadia subduction zone as well as within the individual tectonic plates and along well-defined faults;
- The inner gorge of the Redwood Creek channel is particularly prone to yielding sediment from stream side landslides;
- High rates of regional uplift provide a continual source of sediment to the basin.

Much of the naturally occurring erosion resulting from slope instability has been compounded by human activities:

- Land management on unstable slopes often exacerbates slope instability and the release of sediment. Relatively minor land use actions, such as undercutting the toes of slopes, increasing the duration of ground saturation, or reducing soil shear strength by a relatively small amount, could trigger extensive landslides;
- The combination of naturally unstable terrain, intensive land use and severe storms (such as the one that occurred in December 1964) can trigger major episodes of erosion;
- Much of the erosion in the basin is linked to legacy impacts from past land uses;

- There are high road densities in much of the basin and large amounts of sediment is generated from road related failures, especially from roads located on steep, unstable slopes;
- Large scale removal of timber accelerates storm runoff and contributes to an increase in erosion;
- Fine sediment accumulations in stream channels are typically more abundant where land use activities such as roads or land clearing expose soil to erosional processes;
- High turbidity levels in Redwood Creek are believed to occur more frequently and persist longer than observed in the past;
- Many of the effects from land use activities on upland sediment sources are spatially and temporally displaced from response reaches;
- Past fluvial erosion was accelerated by land use and this erosion could have been minimized with better erosion-control and road-maintenance measures.

Riparian and near stream forests functions have been altered by timber harvests and bank erosion:

- Timber harvests in riparian and nearstream forest areas contribute to a reduction in both overstory shade canopy and LWD input potential;
- Shade over the water from willow and alder riparian vegetation alone is not enough to keep water cold;
- Micro-climate benefits provided by near stream forests and overstory shade are important to help provide cool air near streams that helps maintain cool water temperature;
- Retention and recruitment of large trees is needed along streams, especially along mainstem Redwood Creek;
- As trees grow and become subject to harvest, how will management protect valuable aquatic and fishery resources from similar impacts as occurred in past years?

The Redwood Creek basin is an excellent candidate for a successful long-term, programmatic watershed improvement effort:

- Management strategies should take a basin-wide perspective;
- It is important to note that without management strategies that promote restoring integrity to watershed ecosystem process by addressing root causes of problems, instream improvement projects will likely be short-lived patches on the environment;
- Stream condition improvement and increasing anadromous salmonid populations largely depends on achieving a balance between the socio-economic needs for timber resources and management needed to maintain or improve basin conditions that sustain viable fish populations;
- Most of the basin has a high potential to improve fish habitat conditions. Reaching that goal is dependent upon the formation of a well organized and thoughtful improvement program founded on broad based community support for the effort.

Integrated Analysis and Cumulative Effects

Fish Habitat and Watershed Relationships

The Redwood Creek Basin sustains populations of Chinook and coho salmon, steelhead and sea run coastal cutthroat trout. However, present populations of these anadromous salmonids are overall less abundant and less widely distributed compared to their historic presence in the basin. Impairments to freshwater and estuarine habitat needed to complete their freshwater life cycles have been identified as a leading factor in the decline.

Stream conditions over much of the Redwood Creek basin are below standards for preferred salmonid habitat, particularly in the mainstem Redwood Creek where high water temperature is a prominent limiting factor. Salmonid production in mainstem reaches may be also limited by poor pool characteristics, poor spawning habitat, or lack of instream shelter. Many tributaries across the basin have cool water temperatures but often lack the combination of structural components that create the habitat diversity and complexity needed by salmonids to support abundant populations. In the estuary, modifications associated with flood control levees, removal of riparian vegetation, and wetland conversions have adversely altered estuarine ecosystem processes and reduced the suitability of the estuary as anadromous salmonid habitat.

The NCWAP team confirmed the status of stream habitat factors (such as water temperature and pool characteristics) that characterize stream condition are a cumulative product of watershed conditions, land use, and dynamic watershed processes and stream conditions and limiting factors may be linked to actions or events that occur at various spatial and temporal scales. These findings illustrate that relatively short term disturbance to watersheds can have long term effects to stream systems and salmonid populations.

To simplify a complex problem of identifying numerous watershed factors that affect stream conditions, the NCWAP team identified four primary factors: 1) the unstable geology and relatively weak lithology make lands of the Redwood Creek Basin naturally susceptible to erosional process; 2) large winter storm events elicit erosional processes on the landscape; 3) land management actions often increase erosion potential, exacerbate land instability, or accelerate runoff that results in excessive sediment input to streams; and 4) land management actions can devalue beneficial qualities of near stream forests, upland forests, and other vegetation characteristics that lead to a reduction in shade canopy, reduces LWD loading potential, and eliminates air cooling microclimate effects.

The present habitat problems observed in most streams of the basin are often related to excessive sediment inputs to stream channels and/or the lack of a large conifer component in nearstream forests. When excessive amounts of sediment is delivered to the stream network, fluvial processes and stream channels respond in ways that can result in several adverse impacts to salmonid habitat. These include channel aggradation, stream bank erosion, widened channels, increased width to depth ratios, filling of pools, loss of riparian shade, increased water temperature, loss of channel diversity, loss of stream connectivity, impediments to spawning migrations and prolonged high turbidity levels. The negative impacts from excessive sediments are in some cases elevated by the general lack of instream large wood debris (LWD) needed for pool scour and sediment routing processes.

As a result of timber harvests and stream bank erosion, there is a low potential for near term LWD input to several anadromous reaches in the basin. In the Middle and Upper subbasins, over 75% of the area within a 150 foot buffer width along anadromous salmonid bearing reaches is composed of trees that average less than 24 inches diameter at breast height (DBH) and 35% of the area has trees that average less than 12 inches DBH. Fox (1994) suggested that for streams ranging from 20 to 45 feet channel width, key individual LWD pieces should be 22 to 25 inches in diameter and 32 to 59 feet long. For a channel the size of mainstem Redwood Creek, the size of functional LWD is much larger. Based on these data, near term LWD recruitment to streams falls short of what is needed for channel maintenance, instream cover for fish, and nutrient inputs.

The lack of large tress and the shade they provide has also contributed to the warming of the mainstem Redwood Creek. Salmonid habitat is impaired by warm water for most of its length. The bulk of the temperature increase occurs in the Upper Subbasin where the water warms quickly between Minon Creek and the O'Kane gauging station near the Highway 299 crossing. The widened channel does not receive beneficial shade from riparian vegetation that existed prior to the 1964 flood. Legacy impacts from the large storm runoff, hillslope erosion, and stream bank erosion increased the channel width, caused a loss of riparian vegetation and consequently a loss of shade over the water (Madej and Ozaki 1996). The mainstem water remains warm from above the Highway 299 crossing until it reaches the coastal fog belt where it cools slightly before entering the estuary. Most tributaries provide cool water temperatures. However, the reduction of shade and air temperature moderating effects from mature near stream forests has likely led to an increase in water temperature along lower Lacks and Minor creeks and possibly other tributary reaches.

The estuary/lagoon plays a vital role in the production of Redwood Creek's Chinook, steelhead, coastal cutthroat trout, coho and other valuable fishery resources. In addition to the connection between the riverine and marine environments used during seaward and spawning migrations, the estuary/lagoon provides important rearing habitat for juvenile Chinook, coho, steelhead, and all life stages of coastal cutthroat trout. However, the estuary/lagoon, in its current modified condition acts as a significant limiting habitat factor to salmonid production. Flood control modifications, levees, removal of riparian vegetation, sediment accumulations and conversion of wetland and forest areas to pasture are all contributing factors to the large decline of estuarine habitat utility for salmonids.

Historically Active Landslides, Vegetation Type, and Land Use

The combination of tectonic, geologic, basin morphology, and climatic factors makes much of the Redwood Creek basin very susceptible to erosional processes. The amount of erosion that occurs on an annual basis is also related to hydrologic factors such as the duration and intensity of winter storms and soil saturation levels. In addition, because the basin terrain is naturally unstable, any land use that weakens structural integrity of hillslopes can add significantly to landsliding and cause excessive amounts of sediment inputs to stream channels.

Historically active landslide features show evidence of recent movement within about the last 150 years, spanning the time of the first European settlers in the North Coast to the present. These active landslide features include rockslides, earthflows, debris slides and debris flows. Table III- 37 enumerates the spatial overlay between active landslide features, roads, woodlands, and recent (1991-2001) timber harvest lands. The purpose of Figure III- 31 is to compare vegetation types and land use in juxtaposition with historically active landslides. This comparison can help us to understand how one indicator of the landscape's stability—historically active landslides of various types underlies recent land use. Instability has implications for the activities carried out on the landscape–roads may fail, structures may collapse–and for fluvial systems and aquatic habitat may be affected by delivery of sediment to streams from landslides. Removal of trees by timber harvests or fires may also increase runoff rates, and increase suspended sediments levels during winter storms. A discussion of the factors affecting the different landslide types and management objectives for mitigating potential problems is located in the CGS appendix and in CGS Note 50.

The land use or land type categories are divided into the following categories: woodland and grassland, timber harvesting plans (THPs) from 1991 through 2000, timberland (including parklands with timberland characteristics) with no recent harvest (i.e., not harvested since 1991), and roads. Roads are based on length (miles). The other categories are examined on an area (acres) basis. The woodland or grassland category is intended to capture a vegetation type that also implies grazing as a land use. On private lands in the Redwood Creek basin, this land type is used for grazing. Areas where THPs were conducted in the 1991-2000 period represent areas of recent, active timber management. Timberland areas without recent harvest represent areas where active timber management (i.e., at the level that would require a THP) during this same period has not occurred. However, these areas could include less substantial forms of timber management, such as pre-commercial thinning.

Approximately 5.6% of the basin area is in historically active landslide features (Table III- 37). In terms active landslide area, the Middle Subbasin contains 41% of all active landslide features. The Upper Subbasin contains 29% and Lower Subbasin contain 26% of active landslide features. Prairie Creek Subbasin contains the remaining 3% of active landslides features in the basin. Note that the percentages reported in Table III- 37 refer to the basin unit of analysis; i.e., in the section for the entire Redwood Creek basin, the percentages pertain to that entire basin area; where when the unit of analysis is the subbasin, the percentages are based on the total area of the specific subbasin.

Woodland and grassland area with historically active landslide features comprises 2% of the basin area or 18.5% of the area of this land type (20,579 acres). About 1,000 acres of THP activity occurred on historically active landslide areas for 1991-2000; this area represents 0.6% of the entire basin or 6.7% of the total area of THPs (14,906 acres) conducted during this period. Timberland with no recent harvest and historically active landslide features comprised 3.0% of the Redwood Creek basin or 3.4% of the total area of this land type (156,327 acres). Looking at roads in the basin, 72 miles or 4.9% of the total road length (1,479 miles) occurred on historically active landslides.

Land uses such as timber harvest, roads, or construction can be contributing factors or causes of landslides by exacerbating slope instability. Activities such as removing lateral and end support from landslides, loading the head of a landslide or increasing the pore pressure of the landslide mass by improper drainage or diverting water to the landslide mass can contribute to initiating slope failures or reactivating landslides. Roads are major sources of sediment inputs to stream channels through a combination of surface erosion, watercourse diversion, and mass wasting (USEPA 1998; Gucinski and others 2000; Weaver and Hagans 1994; Packer and Christiansen 1977). The NCWAP analysis added to this body of data by finding the incidence of point landslides within about 75 feet of roads in the Redwood Creek basin is approximately 58% greater than that beyond 150 feet and road failures were more often associated with roads in the logged areas. In addition, Pitlick (1995) found that the frequency of landslides was the same for logged and unlogged slopes. However, he found that slides in logged areas were substantially larger and account for nearly 80% of the total landslide related erosion. In another study, the USEPA (1998) estimated that more than 50% of the sediment yield to streams is related to land use.

Sediment production by mass-movement processes and streambank erosion is sometimes less clearly related to land use, and also more difficult to control, than fluvial hillslope processes on roads. A challenge to restoring basin integrity involves identifying and repairing adverse legacy effects from past timber practices. Sediment production by mass-movement processes and streambank erosion is sometimes less clearly related to land use, and also more difficult to control, than fluvial hillslope processes on roads.

If we look at the subbasin level, Table III- 37 shows that the woodland and grassland features located on historically active landslides are concentrated more in the Middle and Upper subbasins than in the Lower Subbasin area. This distribution, in general, matches the higher proportion of this vegetation type found in these two subbasins. Similarly, the recent (1991-2000) THPs on historically active landslides are concentrated in the Middle Subbasin, where 2.8% of the subbasin area consists of recent THPs on historically active landslides. Roads on historically active landslides are found more in the Lower, Middle, and Upper subbasins than in the Estuary and Prairie Creek subbasins. Basin wide or on any given subbasin, less than 6% of the analyzed road length is found on historically active landslides. For any of the geographic units of analysis (the entire basin or any of the subbasins) the percentage of road length underlain by historically active landslides is only a percentage point or less than the percentage area of the landscape that is underlain by historically active landslides, with the exception of the Upper Subbasin, which is 2.4 percentage points less. This similarity of extent may indicate that roads could be better located to avoid exacerbating potential instability of historically active landslides.

Table III- 37. Historically active landslide features associated with vegetation type and land use.

Unit of Analysis	Historically Active Landslide Feature[1]	Entire Unit of Analysis		Woodland and Grassland[2]		THPs 1991 – 2000[3]		Timberland, No Recent Harvest[4]		Roads	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Redwood Creek Basin (180,688 acres) (1,479 road miles)	Earthflow	7,602	4.2%	3,405	1.9%	955	0.5%	3,373	2%	53.8	3.6%
	Rock Slide	1,710	0.9%	380	0.2%	1	0.0%	1,327	1%	11.8	0.8%
	Debris Slide	591	0.3%	33	0.0%	37	0.0%	511	0%	5.3	0.4%
	Debris Flow	170	0.1%	13	0.0%	6	0.0%	149	0%	1.0	0.1%
	All Features	10,073	5.6%	3,831	2.1%	999	0.6%	5,361	3.0%	72.0	4.9%
Estuary Subbasin	All Features	2	0.1%	0	0.0%	0	0.0%	1	0.0%	0	0.0%
Prairie Creek Subbasin	All Features	348	1.4%	0	0.0%	0	0.0%	346	1.4%	1	1.1%
Lower Redwood Creek Subbasin	All Features	2,662	6.0%	274	0.6%	0	0.0%	2,377	5.3%	7.0	5.0%
Middle Redwood Creek Subbasin	All Features	4,166	6.5%	1,802	2.8%	852	1.3%	1,717	2.7%	42.3	5.9%
Upper Redwood Creek Subbasin	All Features	2,892	6.7%	1,756	4.1%	147	0.3%	919	2.1%	22	4.3%

[1] Refer to Plate 1 and California Geological Survey appendix
[2] Woodland and grassland category includes areas mapped in 1998 as grassland and non-productive hardwood.
[3] THPs that were completed or active between the 1991 and 2000 timeframe.
[4] Area of timberlands that were not contained in a THP during the 1991 to 2000 period, but may include pre-commercial thinning and includes parklands with timberland characteristics.

Relative Landslide Potential and Land Use

Table III- 38 is similar to Table III- 37, except that it looks at land use in the context of relative slope stability rather than active landslide features. Since the discussion of Table III- 37 was focused on relative landslide potential in general for the basin and subbasins, the discussion here will be focused on relative landslide potential and land use. The two categories of relative landslide potential that pose the greatest concern are "high" and "very high." Lands with High Landslide Potential were identified based on the known occurrence of dormant earth flows, rockslides, disrupted ground and debris slide slopes on moderate to steep slopes (30–64%). There is the likelihood that land use changes in these areas could activate and or increase existing land sliding activity if appropriate precautions and/or mitigation measures are not considered and implemented. A risk assessment should be used before undertaking any land use alteration in these areas. Land with Very High Landslide Potential were identified based on the known occurrence of historically active earth flows, rockslides, debris flows and debris slides and the presence of debris slide slopes, inner gorges, and slopes greater than 65%. There is a strong likelihood that land use changes in these areas could increase or activate land sliding activity if appropriate precautions and/or mitigation measures are not considered and implemented.

The bulk of the woodland and grassland area of the basin is found in the high and very high relative landslide potential classes. This area of 16,706 acres is about 81% of the woodland and grassland acres or 9.2% of the entire Redwood Creek basin area. Looking at the subbasin level, the Estuary and Middle and Upper Redwood Creek subbasins have the greatest amounts of woodland and grassland area. On the Middle and Upper subbasins, 82.7% and 77.1% of this area has a high or very high relative landslide potential. Given that a high percentage of the woodland and grassland land type is found on areas of high and very high relative landslide potential, management activities on this land—primarily related to grazing—need to take caution to avoid activities that are likely to disturb the inherent instability.

Looking at THPs filed or completed during the 1991-2000 period, this land use also occurred predominantly on areas with a higher relative landslide potential. Of the 14,602 acres of THPs, 11,052 acres or 75.6% were conducted on areas of high or very high relative landslide potential. This area represents 6.1% of the Redwood Creek basin area. For comparison, we look at areas of timberland with no recent harvest. The bulk of this area, 101,320 of 156,327 acres, or 64.8%, is found on areas of high and very high relative landslide potential. This area represents 56.1% of the Redwood Creek basin area. Since a significant amount of this timberland area is found within the Redwood National and State Parks, is should be kept in mind that it is not all subject to timber harvest. As Figure III- 32 shows, the harvest that occurred in the basin between 1991 and 2000 all occurred in the Middle and Upper Redwood Creek subbasins.

In the Middle Subbasin, 83.2% of the timber harvest during 1991-2000 occurred on areas with high and very high relative landslide potential. On the Upper Subbasin, the percentage was lower at 56.8%. Looking at timberland with no recent harvest in these subbasins, the Middle Subbasin has 78.5% of its timberland with no recent harvest on areas of high and very high landslide potential. Upper Redwood subbasin has 71.9% of its timberland with no recent harvest on areas with high and relatively high landslide potential.

Since timber harvesting can cause disturbances that may contribute to slope instability, harvesting and associated management (such as road construction and maintenance) must be conducted with care on slopes with higher levels of relative landslide potential. Existing processes for the preparation and review of THPs include significant steps to examine and address mass wasting potentials. These processes often include the use of geologists by land managers preparing THPs, as well as the participation of CGS on THP review teams and during pre-harvest inspections.

Table III- 38. Relative landslide potential and land use or type classes, Redwood Creek basin and subbasins.

Unit of Analysis	**Relative Landslide Potential[1]**	**Entire Unit of Analysis**		**Woodland or Grassland[2]**		**THPs 1991-2000[3]**		**Timberland, No Recent Harvest[4]**		**Roads**	
		Area (acres)	**% of Area**	**Area (acres)**	**% of Area**	**Area (acres)**	**% of Area**	**Area (acres)**	**% of Area**	**Length (miles)**	**% of Total Length**
Redwood Creek basin (180,688 acres) (1,480 road miles)	Very Low	12,963	7.2%	2,001	1.1%	855	0.5%	9,315	5.2%	156	10.5%
	Low	14,298	7.9%	1,090	0.6%	1,243	0.7%	11,720	6.5%	155	10.4%
	Moderate	22,285	12.3%	765	0.4%	1,451	0.8%	19,816	11.0%	193	13.0%
	High	60,841	33.7%	6,223	3.4%	3,957	2.2%	50,219	27.8%	472	31.7%
	Very High	69,361	38.4%	10,483	5.8%	7,094	3.9%	51,101	28.3%	503	33.8%
	High/Very High Subtotal	130,202	72.1%	16,706	9.2%	11,052	6.1%	101,320	56.1%	975	65.5%
	TOTAL	**180,391**	**100%**	**20,579**	**11%**	**14,602**	**8%**	**156,327**	**87%**	**1,479**	**100%**
Estuary (3,433 acres) (15.9 road miles)	Very Low	1,457	42.4%	641	18.7%			223	6.5%	8.1	50.9%
	Low	67	2.0%	7	0.2%			57	1.7%	1.0	6.3%
	Moderate	216	6.3%	55	1.6%			136	4.0%	1.7	10.7%
	High	1,200	35.0%	76	2.2%			1,095	31.9%	4.0	25.2%
	Very High	486	14.2%	21	0.6%			451	13.1%	1.1	6.9%
	High/Very High Subtotal	1,686	49.1%	97	2.8%			1,546	45.0%	5	32.1%
	TOTAL	**3,426**	**100%**	**800**	**23%**	**0**	**0%**	**1,963**	**57%**	**16**	**100%**
Prairie Creek Subbasin (25,305 acres) (110.2 road miles)	Very Low	3,492	13.8%	360	1.4%			3,068	12.1%	28.6	26.6%
	Low	3,017	11.9%	3	0.0%			2,989	11.8%	14.5	13.5%
	Moderate	4,565	18.0%	8	0.0%			4,526	17.9%	19.2	17.8%
	High	9,480	37.5%	13	0.1%			9,424	37.2%	30.9	28.7%
	Very High	4,750	18.8%	4	0.0%			4,731	18.7%	14.4	13.4%
	High/Very High Subtotal	14,230	56.2%	17	0.1%			14,155	55.9%	45.3	42.1%
	TOTAL	**25,304**	**100%**	**405**	**2%**	**0**	**0%**	**24,738**	**98%**	**107.6**	**100%**
Lower Redwood Creek Subbasin (44,479 acres) (137.9 road miles)	Very Low	2,666	6.0%	92	0.2%			2,172	4.9%	17.7	12.8%
	Low	3,028	6.8%	96	0.2%			2,905	6.5%	14.0	10.2%
	Moderate	7,259	16.3%	96	0.2%			7,144	16.1%	30.6	22.2%
	High	17,431	39.2%	676	1.5%			16,734	37.6%	49.7	36.0%
	Very High	14,033	31.5%	25	0.1%			13,468	30.3%	26.0	18.9%
	High/Very High Subtotal	31,464	70.7%	701	1.6%			30,202	67.9%	75.7	54.9%
	TOTAL	**44,417**	**100%**	**985**	**2%**	**0**	**0%**	**42,423**	**95%**	**138.0**	**100%**
Middle Redwood Creek Subbasin (64,082 acres) (716.1 road miles)	Very Low	2,689	4.2%	375	0.6%	334	0.5%	1,840	2.9%	44.5	6.2%
	Low	3,868	6.0%	454	0.7%	571	0.9%	2,803	4.4%	57.4	8.0%
	Moderate	6,002	9.4%	209	0.3%	849	1.3%	4,851	7.6%	81.4	11.4%
	High	20,402	31.8%	3,040	4.7%	2,836	4.4%	14,409	22.5%	241.3	33.7%
	Very High	31,023	48.4%	5,133	8.0%	5,859	9.1%	20,192	31.5%	291.6	40.7%
	High/Very High Subtotal	51,425	80.2%	8,173	12.8%	8,695	13.6%	34,601	54.0%	532.9	74.4%
	TOTAL	**63,984**	**100%**	**9,211**	**14%**	**10,448**	**16%**	**44,095**	**69%**	**716.2**	**100%**
Upper Redwood Creek Subbasin (43,343 acres) (501.2 road miles)	Very Low	3,302	7.6%	533	1.2%	521	1.2%	2,012	4.6%	57.3	11.4%
	Low	4,318	10.0%	530	1.2%	672	1.6%	2,966	6.8%	67.8	13.5%
	Moderate	4,243	9.8%	397	0.9%	603	1.4%	3,159	7.3%	60.0	12.0%
	High	12,328	28.4%	2,418	5.6%	1,121	2.6%	8,557	19.7%	145.9	29.1%
	Very High	19,069	44.0%	5,300	12.2%	1,235	2.9%	12,259	28.3%	170.2	34.0%
	High/Very High Subtotal	31,397	72.4%	7,718	17.8%	2,357	5.4%	20,816	48.0%	316.1	63.1%
	TOTAL	**43,260**	**100%**	**9,178**	**21%**	**4,153**	**10%**	**28,953**	**67%**	**501.2**	**100%**

1 Refer to Plate 1 and California Geological Survey appendix.
2 Woodland and grassland category includes areas mapped in 1998 as grassland and non-productive hardwood.
3 THPs that were completed or active between the 1991 and 2000 timeframe.
4 Area of timberlands that were not contained in a THP during the 1991 to 2000 period, but may include pre-commercial thinning and includes parklands with timberland characteristics.

Table III- 39 provides another level of detail of the interrelationship between relative landslide potential and recent timber harvesting activities. This table shows the area and percent of total area by silvicultural and yarding systems. This classification is provided for the entire Redwood Creek basin and for the Middle and Upper subbasins. The Estuary, Prairie Creek, and Lower subbasins are not included since there was no timber harvest in these three subbasins during the subject period. Looking basin wide, Figure III- 33 shows that the largest categories of silvicultural system and yarding method were all three silviculture categories (category 1 includes clearcut, rehab, seed tree step, and shelterwood seed step prescriptions; category 2 silviculture includes shelterwood prep step, shelterwood removal step, and alternative prescriptions; category 3 silviculture includes selection, commercial thin, sanitation salvage, transition, and seed tree removal step prescriptions) and tractor yarding occurring on ground of high and very high relative landslide potential. Since category 1 silviculture and tractor yarding are the most disruptive of harvesting and yarding methods, and hence have the highest potential for erosion and sedimentation, these practices on areas of high and very high relative landslide potential can be of concern. Category 1 silviculture and tractor yarding occurred on 2,621 acres of high and very high landslide potential on the Redwood Creek basin during the 1991-2000 period. This area represents just 1.5% of the entire basin area, and given other protections and on-the-ground reviews applied in the THP process, does not likely represent a significant threat to the basin as a whole.

If we look at this same class (category 1 silviculture, tractor yarding, and high to very high relative landslide potential) at the subbasin level, this class represents 2,333 acres or 3.6% of the area on the middle subbasin and only 288 acres of 0.7% of the area on the upper basin. Clearly, this class of higher risk (erosion- and sediment-wise) activity is largely found on the middle subbasin, though it is still a relatively small percentage of the entire subbasin area.

Table III- 39 shows that cable and helicopter yarding are more likely to be used on areas of higher relative landslide potential than on areas of lower relative landslide potential. This may indicate, as one would expect, that land managers are choosing yarding methods with an eye to slope stability considerations.

Table III- 39. Relative landslide potential by silvicultural system and yarding method, 1991-2000 THPs.

	Relative Landslide Potential[1]	Silvicultural System and Yarding Methods for THPs 1991 - 2000[3]																								Total THPs 1991-2000	
		Category 1 Silviculture[2]								Category 2 Silviculture								Category 3 Silviculture									
		Tractor		Cable		Copter		Total		Tractor		Cable		Copter		Total		Tractor		Cable		Copter		Total			
		Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area	Area (ac.)	% of Area
Redwood Creek basin (180,688 acres)	Very Low	488	0.3%	9	0.0%	4	0.0%	501	0.3%	88	0.0%	0	0.0%	5	0.0%	93	0.1%	225	0.1%	9	0.0%	25	0.0%	259	0.1%	853	0.5%
	Low	714	0.4%	9	0.0%	11	0.0%	734	0.4%	117	0.1%	0	0.0%	2	0.0%	119	0.1%	384	0.2%	9	0.0%	1	0.0%	394	0.2%	1,247	0.7%
	Moderate	772	0.4%	37	0.0%	25	0.0%	834	0.5%	44	0.0%	0	0.0%	1	0.0%	45	0.0%	512	0.3%	44	0.0%	14	0.0%	570	0.3%	1,449	0.8%
	High	1,498	0.8%	259	0.1%	89	0.0%	1,846	1.0%	585	0.3%	9	0.0%	74	0.0%	668	0.4%	1,217	0.7%	110	0.1%	112	0.1%	1,439	0.8%	3,953	2.2%
	Very High	1,629	0.9%	656	0.4%	361	0.2%	2,646	1.5%	1,489	0.8%	44	0.0%	173	0.1%	1,706	0.9%	1,730	1.0%	425	0.2%	583	0.3%	2,738	1.5%	7,090	3.9%
	High/V. High Subtotal	2,621	1.5%	790	0.4%	450	0.2%	4,492	2.5%	2,074	1.1%	53	0.0%	247	0.1%	2,374	1.3%	2,379	1.3%	535	0.3%	695	0.4%	4,177	2.3%	11,043	6.1%
	TOTAL	5,194	2.9%	970	0.5%	490	0.3%	6,561	3.6%	2,323	1.3%	53	0.0%	255	0.1%	2,631	1.5%	4,068	2.3%	597	0.3%	735	0.4%	5,400	3.0%	14,592	8.1%
Middle Redwood Creek Subbasin (64,082 Acres)	Very Low	139	0.2%	8	0.0%	2	0.0%	149	0.2%	33	0.1%	0	0.0%	5	0.0%	38	0.1%	121	0.2%	6	0.0%	18	0.0%	145	0.2%	332	0.5%
	Low	268	0.4%	9	0.0%	0	0.0%	277	0.4%	75	0.1%	0	0.0%	2	0.0%	77	0.1%	212	0.3%	8	0.0%	0	0.0%	220	0.3%	574	0.9%
	Moderate	392	0.6%	30	0.0%	6	0.0%	428	0.7%	37	0.1%	0	0.0%	1	0.0%	38	0.1%	330	0.5%	40	0.1%	12	0.0%	382	0.6%	848	1.3%
	High	945	1.5%	198	0.3%	5	0.0%	1,148	1.8%	449	0.7%	9	0.0%	69	0.1%	527	0.8%	945	1.5%	107	0.2%	107	0.2%	1,159	1.8%	2,834	4.4%
	Very High	1,388	2.2%	523	0.8%	98	0.2%	2,009	3.1%	1,162	1.8%	44	0.1%	153	0.2%	1,359	2.1%	1,517	2.4%	420	0.7%	551	0.9%	2,488	3.9%	5,856	9.1%
	High/V. High Subtotal	2,333	3.6%	596	0.9%	103	0.2%	3,157	4.9%	1,611	2.5%	53	0.1%	222	0.3%	1,886	2.9%	1,894	3.0%	527	0.8%	658	1.0%	3,647	5.7%	8,690	13.6%
	TOTAL	3,132	4.9%	768	1.2%	111	0.2%	4,011	6.3%	1,756	2.7%	53	0.1%	230	0.4%	2,039	3.2%	3,125	4.9%	581	0.9%	688	1.1%	4,394	6.9%	10,444	16.3%
Upper Redwood Creek Subbasin (43,343 acres)	Very Low	349	0.8%	1	0.0%	2	0.0%	352	0.8%	55	0.1%	0	0.0%	0	0.0%	55	0.1%	104	0.2%	3	0.0%	7	0.0%	114	0.3%	521	1.2%
	Low	446	1.0%	0	0.0%	11	0.0%	457	1.1%	42	0.1%	0	0.0%	0	0.0%	42	0.1%	172	0.4%	1	0.0%	1	0.0%	174	0.4%	673	1.6%
	Moderate	380	0.9%	7	0.0%	19	0.0%	406	0.9%	7	0.0%	0	0.0%	0	0.0%	7	0.0%	182	0.4%	4	0.0%	2	0.0%	188	0.4%	601	1.4%
	High	553	1.3%	61	0.1%	84	0.2%	698	1.6%	136	0.3%	0	0.0%	5	0.0%	141	0.3%	272	0.6%	3	0.0%	5	0.0%	280	0.6%	1,119	2.6%
	Very High	241	0.6%	133	0.3%	263	0.6%	637	1.5%	327	0.8%	0	0.0%	20	0.0%	347	0.8%	213	0.5%	5	0.0%	32	0.1%	250	0.6%	1,234	2.8%
	High/V. High Subtotal	288	0.7%	194	0.4%	347	0.8%	1,335	3.1%	463	1.1%	0	0.0%	25	0.1%	488	1.1%	485	1.1%	8	0.0%	37	0.1%	530	1.2%	2,353	5.4%
	TOTAL	2,062	4.8%	202	0.5%	379	0.9%	2,550	5.9%	567	1.3%	0	0.0%	25	0.1%	592	1.4%	943	2.2%	16	0.0%	47	0.1%	1,006	2.3%	4,148	9.6%

Note that the estuary, Prairie Creek, and Lower subbasins are not included as there was no timber harvesting in these subbasins during the subject period. Column for % of area refers to the respective unit of analysis, basin or subbasin.

[1] Refer to Plate 2 and California Geological Survey appendix for relative landslide potential map and description.

[2] Category 1 silviculture includes clearcut, rehab, seed tree step, and shelterwood seed step prescriptions; Category 2 silviculture includes shelterwood prep step, shelterwood removal step, and alternative prescriptions; Category 3 silviculture includes selection, commercial thin, sanitation salvage, transition, and seed tree removal step prescriptions.

[3] THPs are complete or active between the 1991 and 2000 timeframe

EMDS Potential Sediment Production Model

The EMDS potential sediment production model provides a synthesis and cumulative effects assessment tool for the study of Redwood Creek. This model synthesizes information on land use, roads, relative landslide potential, and other factors to evaluate potentials for sediment input to streams. Since the EMDS sediment production potential model uses an empirical approach it provides a relative ranking of sediment production potential for the subbasins and planning watersheds in the Redwood Creek basin, rather than an absolute measure.

Tables III-40 to III-45 provide the results of the EMDS potential sediment production model for each of the Redwood Creek Subbasins. Evaluations at the planning watershed level are provided in the respective subbasin sections of the Analysis and Results section of this report. The model does provide an overall evaluation of the Redwood Creek basin because the model is based on relative rankings of each planning watershed. If all the relative rankings of the planning watersheds were aggregated to the level of the entire basin, the results would be the mean and, hence, not meaningful. EMDS potential sediment production potential rankings at the subbasin level are the area-weighted average of the planning watersheds that comprise the subbasin. As noted above, the EMDS models are continuing to undergo improvements. Due to limitations in the current sediment production model, we recommend its use only as an indicative model, in that it indicates the quality of basin or instream conditions based on available data and the model structure. It is not intended to provide highly definitive answers, such a statistically-based process model might offer. It does provide a reasonable first approximation of conditions through a robust information synthesis approach; however its outputs need to be considered and interpreted in the light of other information sources and the inherent limitations of the model and its data inputs.

Table III- 40 looks at the three highest levels of the EMDS sediment production, all sediment sources combined, and the latter's components, sediment from natural processes and form management-related sources. For all of the factors, the three lower subbasins (Estuary, Prairie Creek, and Lower Creek) generally have more suitable conditions than the Middle and Upper subbasins. This relationship holds for both natural sediment sources and management related sources. This pattern agrees with information presented earlier: the Middle and Upper subbasins have more geologically unstable ground and greater amounts of roads and timber harvest than the lower three subbasins.

Table III- 40. EMDS ratings for potential stream sediment production; top three levels of model.

Subbasin	All Sources	Natural Processes				Management-Related Sources			
		All	Surface Erosion	Streamside Erosion	Mass Wasting	All	Surface Erosion	Streamside Erosion	Mass Wasting
Estuary Subbasin	++	++	U	++	++	++	++	++	++
Prairie Creek Subbasin	++	++	U	++	++	+	+	+	+
Lower Redwood Subbasin	+	+	U	+	+	+	-	++	+
Middle Redwood Subbasin	-	-	U	+	-	-	-	-	-
Upper Redwood Subbasin	-	-	U	+	-	-	-	-	-

The "+++" score represents the most suitable conditions on a relative scale; the "---" score represents the least suitable conditions. A 'U' represents data that lie in between suitable and unsuitable conditions, or there is a lack of data to categorize.

Table III- 41 looks deeper into the EMDS potential sediment model to management related surface erosion. The pattern of lower sediment production potentials lower in the basin continues to hold at this level of the model. One notable difference is that the Prairie Creek and Lower subbasins both appear relatively less suitable for salmonids and that the Middle Subbasin appears somewhat more suitable. Since the Prairie Creek and Lower subbasins have not had any notable amount of timber harvest since at least the late 1970s, the EMDS model appears to be carrying forward the legacy of potential harvesting impacts in these subbasins.

Table III- 41. Potential stream sediment production from management-related surface erosion sources.

Subbasin	All Mgmt.-Related Surface Sources	Road Related		
		All Road Related	Density of Roads by Hillslope Position	Density of Roads Proximate to Streams
Estuary Subbasin	++	+	++	+++
Prairie Creek Subbasin	+	+	++	+
Lower Redwood Subbasin	-	+	++	++
Middle Redwood Subbasin	-	-	--	-
Upper Redwood Subbasin	-	-	--	--

Table III- 42 looks at management related streamside sources of potential sediment. Roads (density of roads near streams and density of road crossings) are the only factor looked at in this portion of the current version of the EMDS model. Again, we see the Middle and Upper subbasins as having relatively lower suitability of sediment production potential as compared to the lower three subbasins. Again, this reflects the relatively higher levels of roads currently found in the Middle and Upper subbasins.

Table III- 42. Potential stream sediment production from management-related streamside erosion sources.

Subbasin	All Management-Related Streamside Sources	Road Related	
		Density of Roads near Streams	Density of Road Crossings
Estuary Subbasin	++	+++	++
Prairie Creek Subbasin	+	+	+
Lower Redwood Subbasin	++	++	++
Middle Redwood Subbasin	-	-	-
Upper Redwood Subbasin	-	--	--

The EMDS potential stream sediment production model is based on the data distribution of factors at the planning watershed level, hence it is a relative measure of conditions. The sediment production potential rating is assigned with respect to suitability for anadromous salmonid production. The "+++" score represents the most suitable conditions on a relative scale; the "---" score represents the least suitable conditions.

Table III- 43, the final table in the EMDS sediment potential model series, looks at potential sediment production from management related mass wasting sources. The results are very similar to those reported in Table III- 41, which looked at surface sources rather than mass wasting. One notable difference is the relatively low suitability of the density of roads on unstable slopes in the estuary subbasin.

Table III- 43. Potential stream sediment production from road-related mass wasting sources.

Subbasin	Road Related			
	All Road Related	Density of Roads Crossings	Density of Roads by Hillslope Position	Density of Roads on Unstable Slopes
Estuary Subbasin	+	++	++	--
Prairie Creek Subbasin	++	+	++	++
Lower Redwood Subbasin	++	++	++	++
Middle Redwood Subbasin	-	-	--	--
Upper Redwood Subbasin	-	--	--	-

Table III- 44 presents a large summary of a wide range of information at the Redwood Creek basin and subbasin levels. It provides the reader the opportunity to compare a large number of factors across the basin and subbasins and, for some of the subbasins, to look at potential interactions between potential disturbance factors and instream fish habitat.

Table III- 44. Integrated information for the Redwood Creek basin and subbasins.

Factor	Redwood Creek Basin		Estuary Subbasin		Prairie Creek Subbasin		Lower RC Subbasin		Middle RC Subbasin		Upper RC Subbasin	
Relative Landslide Potential[1]	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Very Low	12,963	7.2%	1,448	42.2%	3,475	13.7%	2,653	6.0%	2,521	3.9%	2,866	6.6%
Low	12,282	6.8%	64	1.9%	2,868	11.3%	2,809	6.3%	3,192	5.0%	3,350	7.7%
Moderate	19,931	11.0%	115	3.4%	4,268	16.9%	6,523	14.7%	5,356	8.4%	3,670	8.5%
High	66,112	36.6%	1,318	38.4%	9,985	39.5%	18,442	41.5%	22,005	34.3%	14,363	33.1%
Very High	69,094	38.2%	481	14.0%	4,710	18.6%	13,982	31.4%	30,913	48.2%	19,008	43.9%
High/Very High Subtotal	135,144	74.8%	1,736	50.6%	14,695	58.1%	32,424	72.9%	52,918	82.6%	33,370	77.0%
Total All Categories	**180,383**	**100%**	**3,426**	**100%**	**25,305**	**100%**	**44,409**	**100%**	**63,987**	**100%**	**43,256**	**100%**
Landslide and Selected Geomorphic Features												
Historically Active Landslide Features Total	10,070	5.6%	2		348	1.4%	2,662	6.0%	4,166	6.5%	2,892	6.7%
Earthflow	169	0.1%	1	0.0%	13	0.1%	78	0.2%	68	0.1%	9	0.0%
Rock Slide	591	0.3%	0	0.0%	25	0.1%	82	0.2%	257	0.4%	227	0.5%
Debris Slide	7,602	4.2%	0	0.0%	161	0.6%	1,762	4.0%	3,187	5.0%	2,492	5.8%
Debris Flow	1,708	0.9%	1	0%	148	0.6%	740	1.7%	654	1.0%	165	0.4%
Dormant Landslide Features Total	38,837	21.5%	700	20%	2,022	8%	5,263	11.8%	15,150	23.7%	15,702	36.3%
Selected Geomorphic Features Total	31,215	17.3%	617	18%	2,493	10%	5,540	12.5%	13,495	21.1%	9,070	21.0%
Disrupted Ground	18,782	10.4%	277	8%	355	1%	2,831	6.4%	10,099	15.8%	5,219	12.1%
Debris Slide Slope	10,599	5.9%	337	10%	2,067	8%	2,472	5.6%	2,943	4.6%	2,780	6.4%
Inner Gorge (area)2	1,834	1.0%	3	0%	71	0%	236	0.5%	453	0.7%	1,071	2.5%
Total All Categories	**80,122**	**44.4%**	**1320**	**39%**	**4,863**	**19%**	**13,465**	**30.3%**	**32,811**	**51.3%**	**27,664**	**63.9%**
Timber Harvest by Silviculture Method[3] 1990 -20003												
Category 1												
Tractor	5,381	3.0%	0	0.0%	0	0.0%	0	0.0%	3,375	5.3%	2,006	4.6%
Cable	1,123	0.6%	0	0.0%	0	0.0%	0	0.0%	896	1.4%	227	0.5%
Helicopter	492	0.3%	0	0.0%	0	0.0%	0	0.0%	112	0.2%	380	0.9%
Total	6,996	3.9%	0	0.0%	0	0%	0	0%	4,383	6.9%	2,613	6.0%
Silviculture Category 2												
Tractor	2,342	1.3%	0	0.0%	0	0.0%	0	0.0%	1,761	2.8%	582	1.3%
Helicopter	79	0.0%	0	0.0%	0	0.0%	0	0.0%	79	0.1%	0	0.0%
Cable	228	0.1%	0	0.0%	0	0.0%	0	0.0%	203	0.3%	24	0.1%
Total	2,649	1.5%	0	0.0%	0	0%	0	0%	2,043	3.2%	606	1.4%
Silviculture Category 3												
Tractor	4,078	2.3%	0	0.0%	0	0.0%	0	0.0%	3,129	4.9%	949	2.2%
Helicopter	598	0.3%	0	0.0%	0	0.0%	0	0.0%	582	0.9%	17	0.0%
Cable	736	0.4%	0	0.0%	0	0.0%	0	0.0%	689	1.1%	47	0.1%
Total	5,413	3.0%	0	0.0%	0	0%	0	0%	4,400	6.9%	1,013	2.3%
Total Harvest	**15,058**	**8.3%**	**0**	**0.0%**	**0**	**0%**	**0**	**0%**	**10,826**	**16.9%**	**4,232**	**9.8%**
Other Land Uses												
Grazing	2,659	1.5%	113	3.3%	230	0.9%	29	0.1%	1,301	2.0%	986	2.3%
Agriculture	1,418	0.8%	1	0.0%	1,393	5.5%	0	0.0%	24	0.0%	0	0.0%
Development	1,436	0.8%	0	0.0%	1,421	5.6%	4	0.0%	11	0.0%	0	0.0%
Timberland, No Recent Harvest	136,388	75.6%	1,963	57.3%	23,345	92.3%	38,032	85.6%	44,095	68.9%	28,953	66.9%
Total	**139,114**	**77.1%**	**2,077**	**60.6%**	**23,603**	**93%**	**38,065**	**85.7%**	**45,430**	**71.0%**	**29,939**	**69.2%**
Roads												
Road Density (miles/sq. mile)	5.3		3.0		2.7		2.0		7.2		7.4	
Density of Road Crossings (#/stream mile)	0.3		0.2		0.6		0.1		1.1		1.2	
Roads within 200' of Stream (miles/stream mile)	0.2		0.1		0.2		0.1		0.2		0.3	
Streams												
% Stream by Gradient	**% Stream Length**		**% Stream Length**		**% Stream Length**		**% Stream Length**		**% Stream Length**		**% Stream Length**	
< 1% (Response Reach)	13.7%		77.4%		14.7%		17.8%		11.6%		7.0%	
1-4% (Response Reach)	11.6%		6.8%		25.5%		10.4%		5.1%		9.8%	
4-20% (Transport Reach)	35.7%		11.6%		43.8%		31.7%		31.1%		43.7%	
>20% (Source Reach)	38.9%		4.3%		16.0%		40.1%		52.3%		39.5%	
Historically Active and Dormant Landslide and Selected Geomorphic Features[4]	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**
Within 180' of Blue Line Stream	5.3%	29.3%	1.2%	2.5%	2.6%	8.0%	4.2%	16.1%	6.4%	20.5%	6.8%	70.2%

[1] Refer to California Geological Survey appendix for landslide map (Plate 1), relative landslide potential map (Plate 2) and description

[2] Area based on inner gorges captured as polygons plus inner gorges captured as linear features, which are treated as having an average width of 100 feet.

[3] Category 1 includes clearcut, rehab, seed tree step, and shelterwood seed step prescriptions; Category 2 includes shelterwood prep step, shelterwood removal step, and alternative prescriptions; Category 3 includes selection, commercial thin, sanitation salvage, transition, and seed tree removal step prescriptions.

[4] Landslide features and selected geomorphic features include earth flow, rockslide, debris slide, debris flow, debris slide slopes, disrupted ground, eroding banks, inner gorges.

Limiting Factors Analysis and Stream Reach EMDS

Salmonid production may be limited by a single factor or combination of factors. Factors that contribute to limiting salmonid production include warm water temperature, lack of deep pool habitat, lack of instream shelter complexity, lack of high quality spawning habitat, lack of instream LWD, embedded spawning substrate, lack of shade canopy, and the modified condition of the estuary. Water temperature, estuarine condition, instream LWD, LWD loading potential and excessive in-channel sedimentation are not included in the EMDS evaluation. However, because these are highly significant habitat factors, they are included in this discussion of limiting factors.

Warm water temperature in mainstem Redwood Creek limits salmonid production in most of the Upper Subbasin and all of the Middle and Lower subbasins. Ambient surface water temperature measured by MWATs along Redwood Creek were above 68°F from the O'Kane gauging station near the Highway 299 Bridge to the confluence with Tom McDonald Creek. However, localized patches of cool water refuge do exist near confluences with cool water tributaries, cool water seeps, and deep, temperature stratified pools. The lower reaches of tributaries in the Middle Subbasin also showed MWATs of above desirable levels.

Instream LWD is low in abundance in Redwood Creek streams in the Estuary, Lower, Middle and Upper subbasins according to stream habitat surveys. Where LWD was found, it was often clumped into debris jams rather than dispersed randomly through stream channels. LWD provides much of the shelter complexity in forested streams, is a major pool-forming element, facilitates sediment transport, and contributes to nutrient storage and production. Large conifers (>3 feet DBH) are often needed for channel maintenance in most tributary streams and even larger pieces are needed in the mainstem Redwood Creek. Since the average size of 70% of conifers in the near stream forests is 24 inches or less in the Middle and Upper subbasins and portions of the Lower Subbasin, LWD loading will be impaired until trees are allowed to grow and are delivered to stream channels. Thus beneficial fluvial process are limited by the low amount of LWD presently in stream channels and LWD loading potential will be impaired for some time to come.

Excessive accumulations of sediments have moved stream habitats far from the desired conditions. Adverse impacts associated with excessive sediments inputs to stream channels include, stream bank erosion, widened stream channels, filling of pools, loss of channel diversity and complexity, loss of stream connectivity, loss of shade canopy, elevated water temperature, increase of fine sediments in spawning gravels and a rise in ground water elevation. Some of these factors directly limit salmonid production while others affect basin processes that cumulatively effect stream habitat condition.

Summary results from the stream reach EMDS evaluations are shown by subbasin in Table III- 45. Habitat factors that have negative scores evaluated to the unsuitable range and are considered as potential limiting factors to salmonids production. Alternatively, factors that receive positive scores by EMDS are considered to favor salmonid production.

Evaluations of the amount deep pool habitat generally received negative EMDS scores at most sample sites and survey reaches throughout the Redwood Creek basin (Table III- 45). Therefore the lack of deep pool habitat should be considered a limiting factor to salmonid production. A closer review found that at times the number of pools per reach was within a normal range of variation measured by a ratio of pool frequency to bank full widths. These pools were cumulatively short in length. While other reaches were deficient in the frequency and length of deep pools. Deep pools are important for year-round habitat for juvenile salmonids as well as important for adult salmonid holding areas during spawning migrations**.** Deep pools provide isolation from predators and provide areas to escape from high winter flows. Deep pools may provide the majority of useable aquatic habitat in tributaries during low summer flows or droughts. Deep pool habitat in the mainstem Redwood Creek and lower reaches of some tributaries is especially critical to the over summer survival of summer steelhead.

Table III- 45. Results from EMDS Stream Reach Condition subbasin analysis.

Subbasin	Total survey Length (feet)	Canopy Density	Pool Quality	Pool Depth	Pool Shelter	Embeddedness
Prairie Creek Subbasin						
9 sample sites and Godwood survey	5,495	+++	-	--	+	+
Lower Redwood Subbasin						
3 tributary sample sites	2,483	++	--	--	-	--
6 Redwood Creek sample sites	10,066	--	--	---	--	+
Middle Redwood Subbasin						
16 tributary surveys	103,194	++	--	--	--	+
Redwood Creek survey	130,520	--	--	-	---	-
Upper Redwood Subbasin						
2 tributary surveys	7,031	++	--	---	--	+
Redwood Creek survey	13,996	-	--	---	--	-

+++ Fully Suitable ++ Moderately Suitable + Somewhat Suitable
--- Fully Unsuitable -- Moderately Unsuitable - Somewhat Unsuitable

Pool shelter complexity was also identified as a potential limiting habitat factor in all subbasins except for the Prairie Creek Subbasin. Pool shelter complexity is a relative measure of the quantity and percent composition of LWD, root wads, boulders, undercut banks, bubble curtain, and submersed or overhanging vegetation in pool habitats. Pool shelter complexity elements are needed to provide escape cover from predators such as birds and otters. These shelter elements also serve as instream habitat, create areas of diverse velocity, needed as shelter from high winter flows, and provides separation of territorial units to reduce density related competition.

Streamside canopy density evaluated as unsuitable to provide sufficient shade along the entire mainstem Redwood Creek. However, shade canopy was generally suitable along tributary streams. In addition to shade, tree canopy provides nutrients in the form of terrestrial insects, organic debris, and leaf litter, and contributes to LWD recruitment. The roots of riparian vegetation also contribute maintaining soil and stream bank stability.

Spawning cobble embeddedness was the most variable habitat factor throughout the basin and received negative evaluations in Lower Subbasin tributaries and from Middle and Upper subbasin mainstem reaches. Percent cobble embeddedness estimates substrate suitability for spawning, egg incubation, and fry emergence. High embeddedness ratings also may indicate elevated levels of erosion occurring in the basin.

An additional factor affecting salmonid production is the large reduction in area and habitat quality of the estuary/lagoon. Flood control modifications, levees, sediment accumulations and conversion of wetlands and riparian areas to pasture are all part of a large decline of estuarine habitat utility for salmonids. The present condition of the estuary/lagoon is considered a major limiting factor to the production of anadromous salmonids of the basin.

In-Stream and Riparian Zone Recommendations for each of the Redwood Creek Subbasins

The following recommendations were derived from the analysis and interpretation of data generated from randomly selected sample sites in the Prairie Creek and Lower subbasins, stream inventory surveys conducted in the Prairie Creek, Middle and Upper subbasins, and reviews of biologic studies and physical conditions of the Redwood Creek Basin. It is important to note that stream surveys and sample sites were limited to anadromous salmonid bearing stream reaches and therefore do not include observations of influential factors located further upstream such as roads, riparian canopy and eroding stream banks

Stream habitat improvements often need to be prioritized to obtain efficient results. Various project treatments can be made concurrently if basin and stream conditions warrant. In some cases, improvements in basin conditions may be needed before successful instream treatment, or riparian restoration activities. The most frequently listed recommendation category among the subbasins is to improve instream habitat factors followed by erosion/sediment and riparian/temperature treatments (Table III- 46 and Table III- 47).

Fish passage problems, especially in situations where favorable stream habitat reaches are separated by a man-caused feature (e.g., culvert), are usually a treatment priority. In general, implementation projects that involve erosion and sediment reduction by treating roads and failing stream banks precede the instream recommendations for pool development and spawning gravel projects. Insuring suitable stream temperature regimes are present should also precede instream projects, although water temperature improvement may result from developing shade to help maintain cool water temperature, promoting near stream conifer growth, pool development, and by facilitating the exchange between intragravel and surface flows. Various project treatment recommendations can be made concurrently if basin and stream conditions warrant. Because overall stream habitat condition is a product of the interaction of several habitat elements and fluvial processes, a balance of basin features is needed for maintaining desirable channel characteristics. Stream habitat improvement projects should aim to restore this balance.

It is also important to note that without management strategies that promote restoring integrity to watershed ecosystem process by addressing root causes of problems, instream improvement projects will likely be short-lived patches on the environment. The design of management strategies must take a basin-wide perspective. Therefore it also may be necessary to provide additional protection beyond the minimum requirements of current basin management practices to help reestablish desirable functions of riparian and aquatic ecosystems. To maintain and increase the fish populations of the Redwood Creek depends in part on identifying limiting factors, and linking them to watershed processes and the management activities that act on those processes. Management activities that address the links or root causes between land use and adverse habitat condition should receive high priority for implementation.

Additional considerations must enter into the decision process before these general recommendations are developed into improvement activities. In addition to basin condition considerations as a context for these recommendations, there are certain logistic considerations that enter into a recommendation's subsequent ranking for project development. These can include work party access limitations based upon lack of private party access permission and/or physically difficult or impossible locations of the candidate work sites. Biological considerations are made based upon the potential for benefits to single or multiple fishery stocks. Cost benefit and project feasibility are also factors in project selection for design and development. Recommendations that may be applied bas in wide are provided below. Recommendations specific to subbasins are found in Part IV of this report.

Table III- 46. Prioritization of steps to address limiting factors.

Subbasin	Survey Length (feet)	Temp	Pool	Cover	Bank	Roads	Canopy	Spawning Gravel	LDA	Livestock	Access
Prairie Creek Subbasin Sample Sites (N=9)	5,495		1	1		1		1			
Lower Subbasin Tributary Sample Sites (N=3)	2,843		1	1	1			1			
Lower Subbasin Redwood Creek Sampling Sites (N=6)	10,066	1	1				1				
Middle Subbasin Tributaries (N= 15)	102,342	3	14	15	6	1	2	4	1		2
Middle Subbasin Mainstem Redwood Creek (N= 1)	122,095	1	1	1							
Upper Subbasin Tributaries (N = 2)	7,031		2	2	2						
Upper Subbasin Mainstem Redwood Creek (N = 2)	22,421	1	1		1						

Tributaries and sections of mainstem Redwood Creek were assigned prioritized treatment recommendations for addressing limiting factors. The total number of treatments ranked 1,2, or 3 for each tributary or mainstem reach of the Middle and Upper subbasins is shown. The recommendations for sample sites located in the Prairie Creek and Lower Redwood Creek subbasins were determined only at the subbasin scale.

Key to fields: Temp = summer water temperatures seem to be above optimum for salmon and steelhead; Pool = pools are below target values in quantity and/or quality; Cover = escape cover is below target values; Bank = streambanks are failing and yielding fine sediment into the stream; Roads = fine sediment is entering the stream from the road system; Canopy = shade canopy is below target values; Spawning Gravel = spawning gravel is deficient in quality and/or quantity; LDA = log debris accumulations are retaining large amounts of gravel and could need modification; Livestock = there is evidence that stock is impacting the stream or riparian area and exclusion should be considered; Access = there are human made barriers to fish migration in the stream.

Table III- 47. Top three ranking recommendation categories by number of tributaries and mainstem reaches in the Redwood Creek basin.

Basin Target Issue	Related Table Categories	Count
Erosion/Sediment	Bank/Roads	11
Riparian/Water Temperature	Canopy/Temperature	9
Instr3eam habitat	Pool/Cover	41
Gravel/Substrate	Spawning Gravel/LDA	7
Other	Livestock/Barrier	2

CDFG general habitat improvement strategies to treat stream habitat/fishery limiting factors are provided below. Specific treatment and priority strategies are presented in Flosi et al., 1998.

Bank Erosion:

- Inventory and map sources of stream bank erosion and prioritize them according to present and potential sediment yield. Identified sites should then be treated to reduce the amount of fine sediments entering the stream.

Roads:

- Active and potential sediment sources related to the road system need to be identified, mapped, and treated according to their potential for sediment yield to the stream and its tributaries.

Access:

- Fish passage should be monitored and improved where possible.

Pools:

- Design and engineer pool enhancement structures to increase the number of pools or deepen existing pools, where the banks are stable or in conjunction with stream bank armor or road improvements to control excessive erosion.

Cover:

- Increase woody cover in the pool and flatwater habitat units, with complex, woody cover, especially where the material is locally available.

Spawning Gravel:

- Projects should be designed at suitable sites to trap and sort spawning gravel in order to expand redd site distribution in the stream. Reduce excessive erosion and delivery of fine sediments by improving bank stability and treating road related or upslope sediment sources.

Canopy:

- Increase canopy by planting willow, alder, or native conifers along the surveyed stream banks where shade canopy is not at acceptable levels, or in reaches above the survey section when temperature impacts have originated upstream. Planting must be coordinated with bank stabilization and/or upslope erosion control projects.

LDA:

- Modification of log debris accumulations is desirable, but must be done carefully, over time, to avoid excessive sediment loading in downstream reaches, and to preserve the larger beneficial scouring elements.

Livestock:

- Exclusion of livestock from the riparian corridor except at controlled access points should be explored and developed if possible.

Temperature:

- High water temperature may be an example of cumulative habitat problems due to poor basin conditions. Where summer water temperatures are above the acceptable range for salmonids increasing the near stream forest canopy is desirable as is maintaining connectivity between cool sub-surface and surface stream flows.

Salmonid Refugia Identification and Classification

The results from this assessment indicate that patches of important salmonid refugia areas exist within each of the Redwood Creek subbasins (Table III- 48 and Figure III- 40). The Prairie Creek Subbasin received the only designation of high quality refugia streams in the Redwood Creek basin. The presence of four anadromous salmonid species, the relatively good habitat condition, and protection provided by the RNSP in Prairie Creek were key factors that the refugia team considered in the refugia designation process. The streams located in the undisturbed portion of the Prairie Creek Subbasin provide some of the best salmonid habitat in the Redwood Creek basin due to the combination of beneficial riparian vegetation, cool water temperature, desirable pool characteristics, instream shelter, and good spawning habitat. However, there are also sites in the Prairie Creek Subbasin that are lacking in one or more important habitat components. High potential refugia was assigned to streams that provide multi species habitat, required only minor improvements to achieve the high quality status, and were relatively free from risk of degradation from land use projects. Most high potential refugia were located in the Lower Subbasin. The majority of streams in the Middle and Upper subbasins were considered potential refugia because they supported anadromous salmonids but, needed management efforts to increase habitat condition and were at potential risk from future land use. Data limitations made it impossible to rate all streams for refugia.

The best refugia areas are large and meet all of these life history needs and therefore provide complete functionality to salmonid populations (for example: Prairie Creek Subbasin). These large, intact systems are scarce today and smaller refugia areas that provide for only some of the requirements have become very important areas, but cannot sustain large numbers of fish. These must operate in concert with other fragmented habitat areas for life history support and connectivity becomes very important for success.

Table III- 48. Refugia designations for streams of the Redwood Creek basin.

Subbasin	High Quality Refugia	High Potential Refugia	Potential Refugia	Low Quality Habitat	Critical Contributing Areas	Passage Barrier Limited	Other
Estuary			Redwood Creek Strawberry Creek				Redwood Creek Dorrance Creek Sand Cache Creek
Prairie Creek	Prairie Creek Lost Man Creek Little Lost Man Creek Streelow Creek Godwood Creek	Brown Creek	May Creek Boyes Creek				Skunk Cabbage Creek
Lower Redwood Creek		Bridge Creek Emerald Creek (Harry Wier) Tom McDonald Creek Copper Creek Bond Creek Coyote Creek	Mc Arthur Creek Elam Creek Forty Four Creek Redwood Creek		Devils Creek Forty Four Creek Hayes Creek Slide Creek Bond Creek		Miller Creek Dolason Creek
Middle Redwood Creek		Dolly Varden Creek (Karen)	Lacks Creek Minor Creek Panther Creek Wiregrass Creek Beaver Creek Molasses Creek Mill Creek Captain Creek Sweathouse Creek Lupton Creek	Toss Up Creek Pilchuck Creek	Dolly Varden Creek (Karen)	Beaver Creek	Garcia Creek Cashmere Creek Lion Creek
Upper Redwood Creek		Simion Creek	Redwood Creek Minon Creek Fern Prairie Creek Lake Prairie Creek			Lake Prairie Creek	High Prairie Creek Noisy Creek

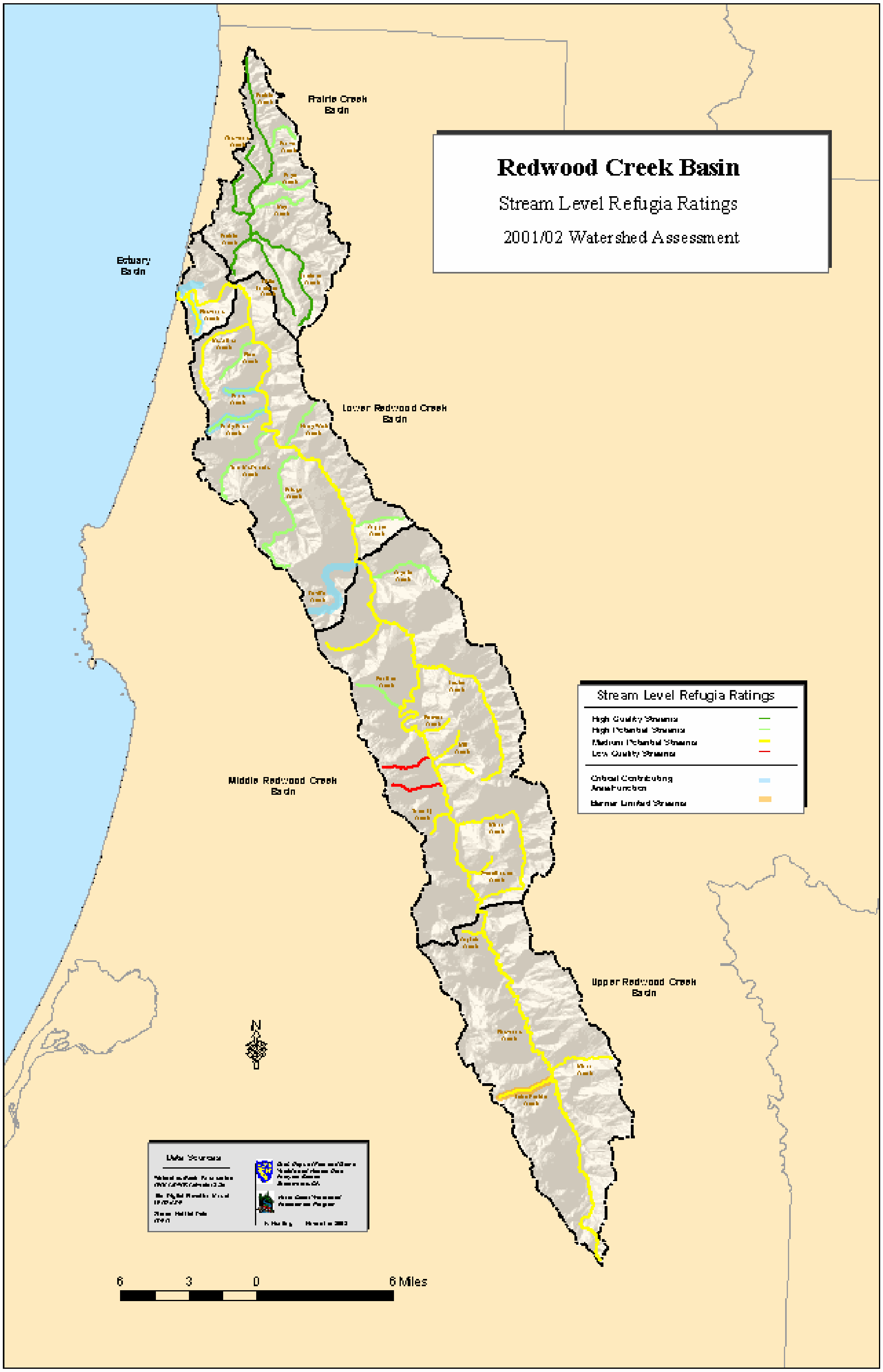

Figure III- 40. Refugia designations for select streams of the Redwood Creek basin.

Basin Scale Responses to Assessment Questions

The following discussion of the assessment questions and recommendations for improvement activities are generalized to the basin scale. Please refer to assessment questions in Section IV of this report for specific subbasin and tributary scale information.

What are the history and trends of the sizes, distribution, and relative health and diversity of salmonid populations in the Redwood Creek basin?

- The Redwood Creek basin supports populations of Chinook and coho salmon, and steelhead and sea run coastal cutthroat trout; Salmonid populations have declined from historic levels, prompting listings under the state and federal ESA;
- Past populations of Chinook and coho salmon, steelhead and coastal cutthroat trout were noted as abundant and widely dispersed throughout the Redwood Creek basin;
- Present populations of anadromous salmonids are overall less abundant and less widely distributed compared to their historic presence in the Redwood Creek basin. It appears that populations declined abruptly during the years following the December 1964 flood;
- Summer steelhead, coho, Chinook salmon and coastal cutthroats have likely suffered widespread declines due to their sensitivity to degradation of specific habitat factors necessary to complete the freshwater and /or estuarine phase of their life cycle;
- Coho were once noted as present or abundant in Middle Subbasin tributary streams. Surveys conducted in 2001and 2002 failed to detect coho presence in any Middle Subbasin streams indicating a decline in coho distribution and abundance within the Redwood Creek basin;
- Because winter steelhead tolerate a wider range of habitat conditions than the other anadromous species, they are more widely distributed in the basin and have persisted in streams where other species have declined or are now rarely observed;
- Summer steelhead may be the most prone to extirpation of all the anadromous salmonid species of the Redwood Creek basin;
- The for capacity for salmonids to increase in abundance and distribution is in part limited by the reproductive potential of existing stocks;
- Given improving aquatic habitat conditions, it will take several generations before salmonid populations rebound to viable levels;
- Not enough population information is available to determine if the long-term declining stocks trend still predominates over the basin.

What are the current salmonid habitat conditions in the Redwood Creek basin? How do these conditions compare to desired conditions?

- There are approximately 60 miles of tributary streams and 65 miles of Redwood Creek mainstem accessible to anadromous salmonids. Approximately one third of the available tributary habitat (22.5 miles) is located in the Prairie Creek Subbasin;
- Patches of good quality salmonid habitat exist within each of the Redwood Creek subbasins;
- Stream conditions over much of the Redwood Creek basin are below desirable standards for salmonid habitat. Cumulative land use and watershed effects have contributed to high stream temperatures and a general lack of stream habitat diversity;
- The impairment of the physical, chemical, and biologic processes of the estuarine ecosystem has reduced the ability of the estuary/lagoon to support juvenile salmonids;
- Presently, high summer water temperatures in the majority of the length of mainstem Redwood Creek is deleterious to summer-rearing juvenile salmonids and adult summer steelhead;

- Salmonids have been observed in Redwood Creek concentrated in patches of cool water refugia during warm summer months, when adjacent water is too warm for suitable habitat;
- Many tributaries have cool water temperatures but may lack the combination of structural components that create the habitat diversity and complexity considered desirable for good salmonid habitat;
- The amount of LWD as pool forming elements and as shelter elements has diminished and is generally below desirable levels for salmonid production in the majority of streams in the Redwood Creek Basin;
- Productivity of Redwood Creek streams may be reduced by a general lack of organic matter inputs from instream LWD and the decline in returning salmon whose carcasses are valuable sources of nutrients to fuel the aquatic food web;
- Riparian shade canopy is poor along Redwood Creek and overstory shade and air temperature moderating benefits provided by large coniferous trees is lacking;
- The riparian shade canopy provided by hardwood trees is generally good along surveyed sections of anadromous fish bearing tributary reaches in all subbasins;
- A general trend towards improved channel conditions measured by declining sediment accumulations and an increase in channel form development has occurred in the mainstem of the Upper Subbasin and portions of the Middle Subbasin and some tributary streams;
- Streams have not recovered in a linear fashion from excessive sediment inputs; rather recovery has been discontinuous and reversed at times at various locations.

What are the relationships of geologic, vegetative, and fluvial processes to stream habitat conditions?

- Significant factors affecting stream habitat conditions are excessive hillslope erosion and associated sediment inputs to streams, a reduction of nearstream shade canopy, and a lack of LWD input from large nearstream coniferous trees;
- Many of the adverse changes to stream habitat conditions have been exacerbated by winter floods and summer droughts;
- The Redwood Creek basin is situated in a tectonically active and geologically complex area. Most of the bedrock is relatively weak, easily weathered and naturally susceptible to landsliding and erosion;
- Historically active landslide features comprise approximately 5.6% (10,000 acres) of the basin area;
- The Middle and Upper subbasins are the most geologically unstable parts of the basin. The instability of these subbasins contributes largely to the movement of sediment from the hillslopes into the stream system;
- The Upper Subbasin contains the highest length of stream channels adjacent to landslides. In about 1993, this subbasin began to yield more annual suspended sediment to the mainstem than the Lower and Middle subbasins combined;
- Excessive sediment generated from landslides or other erosional processes is often delivered to stream channels where it may impair stream habitat conditions;
- Excessive erosion and associated sediment inputs to stream channels contributes to channel bed aggradation, loss of channel complexity, filling of pools, stream bank erosion, channel widening, undercutting and loss of streamside trees, loss of riparian shade, increased stream temperature, a reduction of surface flow, loss of channel connectivity, and the introduction of fine sediments to streams reduces spawning substrate quality;
- Gully and stream erosion at toes of earthflows can accelerate earthflow movement and sediment inputs to stream channels;
- Recent studies indicate that channel-storage reservoirs are still partially full from the last series of large floods and the potential for large scale sediment delivery exists;

- While sediment is generally transported relatively quickly from source reaches and from steeper transport reaches, it can remain for decades in the lower gradient response reaches of the Lower Subbasin mainstem channel;
- The bulk of the heat input to water of Redwood Creek occurs in the Upper Subbasin where the water warms quickly during hot summer days;
- Direct exposure to sunlight due to lack of shade canopy in the Upper and Middle subbasins contributes to higher water temperatures throughout the mainstem Redwood Creek;
- Change in riparian and near stream forest structure and function has also played a role in degrading channel conditions and altering channel maintenance processes. The general lack of LWD in many stream channels impairs pool development, sediment routing, and organic nutrient inputs needed to fuel the aquatic food web;
- A cumulative effect from excessive sediment inputs and lack of shade and lack of other benefits provided nearstream forests in the Upper Subbasin is much of the mainstem Redwood Creek salmonid habitat is impaired by warm water temperature;
- The recruitment of LWD to stream channels is limited due to a lack of large, mature conifers growing near the stream zone in much of the Lower and most of the Middle and Upper Subbasins;
- The riparian and nearstream forest along fish bearing reaches of the Middle and Upper subbasins are mainly composed of small sized trees and these trees are not yet capable of providing full benefits to aquatic habitat conditions;
- General trends in the basin are toward the improvement of a number of the factors that currently act on stream conditions. Recovery appears to be occurring in terms of declining sediment in most channels and increasing tree growth in riparian areas.

How has land use affected these natural processes?

- Primary causes for stream habitat deficiencies can often be traced back to land management actions that increase erosion, or activities that alter characteristics of near stream forests;
- Land management on unstable slopes often exacerbates slope instability and the release of sediment. Relatively minor land use actions, such as undercutting the toes of slopes, increasing the duration of ground saturation, or reducing soil shear strength by a relatively small amount, could trigger extensive landslides;
- Roads, skid trails, and gullies can disrupt natural drainage patterns. Runoff is commonly directed to new areas where gullies erode soil which ends up in streams. Redirected flows also may end up in channels that evolved with lower volumes of water and sediment. The increase in flow causes expansion of the channel and accelerates bank erosion and sediment delivery;
- Modification to the estuary including conversion of wetlands to pasture and construction of flood control levees drastically reduced the estuarine area, changed circulation patterns, reduced tidal connectivity, and removed riparian vegetation. As a result, sediments accumulate in the lower embayment reducing estuarine area and channel depth;
- Several studies have shown that the relatively high road density in the Lower, Middle and Upper subbasins increases erosion which generates excessive sediment inputs to streams;
- Nearstream forests along mainstem Redwood Creek and many tributaries in the basin have undergone timber harvests that removed large conifers from the riparian zone. Harvesting of large conifers has removed the beneficial functions of large riparian vegetation (including shade, moderating air temperature, bank stability, potential recruitment of LWD, and nutrient inputs) needed to maintain salmonid habitat;
- Legacy impacts due to logging and widened mainstem channel from excessive sediment inputs have caused a shortage of trees large enough to provide temperature moderating shade over the water;

- Land use in the basin, including road construction, timber harvesting, livestock grazing, burning and other human activities increases storm runoff rates and accelerates mass wasting processes and erosion rates. These impacts on the basin's unstable terrain contributes to excessive sediment inputs to streams;
- Many of the effects from land use activities on upland sediment sources and are spatially and temporally displaced from response reaches;
- Kelsey (1978) suggested that earthflow activity was accelerated or initiated during the last century by livestock grazing and subsequent conversion of prairie vegetation from perennial long-rooted native bunch grasses to annual short-rooted exotic grass. Between 1865 and 1940, there were an estimated 15,000 to 20,000 sheep within the Bald Hills and Redwood Creek area. Historic overgrazing of the Redwood Creek land base probably contributed to the incipient stages of erosion in portions of the basin;
- The Highway 101 bypass is considered a anthropogenic source of fine sediment delivery to the Prairie Creek Subbasin;
- A considerable amount of restoration work has been done within the RNSP and private lands. Road removal and stabilization and improvement of existing roads and stream crossings, and improving fish passage have been a major focus of this work. Working together, the major landowners recently completed assessment work to identify erosion related problems with the roads throughout the basin. The landowners are now working to implement the road improvement recommendations produced through the road assessments.

Based upon these conditions, trends, and relationships, are there physical elements that could be considered to be limiting factors for salmon and steelhead production?

- Many of the same factors limiting salmonid production occur within all subbasins;
- High water temperature limit juvenile salmonids from utilizing rearing habitat in much of the mainstem Redwood Creek and the lower reaches of some tributary streams;
- Existing conditions of the estuary/lagoon and its inability to support over summer survival of most juveniles limits overall salmonid production;
- Barriers to fish passage from sediment deltas limit fish access to some tributary spawning grounds;
- The lack of high quality spawning substrate in the Lower, Middle, and Upper subbasins may limit successful salmonid egg incubation and emergence of fry from redds;
- The lack of deep pool habitat in all subbasins is a limiting factor for juvenile salmonids and adult summer steelhead;
- Instream shelter complexity provided by LWD is in short supply across the basin and likely limits salmonid production;
- The reduction of nutrients contributed to streams from decaying wood and decaying carcasses may limit salmonid production levels in Redwood Creek.

What habitat improvement and other activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

Barriers to Fish Passage

- Fish barriers were found at culverts, perched sediment deltas, or boulder and/or debris accumulations;
- Facilitate fish passage at sites that may impede upstream fish passage into tributary streams for spawning or downstream movements.

Flow and Water Quality Improvement Activities:

- Water flow does not appear to be and issue at this time over most of the basin. However, fish habitat requirements and channel maintenance flows should be considered prior to any water development projects including riparian diversions and small domestic water use;

- In order to help reduce water temperature in tributaries and the mainstem, ensure that near stream forest management encourages growth and retention of conifers sufficient for providing shade and cool micro climate benefits to stream and riparian zones;
- Consider using willow baffles, tree planting or other applicable methods to promote effective shading from riparian trees and to reduce the channel width along reaches of Redwood Creek;
- Timber harvests or other land use should be conducted in a manner that does not increase peak flows, accelerate runoff rates, or deliver excessive sediment to stream channels.

Erosion and Sediment Delivery Reduction Activities:

- Existing sediment production problem sites that have potential to deliver sediments to streams should be evaluated and mitigated;
- Since timber harvesting and other land use can cause disturbances that may contribute to slope instability, management on slopes with high landslide potential and/or on lands adjacent to streams should first involve a risk assessment or be avoided. Determination of appropriate practices should be made through the use of the CGS landslide and landslide potential maps, in conjunction with site-based geological examinations by licensed and appropriately trained geologists;
- For timber management on steep and/or potentially unstable slopes (in many cases, slopes greater than 35%) we recommend use of lower impact silvicultural prescriptions to maintain vegetative cover and the use of cable or helicopter yarding to reduce the potential for erosion and sediment production, which can result in sediment accumulation in Redwood Creek;
- Landowners should continue road erosion hazard surveys throughout the basin and use this information to set priorities for road removals and upgrades, and implement these improvements as rapidly as private and public funding allow. Roads located on unstable slopes and roads near streams should receive high priority for survey and upgrades and decommissioning projects;
- Consider avoidance or mitigation for risks of excessive erosion when planning, building or removing roads in or near deep-seated landslides and earthflows;
- Reduce road density across the basin especially in the Middle and Upper subbasins;
- If new roads need to be constructed, they should be designed to prevent erosion and not be located near the valley bottom where they may pose a high risk of generating sediment delivery to streams. Consider locating roads along ridge tops where feasible;
- The use of fire for site preparation purposes should be minimized on schist soils during warm, dry periods (late summer and fall).

Riparian and Stream Habitat Improvement Activities:

- To increase shade canopy, promote growth and retention of large conifers in the riparian corridor along mainstem Redwood Creek;
- Where current near stream forest canopy is strongly dominated by hardwoods and site conditions are appropriate, land managers should consider cautious thinning of hardwoods from below to hasten the development of denser and more extensive coniferous canopy component;
- To address the lack of large woody debris in many tributary channels and along the Redwood Creek mainstem, management should promote growth of near stream conifers and allow natural recruitment of trees to stream channels;
- Where near stream conifers are not large enough to function as naturally occurring scour elements, consider importing LWD from nearby hillslopes for placement in locations and orientations where it will provide beneficial habitat elements and will not accelerate adverse bank erosion;
- Add combinations of boulders and LWD to increase shelter complexity to cool water patches located in Redwood Creek. The cool patches may be located in temperature stratified pools or adjacent cool water inputs from springs, seeps and tributary flows;

- For timber harvest plans in the Upper and Middle subbasins, consider additional measures to increase function of watercourse protection zones when justified by lack of large conifers to provide shade and microclimate, lack of instream LWD, and low LWD loading potential;
- Consider the use of conservation easements or other management strategies to maximize potential benefits to aquatic habitats from near stream forest protection along the middle and upper reaches of Redwood Creek;
- Consider limiting cattle access in streams where their presence has caused significant bank erosion and impaired growth of vegetation;
- Prescribed fire use within the Redwood Creek basin could reduce adverse impacts to watercourses and wet areas. Regular use of prescribed fire could reduce fuels so that catastrophic fires are less likely to occur.

Monitoring, Education and Research Activities:

- A long-term, concerted monitoring effort among the land owners, interested parties, and responsible agencies is needed to determine the status and trends of anadromous fish populations of Redwood Creek. Efforts should include annual spawner surveys, weir counts, summer steelhead dive counts, and monitoring juvenile populations;
- Utilize CalVeg GIS layers to locate areas where coniferous trees are too small to provide beneficial functions of LWD loading. These areas should be considered for LWD addition to stream channels if needed to retain and promote desirable pool characteristics, sediment routing and other channel maintenance processes;
- Temperature monitoring by land owners and responsible agencies should continue at current and additional sites to extend trend lines and track changes that may impact salmonids or that may indicate a status change. The establishment of trend lines from these data will aid in future studies, validate improvements from forest and stream recovery and will be helpful for habitat improvement project effectiveness monitoring;
- Monitoring suspended and in-channel stored sediments by sampling sediment size distribution, turbidity, V*, photo points, etc. should be continued, and tracking of streambed levels with stream channel cross sections should be continued by responsible agencies and landowners;
- Biological monitoring, particularly for aquatic insects and aquatic food web dynamics, will be an important addition to monitoring efforts in the Redwood Creek basin;
- Ensure that CEQA-compliant environmental assessment is conducted prior to issuance of the Fish and Game Code 1600 series streambed alteration permits and Corps of Engineers or NOAA Fisheries permitting requirements are complete for significant projects on streams of Redwood Creek;
- It is unclear whether modern timberland management practices will allow full restoration and recovery of desirable watershed ecosystem function. Conservation easements that provide wider buffers along water courses or additional management measures may be needed to provide the protection needed to promote watershed and aquatic ecosystem recovery;
- CDFG stream habitat surveys provide information only for reaches accessible to anadromous salmonids. Additional surveys above the limits to anadromy are necessary to identify upstream conditions that affect anadromous reaches such as riparian canopy status or additional sediment delivery sites that may benefit from erosion control treatments.

Conclusion

The Redwood Creek assessment team considered a great deal of information regarding basin processes related to stream conditions in the basin. The large body of existing scientific studies and reports that portray physical and biological watershed characteristics were combined with the multidisciplinary investigations and integrated synthesis performed by the NCWAP team. This large data base provided a substantial amount information for analysis, interpretation and for addressing the NCWAP assessment questions and making recommendations to improve stream habitat conditions.

The Redwood Creek Basin sustains populations of Chinook and coho salmon, steelhead and sea run coastal cutthroat trout. Present populations of these anadromous salmonids are overall less abundant and less widely distributed compared to their historic presence in the basin. Impairments to freshwater and estuarine habitat have been identified as leading factors in the decline of salmonid populations. The conservation of Redwood Creek's anadromous salmonids largely relies on improving existing habitat conditions through a reduction in sediment delivery to streams, instream improvement projects, and promoting conifer growth in near stream forests. Increasing coho salmon and summer steelhead populations presents the greatest challenges due to their low abundance in the basin and specific habitat requirements. The poor habitat conditions of the estuary/lagoon will likely impede juvenile Chinook survival before ocean entry until major actions are taken to restore historic ecosystem processes in the Redwood Creek estuary/lagoon.

There are good stream habitat conditions found in each of the subbasins. Streams located in the undisturbed portion of the Prairie Creek Subbasin provide some of the best salmonid habitat in the basin. However, sites in the Prairie Creek Subbasin (managed by RNSP since 1968) that endured impacts from past land use still exhibit impaired conditions related to excessive sediments and disturbed forests. These findings illustrate that relatively short term disturbance to watersheds can have long term effects to stream systems and salmonid populations. Similar impacts to habitat and fishery resources are found throughout the basin.

Timber harvest is the dominant land use in the Redwood Creek basin and is of significant socio-economic importance both for employment to local residents and as a source of building materials. Stream condition improvements and increasing anadromous salmonid populations largely depends on achieving a balance between the socio-economic needs for timber resources and implementing management needed to maintain or improve basin conditions that sustain viable fish populations. Recently enacted timber harvest rules include watercourse protections zones and sediment-potential-reducing improvements to roads and other regulatory measures intended to help sustain or improve basin integrity. Effective timberland and other land use management and watershed improvement projects such as road and instream habitat treatments are steps needed to improve aquatic habitat conditions and help increase numbers and distribution of salmonids.

General trends in the watershed are toward the improvement of a number of the factors that currently are limiting salmonids. Recovery appears to be occurring in terms of declining amounts of stored sediment in many stream channels and increasing tree growth in riparian areas. If stream habitats continue to move towards pre 1964 disturbance conditions, anadromous salmonid populations should respond by increasing in numbers and distribution across the basin.

The Redwood Creek Basin is an excellent candidate for a successful long-term, programmatic watershed improvement effort. The likelihood that The Redwood Creek basin will react in a responsive manner to management improvements and restoration efforts is largely a function of existing basin conditions and future land use considerations. It is important to note that without management strategies that promote restoring ecosystem integrity by addressing root causes of problems, instream improvement projects will likely be short-lived patches on the environment. A good knowledge base of current watershed conditions and processes is essential for developing watershed improvement activities and monitoring effectiveness of such projects. Acquiring this knowledge requires property access. Access is a requirement to design, implement, monitor, and evaluate suitable improvement projects. Thus, systematic improvement project development is dependent upon the cooperative attitude of resource agencies, watershed groups and individuals, and landowners and managers. Reaching that goal is dependent upon the formation of a well organized and thoughtful improvement program founded on broad based community support for the effort.

Section IV
Subbasins
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Estuary Subbasin

The Redwood Creek estuary is located approximately three miles west of the town of Orick. The Estuary Subbasin is within the CalWater 2.2.1 Skunk Cabbage Creek Planning Watershed (Figure IV- 1). Main features of the Estuary Subbasin are the estuary/lagoon, the town of Orick, rural residential developments, agricultural and pasture lands, and flood control levees (Table IV- 1). The mainstem Redwood Creek channel of the Estuary Subbasin extends inland approximately 3.0 miles to the confluence with Prairie Creek, but salt water intrusion only extends 1.6 miles upstream from the ocean. Tributary channels to the estuary are Strawberry Creek, and Sand Cache and Dorrance creeks. The lower reaches of Sand Cache and Dorrance creeks from the North Slough channels.

The Redwood Creek estuary seasonally alternates between an open estuary and a closed coastal lagoon. The estuary usually remains open from the first substantial rains in the fall until the early summer season when a sand bar forms across the estuary mouth creating a coastal lagoon. Like many estuaries and lagoons along California's coast, the Redwood Creek estuary/lagoon plays an important role as anadromous salmonid habitat.

Table IV- 1. Estuary Subbasin summary, Redwood Creek.

Square Miles	5.4
Total Acreage	3,430
Private Acres	2,010
Federal Acres	1,420
State Acres	0
Principal Communities	Orick
Predominant Land Use	Livestock grazing
Predominant Vegetation Type	Pasture/Ag Land
Miles of Anadromous Stream	~5
Low Elevation (feet)	0
High Elevation (feet)	1,243

Geology

The Estuary Subbasin consists of a broad flood-plane valley surrounded by steep hillsides. The hillsides are underlain by Redwood Creek schist and remnants of uplifted marine terraces from flat-topped ridge crests. Slopes north of the estuary are mantled with several earthflow complexes. Several rotational landslides as well as large areas of disrupted ground and debris-slide slopes are found on the south side of the estuary. Several small alluvial fans have built out upon the valley floor.

The Estuary Subbasin is unique to the Redwood Creek basin in that the dominant landslide potential classes are either very low or high and very high (Table IV- 2). This condition exists because of the contrasting topography of flood plain and the relatively unstable hillsides of this subbasin. Historically active features account for less than 1% of the total subbasin area.

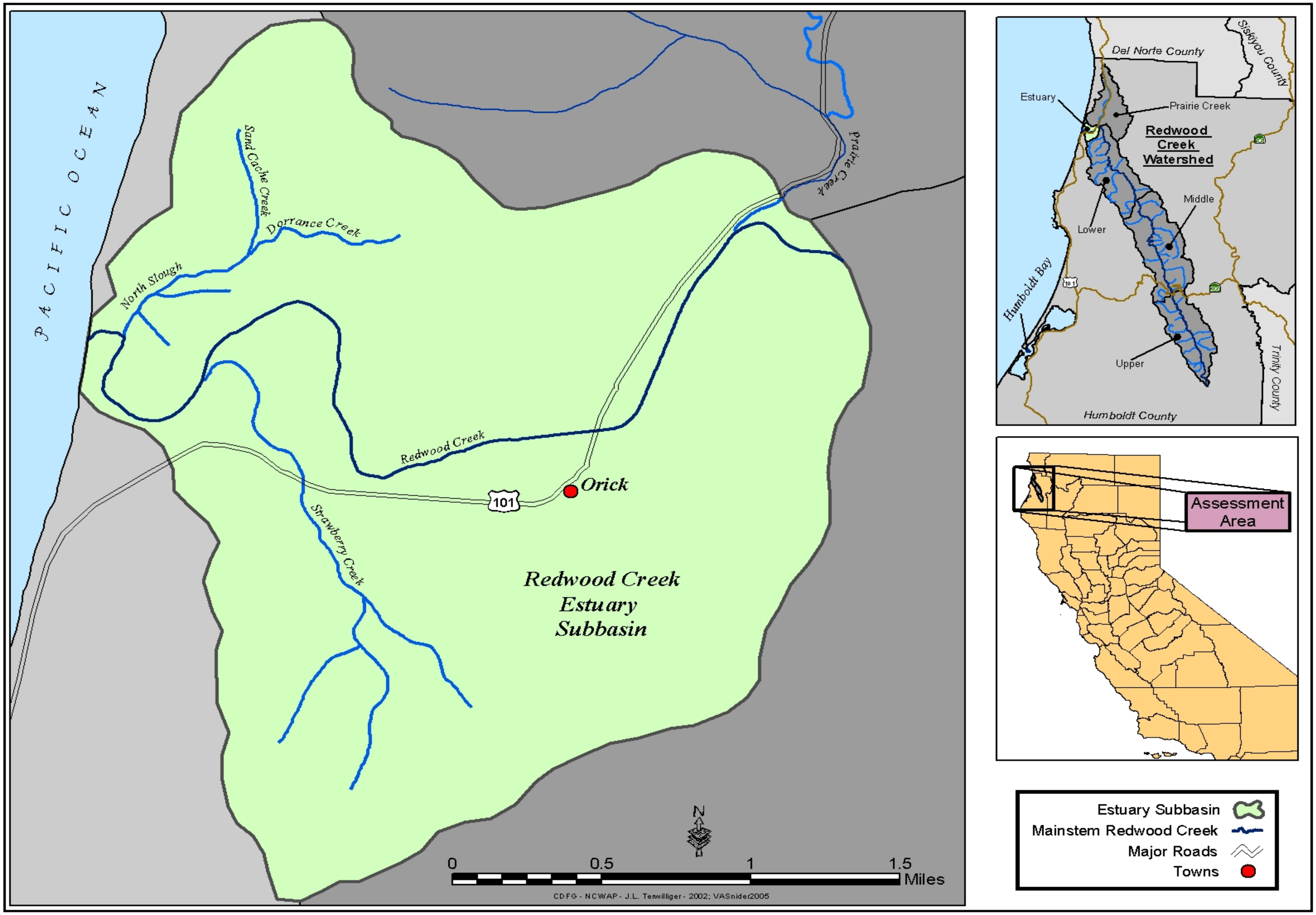

Figure IV- 1. Estuary Subbasin.

Table IV- 2. Estuary Subbasin summary of relative landslide potential and landslide features.

Relative Landslide Potential	Acres	% Area
Very Low	1,457	42.4%
Low	67	2.0%
Moderate	216	6.3%
High	1,200	35.0%
Very High	486	14.2%
High/Very High Subtotal	1,686	49%
Total of Above Features	**3,426**	**100%**
Landslide and Selected Geomorphic Features	**acres**	**% area**
Historically Active Landslide Features Total	2	0.0%
Earthflow	0	0.0%
Rock Slide	1	0.0%
Debris Slide	0	0.0%
Debris Flow	1	0%
Dormant Landslide Features Total	700	20%
Selected Geomorphic Features Total	617	18%
Disrupted Ground	277	8%
Debris Slide Slope	337	10%
Inner Gorge (area)	3	0%
Total of All Above Features	**1,320**	**39%**

Streamside Landslides

Table IV- 3 shows the number of small streamside landslides located on slopes adjacent to tributary streams in the subbasin. From 1984 to 2000, the number of active streamside landslides decreased 50%, from 26 to 13.

Table IV- 3. Estuary Subbasin number and indices of streamside slides.

Subbasin Unit of Analysis	Analysis Unit Area (sq. km.)	1984 # of Active** Slides Along Streams	2000 # of Active** Slides Along Streams	1984 Indexed** Active Slides	2000 Indexed** Active Slides	% Change 1984-2000
Estuary Subbasin	19.6	26	13	133	66	-50

**Index = (# slides/analysis unit area) X 100

Vegetation

Redwood (310 acres or 9% of the subbasin) and Sitka spruce-redwood (640 acres or 20% of the subbasin) compose most of the conifer cover type in the Estuary Subbasin (Table IV- 4 and Figure IV- 2). Old growth redwood is found within the subbasin, along with previously harvested areas that now support second growth trees. Red alder (770 acres or 24% of the subbasin) occupies a relatively extensive area within this subbasin. Grass lands used as pasture, and agricultural land comprise approximately 35% of the subbasin.

Historic forest condition of the areas were much different than today. By inspection of historic photographs, it is clear that there was once considerably more redwood, Sitka spruce, and red alder forests and sedges surrounding the estuary.

Table IV- 4. Estuary Subbasin generalized vegetation cover type.

Subbasin or Planning Watershed	Cover Type (estimated acres)								
	Agriculture	Barren	Conifer	Hardwood	Grassland	Shrub	Developed	Water	Total
Estuary	350	110	1,075	770	800	30	80	65	3,300

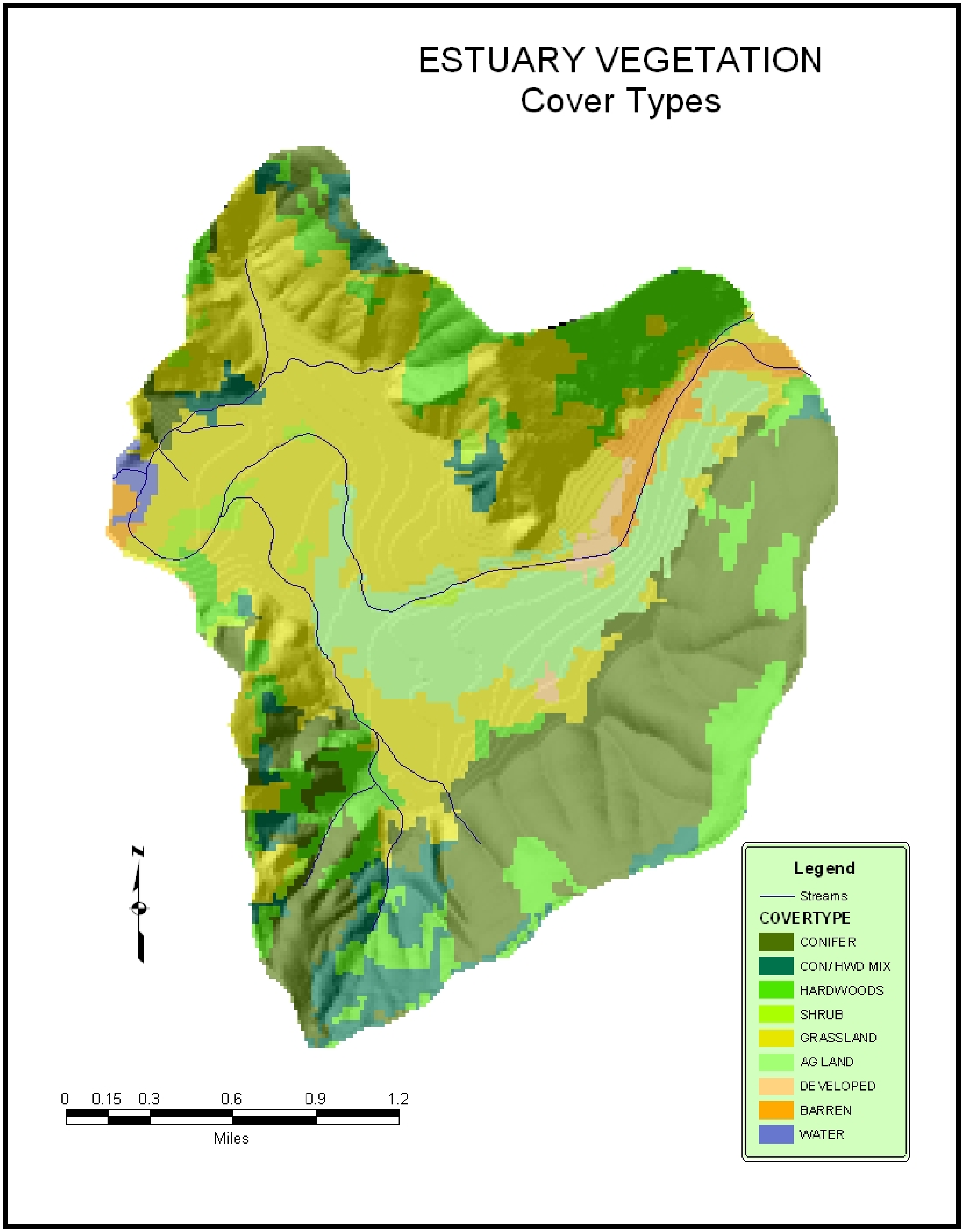

Figure IV- 2. Estuary vegetation map showing cover types.

Land Use

Native Americans were the first people to utilize the Redwood Creek estuary. They built villages located near the ocean along Redwood Creek, but no notable change to the estuarine area can be detected from the Native American presence.

The lands surrounding the estuary were the first areas in the Redwood Creek basin to be modified by western settlers. Land use in the Estuary Subbasin, including farming, grazing, and development, began in the 1850s.

By the early 1900s, much of the present grasslands within the delta area were converted from redwood, Sitka spruce, and red alder forests, and sedges. The estuary subbasin has the largest amount of agricultural land (350 acres or 10% of the subbasin) within the Redwood Creek basin (Table IV- 4). Most of this vegetative cover type is in permanent grazing land and pasture. The town of Orick is located in the Estuary Subbasin and with a population of approximately 500 is the largest settlement in the Redwood Creek Basin. Approximately 80 acres have been developed in and around the town of Orick.

The most significant land use impact to the estuary came from the construction of flood control levees. In response to the 1964 flood, earthen levees were built in 1968 by the Army Corps of Engineers along the lower 3.4 miles of Redwood Creek to protect the town of Orick and agricultural lands located in the valley flood plain. The flood control project included removal of all riparian vegetation growing between the levees; the main channel was also straightened, shortened, and modified to form a 250 foot wide trapezoidal shape. The levee system has had a profound effect on the estuary, including reducing the estuarine area and changing ecosystem processes. Further effects from the levees are discussed in the following sections.

Timber Harvest

Timber harvest operations within the Estuary Subbasin began in the mid 1800s. By 1942, most of the area had been converted to other land uses, such as pastureland and development. Table IV- 5 and Figure IV-3 summarize the timber harvest history for the Estuary Subbasin since 1950. Table IV- 5 and Figure IV-3 do not show acres in the flood plain converted from forest to agricultural land. About 1,470 acres have been harvested in the subbasin during this period, an area equivalent to 42.8% of the total subbasin area. There has been no timber harvest activity in the subbasin since the 1970s.

Table IV- 5. Estuary Subbasin timber harvest history 1950-2000.

Subbasin	Harvest Acres by Period							
	1950 to 1964	1965 to 1974	1975 to 1983	1984 to 1992	1992 to 2000	Total Harvested	Total Subbasin Acres	Percent Harvested
Estuary	1,249	84	137	0	0	1,470	3,433	42.8

Roads

The Estuary Subbasin has approximately 16 miles of roads. Most of the roads are paved. The road density is about 3.3 road miles per square mile. About 32% of the road miles are on areas of high or very high relative landslide potential.

Fire and Fuels

The Estuary Subbasin has 27% of its area in the moderate fuel rank, 49% of its area in the high fuel rank, and 11% in the very high fuel rank (Table IV- 6 and Figure IV- 4). Fourteen percent of the area is in agricultural and developed areas which are not considered in the fuel ranking process. The areas of very high rank are relatively large and contiguous in this subbasin as compared to the other subbasins. Given the relatively cool, damp, marine-influenced weather of the Estuary Subbasin, the fuel rankings alone overstate the fire risk found in the subbasin.

Table IV- 6. Estuary Subbasin fuel ranks summary.

Area of Analysis	Fuel Rank								Total Acres
	Moderate		High		Very High		Not Mapped		
	Acres	%	Acres	%	Acres	%	Acres	%	
Estuary	920	27	1,670	49	378	11	467	14	3,435

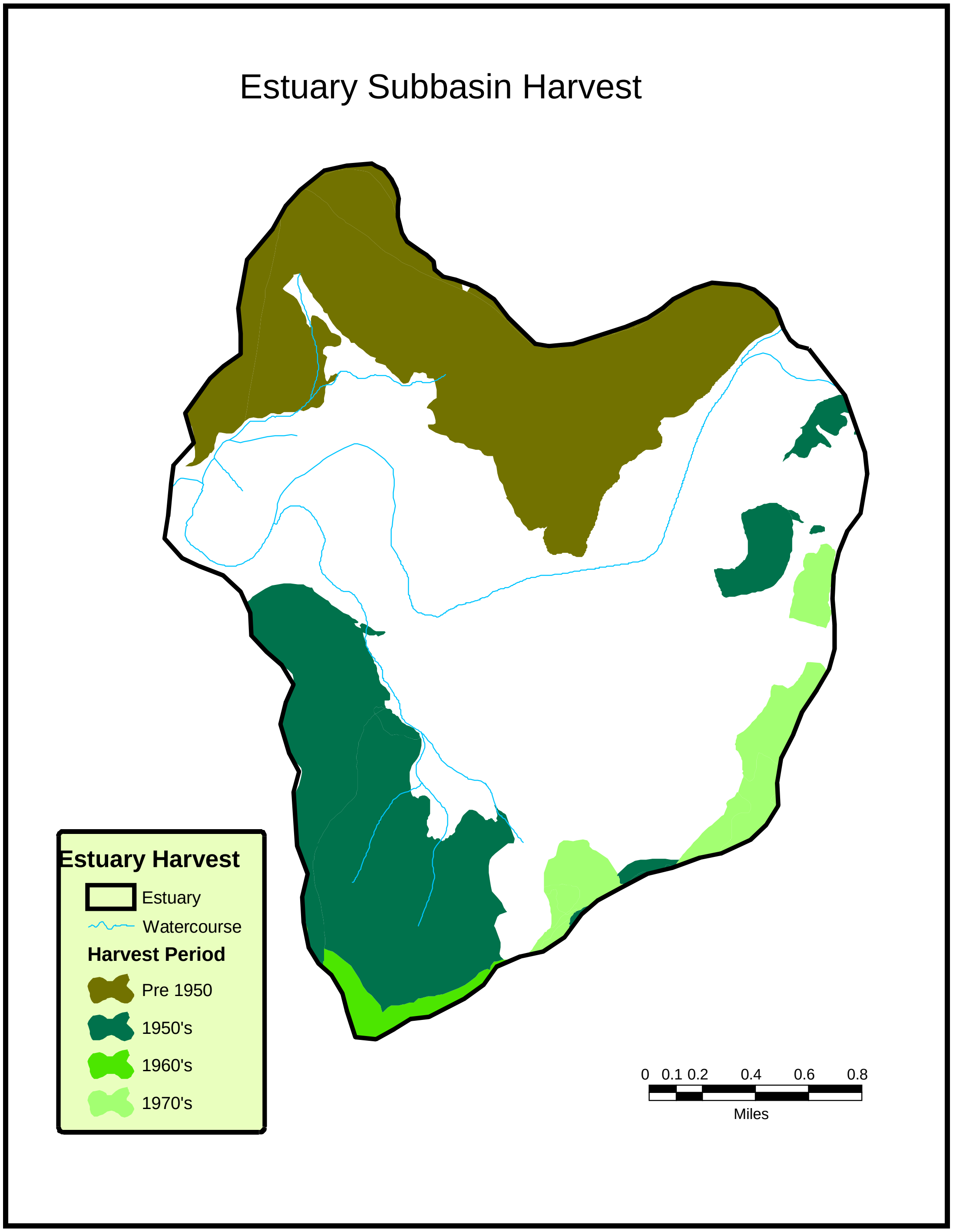

Figure IV-3. Estuary Subbasin timber harvest.

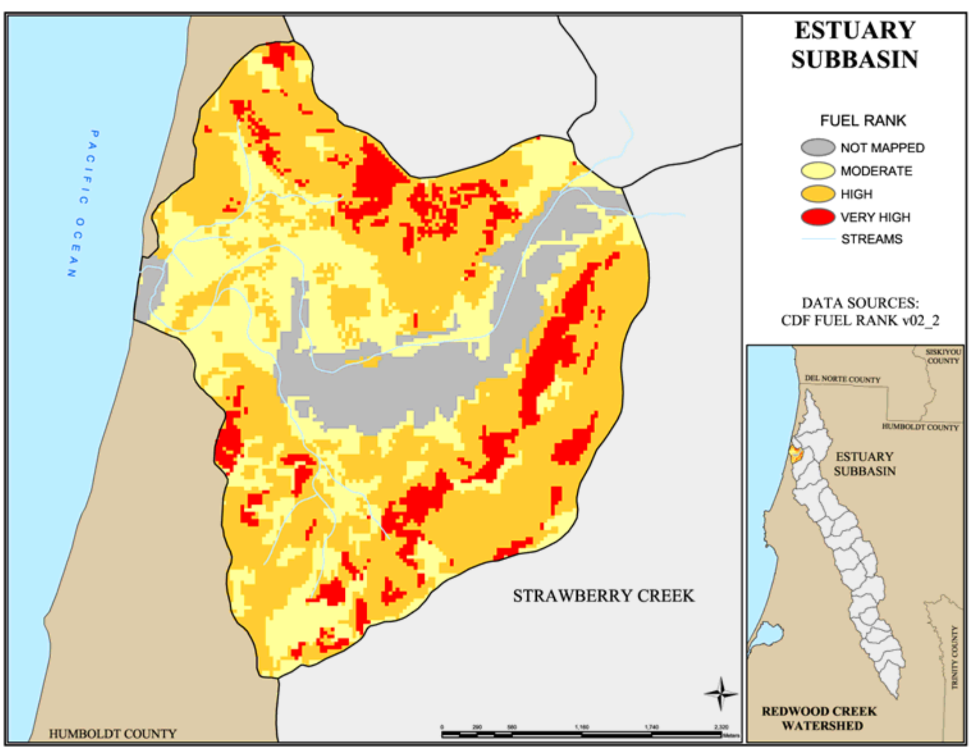

Figure IV- 4. Estuary Subbasin fuel ranking map.

Fluvial Geomorphology

Janda and others (1975) described the estuary at the mouth of Redwood Creek and observed that in the early 1970s, the tidal influence extended 1.6 miles upstream. The subbasin contains 10 blue-line tributaries, four of which have names: Johnson Creek, Skunk Cabbage Creek, Sand Cache Creek, North Sough, and Strawberry Creek.

Aerial photographs taken from 1936 through 1965 (Figures IV-5 through IV-7) show the estuary was significantly larger before flood control levees were built in 1968 (Appendix E includes photos from 1905-2000). Aerial photographs taken in 1988 and 2000 show a remnant embayment at the mouth of Redwood Creek and a constricted estuarine channel at the beach (Figures IV-8 and IV-9).

The levee system was designed to contain a storm runoff of approximately 77,000 cubic feet per second (cfs), a flow frequency recurrence interval of once in more than 200 years (COE 1998). The maximum peak flows on record are 50,500 and 50,200 for the water years 1965 and 1975 respectively.

Recent studies suggest that the levees will begin to overtop at flows of 65,200 cfs (estimated 100 year flood recurrence interval) rather than the design runoff of 77,000 cfs (COE 1998). The reduction in flow capacity of the project is caused by the combination of channel aggradation, subsidence (1 to 2 feet) along the upper and lower reach of the levee system, and vegetation growth on the levees (COE 1998). Hydraulic analysis revealed that 75% of the loss in flow capacity (approximately 9,000 cfs) is from channel aggradation (COE 1998).

The aggradation is partially in response to the presence of flood control levees. The levees form a semi-canal which encourages the deposition of sediment load brought from the sea and from the land. The levees make it impossible for sediment to be dispersed over the sides of the main channel. The overall effect is to encourage sedimentation in the estuarine channel.

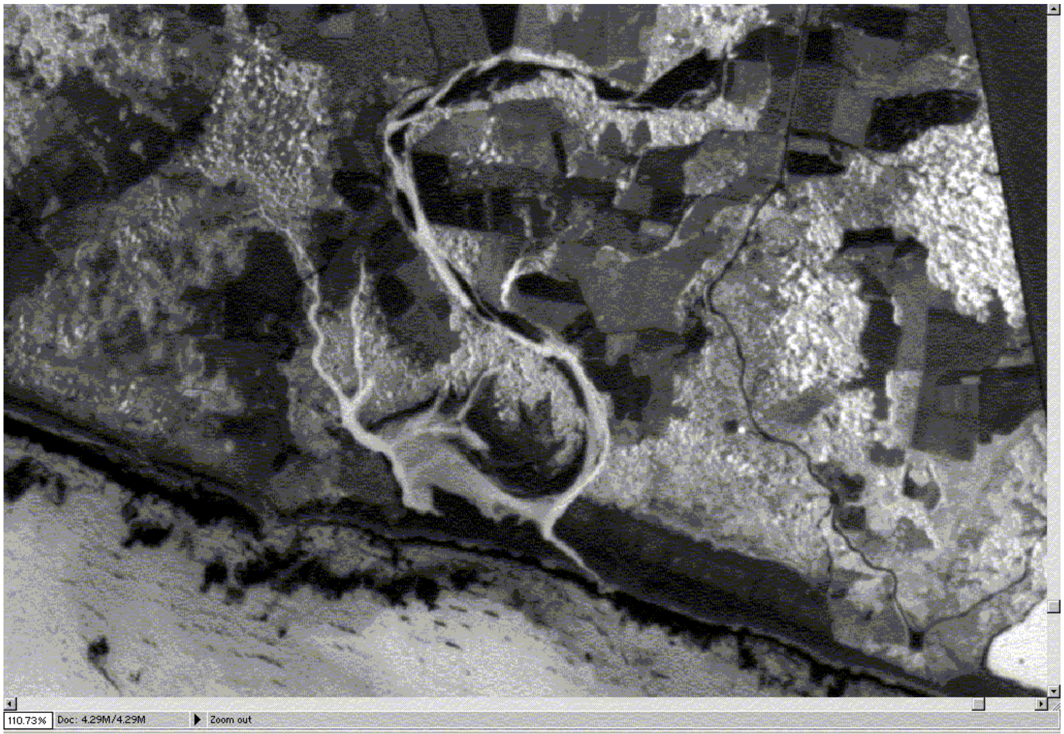

Figure IV- 5. Redwood Creek estuary in 1936.

North is to the left. Note the size and continuity of the water in the estuary and the amount of water in the tidal inlets to northeast. Aerial photography was provided by Redwood National Park.

Figure IV- 6. Redwood Creek estuary in 1948.

North is toward the top of the photograph. Source of aerial photographs is U.S. Forest Service, flight CDF2, 1:26,400.

Figure IV- 7. Redwood Creek estuary in 1965, after the flood of 1964.

There is a great deal of water in the creek and estuary, and the lateral gravel bars are probably submerged. However, the flood did not significantly change the shape or location or area of the estuary or the lower meanders of Redwood Creek. Source: U.S. Department of Agriculture, Soil Conservation Service, flight CVL, 1:20,000.

Figure IV- 8. Redwood Creek estuary in 1988.

Construction of levees in the late 1960s confined lower Redwood Creek to a smaller channel and the size of the estuary diminished Used with permission from W.A.C. Corp., Eugene OR.

Figure IV- 9. Redwood Creek mouth, 2000.

The area of the former estuary is filled with beach sand. The tidal inlets, called the North Slough, are nearly dry. The south meander of the creek is a backwater slough. The estuary is a constriction of Redwood Creek at its mouth. Levee construction did more damage to the estuary than the storm of 1964, because the size of the estuary has been reduced dramatically. The alternating lateral bars in lower Redwood Creek represent an attempt by the stream to form meanders and to dissipate energy. Aerial photography, 1:24,000, used with permission from W.A.C. Corp., Eugene, OR.

Approximately 210,000 cubic yards of gravel was removed from the estuary channel in 1987 and1988. The gravel was used to construct the Highway 101 bypass. Approximately 33% of the gravel was replenished by the following year and 44% had returned within three years (Moffatt and Nichol 2003). The vast majority of bedload measured near Orick was deposited between the levees over those three years (Moffatt and Nichol 2003), indicating the short term effects from removing gravel as a potential solution to the channel aggradation problem.

According to Janda and others (1975), the estuary covered twice its size before the levees were built. The lower two meanders were once active parts of the mainstem of lower Redwood Creek (Baine's Bend and the meander south of Middle Island) and carried the main flow. This part of the channel became a backwater slough after the creek was confined between levees (Janda and others 1975). Slough inlets extended inland from the north side of the estuary to the northeast and east. After the construction of the levees, these inlets were constricted by sediment and largely disappeared from aerial view. Presently, the slough inlets are plugged by marine beach sediment rather than fluvial sediment. Ricks (1985) showed that there was an increase in marine sediment in the estuary following construction of the levees. Sediment samples from well within the estuary showed an increase in blue-green hornblende, which is a mineral carried southward by longshore currents from the Klamath River. Thus, the proportion of marine sediment increased within the estuary after levee construction and contributed to the loss of estuarine habitat area, a loss of slough channel connectivity, and a reduction of the tidal prism.

An important feature of Redwood Creek's estuary is that it forms a lagoon depending on the status of the Redwood Creek mouth. During late spring and early summer, tidal flow through the mouth of the Redwood Creek estuary is restricted by the presence of a sill as longshore transport of sand begins to close the mouth and the lagoon begins to form. The restriction of the tidal flow may result in shorter flood tides, which are characterized by higher velocities, in the presence of low river flow, and a greater transport of marine sediments into the estuary (Larguer et al. 1992). Excessive accumulation of sediments and reduction of tidal prism may contribute to closing the mouth earlier than it did historically. Early closure of the mouth decreases the window of time available for juvenile salmonids to migrate to sea and may alter physical elements of channel morphology and water quality.

Sediment Storage and Transport

Sediment storage and transport through the estuary are influenced by the amount and rate and size of sediment delivered from upstream sources, stream flows, channel gradient, confinement of the channel from levees, and tidal action. The great majority of sediment stored or transported through the estuarine channel is derived from hillslopes located in the Lower, Middle and Upper subbasins. The fluvial sediment supply was enhanced by major floods during the last 50 years in 1955, 1964, 1972, 1975, and a moderate flood in 1996-1997 (RNSP 1999). CGS/NCWAP observed gravel bars in lowermost Redwood Creek aerial photographs from 1936, 1948, 1965, 1984, 1988 and the spring of 2000. The gravel bars vary in size and shape from decade to decade, reflecting storage and transport of sediment. Channel cross sections monitored by RNSP and COE show irregular, net accumulations of sediments throughout the estuarine channel (COE 1998, Moffatt and Nichol 2003). The channel will likely continue to aggrade until the levees are modified and the sediment supply from upstream adjusts with the transport rate of the estuary channel.

Table IV- 7 summarizes findings from examination of aerial photos for negative stream features. CGS found that negative stream features, mostly consisting of elevated sediment, increased 95% by length in the estuary subbasin between 1984 and 2000. This is largely due to the downstream transport and subsequent deposition of sediment originating from the Upper, Middle, and Lower subbasins.

Table IV- 7. Estuary Subbasin length of negative stream features, negative stream feature index, and percent change 1984 to 2000.

Subbasin Unit of Analysis	Analysis Unit Area (sq. km.)	Negative Features 1984 (m)	Negative Features 2000 (m)	Indexed Negative Features 1984*	Indexed Negative Features 2000*	% Change 1984-2000
Estuary	19.6	2,936	5,734	150	293	95

* Index = (length of negative features in meters/area of unit of analysis in square kilometers)

Water Quality

The Estuary Subbasin consists of two distinct water quality zones: an estuarine/lagoon zone and freshwater, riverine zone. The water quality of the Redwood Creek estuary/lagoon is influenced by complex relationships between seasonal changes in freshwater flows, ocean tides, the coastal fog climate, channel morphology, and lagoon conditions. The influence of the estuary/lagoon extends approximately 1.5 miles up the Redwood Creek channel and also for some distance up Strawberry Creek, Dorrance Creek, and Sand Cache Creek. Approximately two miles of Redwood Creek riverine channel extends between the upper limit of the estuary/lagoon and the confluence with Prairie Creek. This reach is somewhat cooled by water coming from Prairie Creek and cool air temperature provided by the coastal climate.

Temperature, Salinity and Dissolved Oxygen

RNSP biologists have studied water quality of the estuary/lagoon and sloughs during the summer months for several years, monitoring vertical profiles of conductivity, salinity, dissolved oxygen, and temperature. Information retrieved from annual estuary monitoring reports (Anderson 1983-87 an d1997-2000) indicate that under lagoon conditions, unfavorable water temperature and dissolved oxygen levels have been limiting factors for salmonids in the lower embayment and slough channels. These conditions begin by mid July of most years, when a sand bar closes the creek mouth and the estuary converts to a lagoon.

In general, the water column develops a salinity gradient or stratifies with freshwater on the surface and saline water in the middle and bottom waters (RNSP 2000). Water temperatures in the lagoon generally raise, dissolved oxygen levels fall, forming conditions can become stressful or lethal to salmonids especially in the slough channels where circulation is minimal (Larson et al. 1982, RNSP 2000). For example, an MWAT in the lagoon of 68°F was recorded in 1997. Maximum daily temperatures recorded during the summers of 1997 and

1998 for sites in the estuary/lagoon were 70 and 68ºF, respectively. These data indicate that during the hottest part of the year, temperatures in the estuary are below the lethal limit of 75ºF but may still cause stress to salmonids. Dissolved oxygen (DO) measurements collected during fish sampling in the early 1990s varied among sites. Adequate levels of DO were observed in the lower embayment, but levels approaching 0 ppm were recorded in the slough channels (RNSP 2000). Cumulative effects from elevated nutrient delivery from livestock grazing lands and dairies, algal growth and decomposition, and lack of water circulation have likely contributed to low (at times lethal to fish) dissolved oxygen levels in the sloughs.

Water Column Chemistry

A monitoring site for water chemistry data near the town of Orick has been sampled quarterly for approximately 30 years. The Orick site is upstream of saline influence from tidal action. Data from this site indicate a slight increasing trend for DO and pH, however both parameters fall within Basin Plan water quality objective goals. There are a few additional monitoring sites closer to the mouth of Redwood Creek in the estuary. The data are scattered and scarce, but can be obtained at the USGS NWIS web website http://waterdata.usgs.gov/ca/nwis. (USGS 2001). Since chemical analysis of the water is performed above the estuarine channel there is no data to determine if waste products from cattle grazing are affecting the water quality of the estuary/lagoon.

The Surface Water Ambient Monitoring Program (SWAMP) sampled a site near the town of Orick thirteen times during 2001-2003. This site samples fresh water upstream from tidal influence. Data showed mainstem waters having mean dissolved oxygen of 10.7mg/L (water quality objective >8mg/L), pH at 7.7 (water quality objective 6.5-8.5), and conductance of 101umhos (water quality objective <220umhos). Samples for nutrients were within normal limits. Low-level metals testing showed presence in small non-threatening amounts. Results from this sampling effort can be found in Appendix B. Organic pesticide and herbicide sampling results were not available at the time of this report. However they will be made available on the following website: http://www.swrcb.ca.gov/swamp. Future sampling efforts from the SWAMP program will extend trend lines for pH, dissolved oxygen, and conductivity, as well as maintain a watch on water quality.

In-Channel Sediment

In-channel sediment was sampled in the estuary subbasin at mainstem Redwood Creek near the town of Orick by USGS. Redwood Creek at Orick was sampled every two years from 1983 to 1995 for percent of fine materials using McNeil cores and sieved dry. See Appendix C for a display of the data. No distinct trends in the gravimetrically measured samples are noticeable. TMDL targets do not apply to estuarine areas under tidal influence due to the natural breakdown of substrate materials and the possible influx of oceanic sediments resulting from wave action. Due to the method of analysis, these streambed data are not comparable to TMDL targets because the samples were not analyzed volumetrically. No D_{50} data exist for this subbasin or the data were not assessed in this report.

Salmonid Habitat Assessment

The estuarine environment provides a transition area between fresh water and marine environments where ocean tides, river flows, sediments, plants, and animals interact to form a dynamic ecosystem. Due to the highly variable measures of salinity and temperature found in estuaries, most fish find estuaries a harsh environment. However, fish that tolerate estuarine conditions benefit from abundant planktonic and macroinvertebrate food supplies and obtain a degree of protection from most predatory fish. The abundance of low trophic level food supplies and the sheltered environment makes estuaries important nursery and rearing areas for juvenile fish including anadromous salmonids. Anadromous salmonids also use the estuarine environment as a transition area to undergo critical physiologic adaptations as they acclimate to changes in salinity and water temperature during downstream seaward migrations as juveniles and upstream spawning migrations as adults. Fish, including salmonids that utilize estuaries and lagoons for juvenile rearing or other important parts of their life cycle may be referred to as estuarine-dependant. Because of this value as nursery grounds and adult holding habitat, the Redwood Creek estuary and lagoon are critical habitat areas for anadromous salmonids. Table IV- 8 presents a list of fish species found in the Redwood Creek estuary/lagoon and length of channels accessible to anadromous salmonids in the Estuary Subbasin.

The Redwood Creek estuary provides juvenile salmonids essential rearing habitat needed to achieve important growth before entering the ocean. Juveniles that rear in estuaries and lagoons for extended periods usually increase in size, giving them a survival advantage upon the onset of their ocean life. It is believed that the larger juveniles are less likely to be preyed upon by other fish and they may also have a wider food base to feed upon during critical first weeks at sea. The estuary/lagoon rearing may be especially beneficial for Chinook salmon and steelhead originating from streams like Redwood Creek where warm summer water temperature or low flows may limit instream rearing in much of the mainstem during the summer and fall seasons. They arrive to the estuary at a relatively small size where they can reside and continue to grow before migrating to the sea.

An estuarine rearing strategy is an important component of behavioral diversity within juvenile salmonid life history strategies. Producing juveniles that successfully rear in both stream and estuarine habitats for variable time periods before they enter the ocean may also promote genetic diversity. This is important as genetic and behavioral diversity helps ensure survival for fish that encounter a wide range of environmental conditions in both the freshwater and marine environments.

Table IV- 8. Estuary Subbasin species present, and number of stream miles accessible to anadromous salmonids.

Stream	Species Observed	Anadromous Length (mi.)	References
Redwood Creek estuarine channel	coho salmon Chinook salmon steelhead coastal cutthroat trout Pacific herring staghorn sculpin prickly sculpin saddleback gunnel Pacific lamprey brook lamprey three-spine stickleback starry flounder eulachon surf smelt night smelt shiner surfperch tidewater goby	3.5	Fish species of Redwood National Park (1992)
Strawberry Creek	coho salmon steelhead coastal cutthroat trout Pacific lamprey	1	RNSP 2000, Draft Strawberry Creek 1994
Sand Cache Creek/North Slough channel	Chinook salmon coastal cutthroat coho salmon steelhead tidewater goby	.5	D. Anderson, RNSP, Personal communications
Dorrance Creek	*na	na	

*not available

During the mid-1800s to the mid-1900s the estuary/lagoon was a popular area for sport fishing on Redwood Creek. Fishers used to troll for salmon in rowboats and also fished from the shore. Frequent articles printed in local newspapers in the early 1900s told of Chinook weighing sixty pounds or more and numerous other salmon that were caught in the estuary, the tidal channel of Strawberry Creek, and North Slough channel (Van Kirk 1994). Coastal cutthroats also were often taken in the four to six pound range. The current effort and catch from sport fishing in the estuary is greatly reduced compared to the past accounts. Presently, much of the fishing effort is focused along the reach above tidewater (~1.5 miles upstream of the mouth) to the confluence of Prairie Creek (Tom Weseloh, California Trout, personal communication). Naturally produced anadromous salmonids are managed as a catch and release fishery.

Over the past 125 years, the estuary area has been altered by conversion of forest and wetland areas to pasture land, and by channel modifications and levee construction in 1968. Flood control levees built in 1968 account for the largest change to the estuarine ecosystem. As a result of modifications, the fish rearing area of the Redwood Creek estuary/lagoon has been reduced by 50 to 75% (Ricks 1983). These changes have impaired the physical and biologic function and reduced the capacity of the estuary/lagoon to support salmonids.

A fundamental study conducted in the Redwood Creek estuary by Larson et al. (1981) noted the importance of the estuary/lagoon as juvenile salmonid rearing habitat. They also identified opportunities for habitat improvements. The years of studies and management recommendations that followed also prompted RNSP and others to develop a series of alternatives to improve conditions in the estuary. Some of the ideas can be found in the *General Management Plan for Redwood National and State Parks* (RNSP 2000) and *Hydraulic Analysis of Alternative Levee Configurations for Lower Redwood Creek* (Moffatt and Nichol 2003). The studies have shown a high potential to improve the estuary/lagoon condition by increasing the channel width while maintaining protection of Highway 101 and the town of Orick, and addressing needs and concerns of landowners of the estuary project area. Alternatives also include efforts to purchase land within the project area and should consider conservation easement strategies. The goals of any estuarine restoration project should promote improvement of estuarine ecosystem integrity by increasing the area of the lower embayment and lower river channel while also increasing depths, shelter, and connectivity and circulation between the main channel and slough channels, and re-establishing riparian forests.

Salmonid Fishery Resources

Chinook Salmon

Juvenile Chinook salmon of the Redwood Creek Basin rear in the estuary/lagoon before entering the sea. The estuarine rearing strategy is important because juvenile Chinook salmon are typically less than 70 mm fork length (FL) when they arrive to the estuary in May, June, and July (Anderson 2000 and 2001, Wilzbach 2001). The average size of these fish is below the optimal size of more than 100 mm FL noted for high survival rates upon ocean entry (Nicholas and Hankin 1989). Rearing in the estuary/lagoon allows Chinook to obtain larger size, but the creek mouth typically closes before Chinook reach 100 mm FL. Thousands of juvenile Chinook remain to rear and grow in the lagoon over the summer season. However, a review of population estimates provided by RNSP studies shows that only 7 to 15% of the Chinook populations survived from July to September in the lagoon during 2000 and 2001(Anderson 2000 and 2001) (Table IV- 9). The impaired condition of the estuary/lagoon likely contributes to the low over summer survival rate of juvenile Chinook and is a factor limiting Chinook production in the basin. Additional information about Chinook use of the estuary can be found in the Anadromous Salmonids Status and Life History in Section III of this report.

Table IV- 9. Juvenile steelhead and Chinook population estimates.

Redwood Creek Estuary Fish Sampling - Summer/Fall 2000						
Date	**Mouth**	**Steelhead Population Estimate**	**Ave FL**	**Chinook Population Estimate**	**95% CI**	**Ave FL**
5-Jun	Open	12,780	126	55,640	± 17,710	72
July 17,18,20	Closed	8,950	202	18,350	± 20,490	74
Sept 11,12	Closed	4,270	220	2,910	± 1,900	94
26-Oct	Closed	na*	na	na	na	111
4-Jun	Open	38,456	113	58,633	± 19,531	62
16-Jul	Closed	34,259	89	34,259	± 27,032	71
13-Aug	Closed	4,612	81	3,616	± 3,035	77
10-Sep	Closed	9,348	126	2,288	± 2,485	86
2-Oct	Closed	na	118	na	na	91
23-Oct	Closed	na	147	na	na	102

*na: population estimate not determined
95% confidence interval (CI), and average fork lengths (FL) collected from Redwood Creek Estuary/Lagoon 2000 and 2001 (Anderson 2000 and 2001).

Steelhead

Steelhead may rear in estuaries/lagoons including the Redwood Creek estuary/lagoon for several months to one year or more before entering the ocean (Anderson 1988, Ridenhour and Hofstra 1994, Cannata 1998, RNSP 2000). The additional growth added in the estuary/lagoon is believed to increase steelhead survival rates upon ocean entry. Steelhead size and growth in the Redwood Creek estuary/lagoon appears highly variable between years. As with Chinook, a large percentage of steelhead residing in the Redwood Creek lagoon do not survive over the summer months (Table IV- 9). However, steelhead seem to survive at a higher rate than Chinook. Additional information about steelhead use of the estuary can be found in the Anadromous Salmonids Status and Life History in Section III of this report.

Coastal Cutthroat

The Redwood Creek estuary once supported a large population of coastal cutthroat trout (Van Kirk 1994). Presently, small numbers of coastal cutthroat trout reside in the estuary and some may stay there year-round (Dave Anderson, RNSP, personal communication). Sport catches of coastal cutthroats in the 3 to 4 pound range were common from the estuary in the late 1800s and early 1900s (Van Kirk 1994). It is thought that some coastal cutthroats use the estuary for adult habitat much like the salmon use the ocean for growing and then return to small streams to spawn. Others use the estuary for juvenile rearing grounds as a transition zone before seaward migrations. Catches of coastal cutthroats are reported in annual RNSP beach seine surveys of the estuary, but their numbers are relatively low. Additional information about coastal cutthroat use of the estuary can be found in Anadromous Salmonids Status and Life History in Section III of this report.

Coho Salmon

Juvenile coho rely on the estuary for feeding, rearing, and for acclimating to changes in salinity before entering the ocean. They tend to be most abundant in June when the mouth is still open, but some have been caught after the mouth has closed (Dave Anderson, RNSP, and personal communication).Several juvenile coho have been collected in the estuary (1,390 ± 630 in year 2000) and a few have resided in the lagoon over the summer (Anderson 2000). Small numbers (<50) of juvenile coho are usually captured in the lagoon during annual (June through October) fish sampling. Some coho may reside in the estuary/lagoon by their own volition as they were not ready for life at sea before the mouth closed. Little is known of juvenile coho use of the estuary/lagoon for winter or spring residence. Additional information about coho salmon use of the estuary can be found in Anadromous Salmonids Status and Life History in Section III of this report.

Estuary Subbasin General Issues

Key salmonid fishery issues of concern identified for the Redwood Creek estuary include:

Channel modifications from the flood control levee system have likely had the most impacts to the physical form and alterations of natural processes that drive the estuarine ecosystem:

- The affects of levees exacerbate sediment accumulations and a contribute to the loss of tidal connectivity to slough channels and a reduction in tidal prism;
- Removal of riparian trees for pasture development and levee construction caused the loss of benefits from the riparian forests;
- Riparian vegetation is periodically removed from the estuary channel as part of a levee maintenance procedure.

Since it is located at the bottom of the basin, the estuary is particularly susceptible to watershed cumulative effects:

- Juvenile salmonids that reside and pass through the estuary during spring and early summer during seaward migrations find favorable water quality conditions for rearing and may acclimate to changes in salinity and temperature;
- Much of the water quality and sediment characteristics of the estuary are related to upstream watershed conditions.

The low gradient, depositional reach of Redwood Creek in the Estuary Subbasin accumulates sediments delivered from upstream source and transport reaches:

- These include relatively warm water inputs and high levels of sediment delivery.

Juvenile salmonid rearing success is impaired by estuarine habitat conditions:

- The fish rearing area of the Redwood Creek estuary/lagoon has been reduced by 50 to 75%;
- Survivorship is very low (estimates of 7-15%) for juvenile Chinook and steelhead that rear in the lagoon through the summer;
- The estuary/lagoon once supported an abundant, year round population of coastal cutthroat trout. At present, only a few coastal cutthroat are found during fish surveys;
- The estuarine channels are shallower compared to historic conditions;
- Habitat shelter complexity is low due to a lack of riparian vegetation and LWD;
- Dissolved oxygen levels can be at stressful or lethal levels in the slough channels.

Estuary habitat improvement projects have been proposed:

- A large amount of work has been done by RNSP, private landowners, public agencies, and interested parties to develop alternatives to improve habitat conditions in the estuary/lagoon, while protecting Highway 101 and the Town of Orick. These include various levee setback alternatives and shortening the extent of the levees to exclude the lowermost channel reach;
- A properly functioning riparian zone is needed to improve the estuarine ecosystem and increase the estuary's value as salmonid habitat.

Integrated Analysis and Cumulative Effects

The Redwood Creek estuary/lagoon receives water and sediment originating from the entire drainage basin. As such, much of the water quality and sediment characteristics of the estuary are related to upstream watershed conditions. These include relatively warm water inputs and high levels of sediment delivery. However, modifications from land development surrounding the estuary and the flood control levee system have likely had the greatest effects to the physical form and alteration of natural processes that drive the estuarine ecosystem. Flood control levees built in 1968 account for the largest change to the estuarine ecosystem. As a result of modifications, the fish rearing area of the Redwood Creek estuary/lagoon has been reduced by 50 to 75%. Cumulatively, these changes to the channels and surrounding delta ecosystem have impaired the physical and biologic function and reduced the capacity of the estuary/lagoon to support salmonids.

Most of the subbasin is located within three miles of the ocean so the local climate is strongly influenced by cool, marine air masses and coastal fog. The marine climate helps to somewhat cool the warm water coming from the much warmer inland areas during the summer months.

The estuarine channel typically maintains an open connection with the sea from the onset of fall rains until the following June or July. While the mouth is open, cool flows of mid-fall to spring seasons conveyed by the creek and cold water delivered by ocean tides mix together to make favorable water temperature and dissolved oxygen levels. Variable salinities in the channel gradually decrease with distance upstream from the mouth. The cool water is important because adult salmon that enter the creek in fall occasionally must hold in the estuary until rains increase stream flows to allow passage upstream to spawning habitat. Juvenile salmonids that reside and pass through the estuary during spring and early summer during seaward migrations find favorable water quality conditions for rearing and may acclimate to changes in salinity and temperature.

The low gradient, depositional reach of Redwood Creek in the Estuary Subbasin accumulates sediments delivered from upstream source and transport reaches. The affects of levees may exacerbate this net sediment accumulation. Because, coarse sediment moving events are of limited duration, it may take several large high flow events to transport coarse gravels and cobbles through the estuary. During coarse sediment transport events, instead of spreading across a wide flood plane, coarse sediments accumulate into tall bars within the confined levee channel (Randy Kline, RNSP, personal communication). The bars also function as large roughness elements and are associated with deep pool habitats needed for fish. However, the aggraded gravel bars reduce channel capacity and the effectiveness of the levees to prevent flooding. At times the channel gravels bars are excavated to remove gravel accumulations. Removing these bars diminishes the pools associated with them.

The estuary flood plain and riparian zone was once dominated by redwoods, Sitka spruce forest and adjacent wetlands were forested with red alder, spruce, and sedge (Ricks 1983). Removal of riparian trees for pasture development and levee construction caused the loss of benefits from the riparian forests. These include a loss of shade to help cool water and elimination of a source of important overhanging and instream vegetation that provides shelter for fish. The loss of riparian vegetation also reduces the amount of terrestrial insect food supplies and stops local delivery of nutrients in the form of leaf litter and wood. To preserve channel capacity, any growing riparian vegetation is periodically removed from the estuary channel as part of a levee maintenance procedure. A properly functioning riparian zone is needed to improve the estuarine ecosystem and increase the estuary's value as salmonid habitat.

There are few historically active landslides in the estuary subbasin (Table IV- 10). Looking at relative landslide potential and land use or land type, about 32% of the road length is found on areas with high or very high relative landslide potential (Table IV- 10). This is the lowest percentage for all of the subbasins.

Timberland comprises the largest land type in the subbasin. Forty-five percent of the Estuary Subbasin area (1,546 acres) consists of timberland on areas of high or very high landslide potential (Table IV- 11). The bulk of the woodland and grassland in the subbasin (641 of 800 acres or 80%) is found on very low relative landslide potential. Table IV- 10 does not show areas that do not fit into any of the three area-based land types or land uses in the subbasin including 663 acres or 19% of the subbasin area predominantly in agriculture and developed areas on relatively flat and stable ground.

Table IV- 10. Historically active landslide features and relative landslide potential by land type or land use.

Unit of Analysis	Historically Active Landslide Feature[1]	Entire Unit of Analysis		Woodland and Grassland[2]		THPs 1991 – 2000[3]		Timberland, No Recent Harvest[4]		Roads	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Estuary Subbasin (3,433 acres) (15.9 road miles)	Earthflow										
	Rock Slide	1	0.0%					1	0.0%		
	Debris Slide										
	Debris Flow	1	0.0%								
	All Features	2	0.1%	0	0.0%	0	0.0%	1	0.0%	0	0.0%
	Relative Landslide Potential										
	Very Low	1,457	42.4%	641	18.7%			223	6.5%	8.1	50.9%
	Low	67	2.0%	7	0.2%			57	1.7%	1.0	6.3%
	Moderate	216	6.3%	55	1.6%			136	4.0%	1.7	10.7%
	High	1,200	35.0%	76	2.2%			1,095	31.9%	4.0	25.2%
	Very High	486	14.2%	21	0.6%			451	13.1%	1.1	6.9%
	High/Very High Subtotal	1,686	49.1%	97	2.8%			1,546	45.0%	5	32.1%
	TOTAL	**3,426**	**100%**	**800**	**23%**	**0**	**0%**	**1,963**	**57%**	**16**	**100%**

[1] Refer to Plate 2 and California Geological Survey appendix. Areas of disrupted ground are not included as active landslide features in this analysis. These areas are likely underlain by earthflow or rockslide complexes. If so, this would substantially increase the miles of roads and area of land type and land use on active landslide features.
[2] Woodland and grassland category includes areas mapped in 1998 as grassland and non-productive hardwood.
[3] THPs are complete or active between the 1991 and 2000 timeframe.
[4] Area of timberlands that were not contained in a THP during the 1991 to 2000 period; includes parklands with timberland characteristics. Percent of area is based on the unit of analysis: watershed or subbasin.

Table IV- 11. Estuary Subbasin integrated information summary.

Relative Landslide Potential	Acres	% Area
Very Low	1,457	42.4%
Low	67	2.0%
Moderate	216	6.3%
High	1,200	35.0%
Very High	486	14.2%
High/Very High Subtotal	1,686	49%
GRAND TOTAL	**3,426**	**100%**
Landslide and Selected Geomorphic Features	**acres**	**% area**
Historically Active Landslide Features Total	2	
Earthflow	1	0.0%
Rock Slide	0	0.0%
Debris Slide	0	0.0%
Debris Flow	1	0%
Dormant Landslide Features Total	**700**	**20%**
Selected Geomorphic Features Total	**617**	**18%**
Disrupted Ground	277	8%
Debris Slide Slope	337	10%
Inner Gorge (area)[2]	3	0%
Total of All Above Features	**1320**	**39%**
Other Land Uses	**acres**	**% area**
Grazing	113	3.3%
Agriculture	1	0.0%
Development	0	0.0%
Timberland, No Recent Harvest	1,963	57.3%
TOTAL	**2,077**	**60.6%**
Roads		
Road Density (miles/sq. mile)	3.0	
Density of Road Crossings (#/stream mile)	0.2	
Roads within 200' of Stream (miles/stream mile)	0.1	
Streams	**% stream length**	
% Stream by Gradient		
< 1% (Response Reach)		77.4%
1-4% (Response Reach)		6.8%
4-20% (Transport Reach)		11.6%
>20% (Source Reach)		4.3%
Historically Active and Dormant Landslide and Selected Geomorphic Features[4]	**% area**	**% stream length**
Within 180' of Blue Line Stream	1.2%	2.5%

[1] Refer to California Geological Survey appendix for landslide map (Plate 1), relative landslide potential map (Plate 2), and description. Areas of disrupted ground are not included as active landslide features in this analysis. These areas are likely underlain by earthflow or rockslide complexes. If so, this would substantially increase the miles of roads and area of land type and land use on active landslide features.

[2] Area based on inner gorges captured as polygons plus inner gorges captured as linear features, which are treated as having an average width of 100 feet.

[3] Category 1 includes clearcut, rehab, seed tree step, and shelterwood seed step prescriptions; Category 2 includes shelterwood prep step, shelterwood removal step, and alternative prescriptions; Category 3 includes selection, commercial thin, sanitation salvage, transition, and seed tree removal step prescriptions.

[4] Landslide features and selected geomorphic features include earth flow, rock slide, debris slide, debris flow, debris slide slopes, disrupted ground, eroding banks and inner gorges.

There was no timber harvest activities in the 1990–2003 period.

EMDS Stream Reach Condition and Limiting Factors Analysis

No stream surveys were performed in the Estuary Subbasin so there are no data to evaluate with the EMDS stream reach model. A list of factors limiting salmonid production in the estuary is provided as a response to the assessment questions below.

Refugia Areas

The channels within the Estuary Subbasin are considered high potential refugia habitat.

Responses to Assessment Questions

What are the history and trends of the size, distribution, and relative health and diversity of salmonid populations?

- The Redwood Creek estuary/lagoon supports populations of Chinook and coho salmon and steelhead and coastal cutthroat trout;
- Juvenile salmonids use an estuarine rearing strategy to increase in size before entering the sea;
- Survivorship is very low (estimates of 7-15%) for juvenile Chinook and steelhead that rear in the lagoon through the summer;
- The estuary/lagoon once supported an abundant, year round population of coastal cutthroat trout. At present, only a few coastal cutthroat are found during fish surveys;
- Small numbers of coho salmon are captured during fish surveys in the lagoon in most years;
- Coho may have used the estuary/lagoon to a greater extent in the past;
- The numbers of adult salmonids returning to the Redwood Creek Basin of any brood year or stock may depend on their numbers and condition when they leave the estuary/lagoon environment as juveniles;
- The estuary once provided a popular and productive sport fishery, but the salmon fishery has drastically declined in angler effort and catch.

What are the current salmonid habitat conditions? How do these conditions compare to desired conditions?

- The estuary/lagoon provides critical year-round juvenile rearing habitat for all salmonids of Redwood Creek;
- Under present conditions the estuary/lagoon is much less suitable for supporting salmonids compared to historic conditions;
- The estuary provides a migration pathway and transitional habitat needed by anadromous salmonids as they migrate to and from the freshwater and marine environments;
- The fish holding and rearing area of the Redwood Creek estuary/lagoon has been reduced by 50 to 75 percent;
- The impaired condition of the estuary/lagoon likely contributes to the low over summer survival rate of juvenile Chinook and steelhead;
- Levees prevent connectivity and change the natural circulation patterns between the main channel, slough channels, and surrounding wetlands;
- The reduction in tidal connectivity and loss of area due to sedimentation has contributed to an overall loss in the estuary tidal prism;
- The estuarine channels are shallower compared to historic conditions;
- Water temperatures raise above desirable levels in the lagoon;
- Low dissolved oxygen levels likely contribute to high mortality rates for juvenile salmonids rearing in the lagoon over the summer and early fall seasons;
- Riparian vegetation is lacking along the Redwood Creek estuary channel. Therefore there is no shade, or nutrient inputs, drifts insect inputs, or shelter provided by overhanging and instream vegetation;
- Habitat shelter complexity is low due to a lack of riparian vegetation and LWD;
- Dissolved oxygen levels can be at stressful or lethal levels in the slough channels;
- Large amounts of blue-green algae cover portions of the north slough channel bottom;

- The lower reach of Strawberry Creek lacks channel complexity and lacks functional riparian vegetation;
- A properly functioning riparian zone is needed to improve the estuarine ecosystem and increase the estuary's value as salmonid habitat.

What are the past and present relationships of geologic, vegetative, and fluvial processes to stream habitat conditions?

- The relatively flat delta area surrounding the estuary was formed from fluvial deposits;
- The delta area is naturally prone to flooding during high winter flows and to a lesser extent under lagoon conditions;
- The area of the embayment near the mouth has accumulated excessive sediments delivered by ocean tides. Sediment accumulations derived from both terrestrial and marine origins have become excessive in the estuary and have contributed to reduction of estuarine area, channel diversity, and channel depth;
- In the past, the estuarine channels were deeper, more diverse, and more complex. At present, the channel is straightened, shallow, and less diverse. Connectivity between the North slough channels is greatly reduced;
- Excessive amounts of accumulated sediment has reduced tidal flows into the north slough channel and contributes to more than a 50% reduction in area and a loss of depth of the lower estuary;
- The North slough channels (Dorrance and Sand Cache creeks) were historically maintained by tidal currents and the flushing of sediments by the tidal prism. The accumulation of marine sediments at the mouth of the North Slough has reduced the connectivity with the main channel and contributed to the loss of tidal prism;
- Algal decomposition may increase the biological oxygen demand, which may contribute to low dissolved oxygen levels observed in the North Slough channel;
- Channel aggradation has been exacerbated by severe erosion in the upstream subbasins and by levee configuration;
- Warm water inflows from Redwood Creek help sustain high water temperatures in the lagoon;
- Intermittent surface flow between the Redwood Creek and the estuary/lagoon in 2001 and 2002 is linked to the aggraded channel, increased bed elevation, and widened lower, mainstem reach in the Lower Subbasin;
- Due to excessive sediment accumulations and reduction of the tidal prism, the estuary mouth may close earlier in the year than it did historically;
- Riparian forests are no longer present to provide a shade canopy, nutrient inputs, or shelter from woody debris.

How has land use affected these natural processes?

- Over the past 125 years, the physical structure and natural processes of the estuary have been altered by conversion of riparian forest and wetlands to pasture lands, and by the impacts from the flood control levee system;
- The removal of riparian vegetation for pasture development and levee construction and maintenance has disrupted the natural processes of trees providing shade to help cool water temperatures. Loss of riparian forests also prevent inputs of woody debris, instream vegetation and overhanging vegetation for fish shelter, and nutrient inputs from terrestrial insects, leaf litter, and wood materials;
- The main estuarine channel is narrowed, confined and straightened by the levees which have altered intrinsic estuarine fluvial processes that transport and store sediments;
- Excessive sediment inputs related to upstream land use have contributed to sediment accumulations in the estuary and associated loss of channel depth and habitat diversity;

- After levee construction, large amounts of marine sediments have accumulated in the lower embayment and at the mouth of the North Slough channel;
- The present levee system has simplified the estuary channel by reducing sinuosity and channel diversity and contributed to aggradation and a loss of channel area and depth;
- Much of the historic connectivity between freshwater and tidal flow is blocked by the levees;
- The Strawberry Creek channel has been ditched, re-routed, and riparian vegetation has been removed. Cattle have free range to graze along the banks of the stream zone contributing to bank instability, fine sediment, and nutrient delivery to the creek. Some vegetation grows in the creek channel, which impedes the transport of sediment downstream;
- Waste from cattle likely enters into the Strawberry Creek and slough channels which may fuel algal growth.

Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?

- The present condition of the estuary/lagoon is considered a significant factor limiting anadromous the production of anadromous salmonids of the Redwood Creek basin;
- High over summer juvenile mortality rates in the lagoon are likely linked to present habitat conditions;
- Limiting factors that impair the ability of the estuary/lagoon to support salmonids include:
    - A reduction in size of the estuarine channel area, restricting rearing area available to salmonids
    - A loss of channel connectivity with adjacent wetlands and sloughs, restricting rearing area available to salmonids;
    - A loss of channel depth, diversity, and complexity, rearing escape/ambush cover, and territorial space;
    - A loss of riparian vegetation function, reducing shade, land, and nutrients for rearing fish;
    - Stressful water temperatures and low dissolved oxygen levels;
    - The lack of instream shelter elements;
    - Predation on salmonids;
    - Intermittent flow delivery from Redwood Creek during dry summer months.

What watershed and habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

- A great amount of work has been done by RNSP, private landowners, public agencies, and interested parties to develop alternatives to improve habitat conditions in the estuary/lagoon, while protecting Highway 101 and the Town of Orick. These include widening the levees and shortening the extent of the levees to exclude the lowermost channel reach;
- The use of levee set backs, reconfiguration, or levee removal strategies to develop a wider flood plain that restores natural sinuosity, improves connectivity with sloughs and adjacent wetlands, and the allows the development of an effective zone of riparian vegetation will contribute to a large improvement to the estuarine ecosystem. The following recommendations are provided to help guide the goals and objectives of a project to benefit the estuarine ecosystem and in turn increase the production and carrying capacity of anadromous salmonids in the estuary/lagoon.

Flow and Water Quality Improvement Activities:

- Increase tidal prism by restoring tidal and riverine flow and connectivity between the main channel and slough channels;
- Increase depth and tidal exchange at the confluence of North Slough channel;
- Increase circulation between the lagoon, Strawberry Creek and sloughs to help mix water and increase dissolved oxygen levels;

- Prevent or reduce cattle waste from entering stream and slough channels;
- Develop a shade corridor of riparian trees along main channel to help cool water;
- Land managers should work to maintain and/or establish adequate streamside protection zones to reduce solar radiation and moderate air temperatures into Redwood Creek and its tributaries throughout the Redwood Creek basin;
- The goal of any controlled breech project must be to maintain the volume in the lagoon to best support the anadromous fisheries;
- Digging of any artificial channel through the beach sand berm that would result in an uncontrolled breech should be discouraged;
- Any controlled breech should be performed as an option and in coordination with the expert judgment of RNSP staff and CDFG to preserve natural resources.

Erosion and Sediment Delivery Reduction Activities:

- Reduce inputs of sands by tidal currents to the embayment and North Slough by modifying levee configuration or removing levees altogether;
- Use levee set back, reconfiguration or removal strategies to achieve more natural flood plain characteristics;
- Land managers should continue their efforts such as road improvements, good maintenance, and decommissioning and other erosion control practices associated with all land use activities throughout the basin to reduce sediment delivery to lowermost Redwood Creek and the estuary.

Riparian and Instream Habitat Improvement Activities:

- A properly functioning riparian zone is needed to improve the estuarine ecosystem and increase the estuary's value as salmonid habitat;
- Where feasible, develop or improve riparian vegetation function along the banks of Redwood Creek, Strawberry Creek, and slough channels;
- Work to restore natural drainage patterns within adjacent wetlands and the subbasin;
- Increase off-channel and rearing habitat by improving conditions of sloughs and tributaries (Strawberry, Dorrance and Sand Cache creeks);
- Increase depth and complexity in the main channel and slough channels;
- Where feasible add LWD to increase salmonid shelter complexity;
- Leave large wood in estuarine channels, on the beach, and on stream banks for potential recruitment into the estuary;
- Relocate drift logs that block tidal connectivity between the embayment and the North Slough channels; logs could be assembled into minimum logjams and anchored into appropriate areas in the main channel;
- Re-establish a corridor of riparian vegetation to lower Strawberry Creek and restore riparian function in areas where vegetation removal or significant cattle impacts have been noted. This may require temporary fencing the riparian zone to prevent cattle and deer from grazing on seedlings and trampling growing trees.

Education, Research, and Monitoring Activities:

- Work should continue by Redwood National and State Parks (RNSP), private landowners, agencies, and interested parties to improve habitat conditions of the estuary by modifying the levee system while protecting Highway 101 and the town of Orick;

- RNSP, CDFG, RWQCB should continue existing monitoring of anadromous salmonid populations and expand to include some winter and early spring sampling;
- Water temperature and dissolved oxygen monitoring in the lagoon and sloughs should continue. Some dissolved oxygen measurements should be collected just before sunrise to capture lowest diurnal levels;
- Monitoring water quality in the lagoon should be expanded to include nutrient levels (ammonia, nitrates, nitrates) that may be elevated from runoff from cattle pastures;
- Work with USACE, Redwood National and State Parks, and Humboldt County Department of Public Works to modify levees and levee maintenance manuals to be consistent with habitat requirements of salmonids and a properly functioning estuarine ecosystem.

Subbasin Conclusions

The Redwood Creek estuary/lagoon plays a vital role as habitat for juvenile and adult anadromous salmonids. The estuary/lagoon once had all of the characteristics of excellent anadromous salmonid habitat, but its present value as fisheries habitat is greatly reduced compared to the historic condition. Over the past 125 years, the estuary area was altered by conversion of forest, riparian and wetland areas to pasture land, and by channel modifications and levee construction. These changes combined with sediment accumulations have impaired the physical and biologic function and capacity of the estuary/lagoon to support salmonids. The present estuary condition limits salmonid production.

The Redwood Creek estuary is an excellent candidate area for channel and riparian improvement projects that benefit for anadromous salmonids. RNSP and others have developed management alternatives to improve the estuarine habitat while offering flood control protection to the town of Orick and pasturelands surround the estuary. The recent project alternatives involve levee removal, relocation, and re-configuration. A restoration project should benefit fish production by increasing the depth and area of the lower embayment while increasing depth, shelter, connectivity, and circulation between the main channel and slough channels. Projects that increase the estuary/lagoon’s juvenile salmonid carrying capacity and survival rate during the summer months should receive high priority. Restoration efforts that move conditions and processes towards historic status also will benefit other fish and wildlife resources of Redwood Creek.

Prairie Creek Subbasin

The Prairie Creek Subbasin includes the May Creek and Lost Man Creek planning watersheds and a large portion of the Skunk Cabbage Creek Planning Watershed. Prairie Creek drains approximately 40 square miles of the northwestern portion of the Redwood Creek basin and joins Redwood Creek near river mile 3.5. (Figure IV- 10). Most of the Prairie Creek watershed (98%) is in public lands managed by the Redwood National and State Parks (RNSP) (Table IV- 12). The RNSP is a World Heritage Site and is part of the California Coast Range Biosphere Reserve, designations that reflect worldwide recognition of the parks' natural resources as irreplaceable.

Prairie Creek and its eight major tributary streams support populations of Chinook salmon, coho salmon, steelhead, and coastal cutthroat trout. Much of the upper watershed of Prairie Creek and Little Lost Man Creek watersheds are relatively undisturbed areas. These areas retain old growth forest characteristics and provide some of the highest quality fisheries habitat within the Redwood Creek basin.

Table IV- 12. Prairie Creek Subbasin summary.

Square Miles	39.59
Total Acreage	25,339
Private Acres	463
Federal Acres	18,247
State Acres	6,629
Predominant Land Use	Park Land
Predominant Vegetation Type	Redwood Forest
Miles of Anadromous Stream	24
Low Elevation (feet)	26
High Elevation (feet)	2,270

Geology

This Prairie Creek Subbasin appears domed and uplifted across a broad zone extending from Orick northward to the town of Klamath. Major drainages trend northwest (e.g., Skunk Cabbage Creek, Squashan Creek, etc.); subsidiary drainages are nearly perpendicular to the trend of the major drainages and are oriented to southwest and west-southwest. The stream orientations may be controlled by a set of fractures in the underlying bedrock.

The Grogan fault zone trends southwest of and parallel to Squashan Creek and the fault may control the location of the creek. However, the fault zone is covered in this area by deposits of the Prairie Creek Formation. The Pliocene-Pleistocene Prairie Creek Formation dominates the bedrock exposures west of Highway 101. The Prairie Creek Formation is moderately cemented sand and gravel deposited at the ancestral mouth of the Klamath River. Other sub parallel structural features (faults or lineaments) may influence the locations and orientations of Fern Canyon, Little Lost Man Creek, and Prairie Creek.

The major drainages on west side of Prairie Creek generally have gentle gradients at their heads and flat-floored valleys. Stream profiles steepen towards the modern Redwood Creek channel rather than flattening downstream as is more typical of drainage profiles. This pattern appears to be in response to the regional deformation.

Hanging valleys visible along Gold Bluffs provide geomorphic evidence of headward erosion and stream capture. Some of the drainages along the coastal bluffs west of Highway 101 have seasonal waterfalls. Main drainages do not appear to be actively moving sediment at this time because there is little incision except around the periphery as the system starts to adjust to lower base level.

Drainages east of Highway 101 are steeper and underlain by the Coherent unit of Lacks Creek. Outcrops at higher elevation have been uplifted along a normal fault (Kelsey 1989, unpublished mapping), and Franciscan Complex rocks are exposed below the Prairie Creek Formation in the eroded fault scarp.

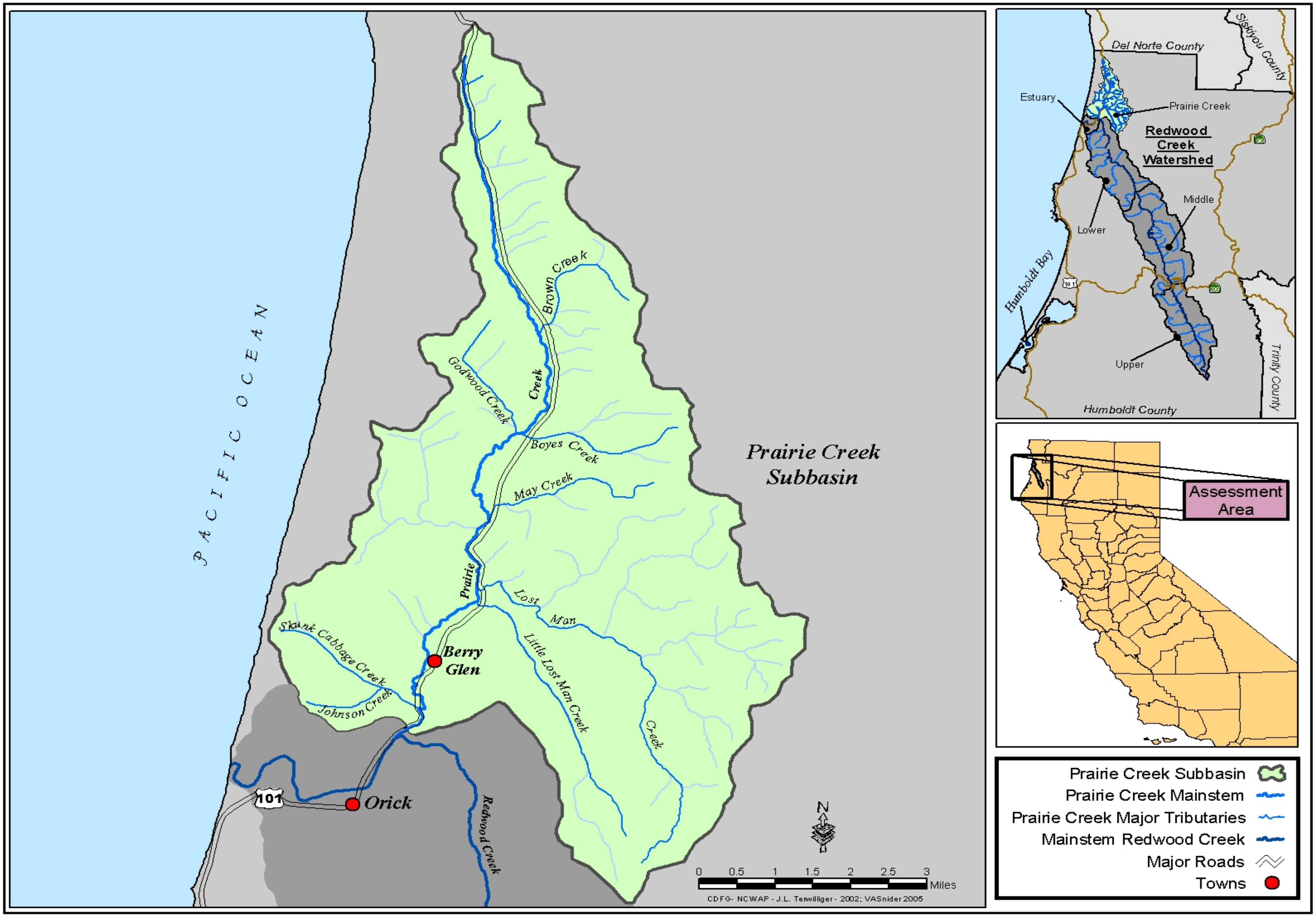

Figure IV- 10. Prairie Creek Subbasin and its tributaries.

Mass wasting features, particularly debris slides, are common in the Prairie Creek Formation (QTpc). Steeper terrain & debris slide slopes are present in the southern half of the subbasin. This difference may be caused by a change in the underlying bedrock. Occasional inner gorges are present near the lower portions of the slopes east of Highway 101.

The southeast portion of the drainage contains numerous rotational landslides and earth flows and is largely underlain by the Coherent unit of Lacks Creek (KJfl). An excessive amount of sediment made its way into the system as a result of the Highway 101 bypass construction. Exposed sandy fills were highly susceptible to erosion, and roadway sanding during icy conditions in the winter continues to pose a major sedimentation problem. Channel bottoms are naturally fine grained because of the sandy parent material and the low channel gradients. The highway activities probably have exacerbated this situation.

While over half of the Prairie Creek Subbasin falls within the high- to very high mass wasting potential category, historically active features account for less than 1.5% of the subbasin area (Table IV- 13). This information is also presented in map form in Plates 1 and 2 in the CGS geology appendix. Debris slides and debris flows are the primary modes of failure, and this is usually in steep areas underlain by the Prairie Creek Formation. Large dormant landslides and earthflows occupy only 8% of the area and most of these are in the portion of the subbasin underlain by the north facies of the incoherent unit of Lacks Creek (Plate A, Sheet 1, CGS appendix).

Table IV- 13. Prairie Creek Subbasin summary of relative landslide potential and landslide features.

Factors	**Prairie Creek Subbasin**		**Planning Watersheds**				**Skunk Cabbage Creek Drainage**	
			Area (acres)	**% of Area**	**Area (acres)**	**% of Area**		
Relative Landslide Potential	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Very Low	3,492	13.8	1,627	12.8	1,664	14.8	201	14.2
Low	3,017	11.9	1,672	13.2	1,214	10.8	131	9.2
Moderate	4,565	18.0	2,106	16.6	2,167	19.3	292	20.6
High	9,480	37.5	4,288	33.8	4,538	40.5	654	46.1
Very High	4,750	18.8	2,980	23.5	1,628	14.5	142	10.0
High/Very High Subtotal	14,230	56	7,268	57	6,166	55	796	56.1
Grand Total	**25,304**	**100**	**12,673**	**100**	**11,211**	**100**	**1,420**	**100.0**
Landslide and Selected Geomorphic Features	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Historically Active Landslide Features Total	348	1.4	279	2.2	69	0.6	0	0.0
Earthflow	13	0.1	12	0.1	1	0.0	0	0.0
Rock Slide	25	0.1	16	0.1	9	0.1	0	0.0
Debris Slide	161	0.6	157	1.2	4	0.0	0	0.0
Debris Flow	148	0.6	94	0.7	55	0.5	0	0.0
Selected Geomorphic Features Total	2,493	10	1,454	11.5	1,040	9.3		
Disrupted Ground	355	1	355	2.8	0	0.0		
Debris Slide Slope	2,067	8	1,083	8.5	985	8.8		
Inner Gorge (area)	71	0	16	0.1	55	0.5		
Dormant Landslide Features Total	**2,022**	**8**	**1,758**	**13.9**	**169**	**1.5**	**95**	**6.7**
Total of all above features	**4,863**	**19**	**3,490**	**27.5**	**1,278**	**11.4**	**95**	**6.7**

Streamside Landslides

Table IV- 14 presents information on the number of streamside landslides for the Prairie Creek Subbasin, which decreased 82% between 1984 and 2000. The decrease mostly reflects improvement in the Lost Man Creek planning watershed, which has the bulk of the streamside landslides found in the subbasin. The May Creek planning watershed also had fewer active streamside landslides in 2000 as compared to1984.

Table IV- 14. Prairie Creek Subbasin number and indices of streamside slides by subbasins and planning watersheds in 1984 and 2000.

Subbasin or Planning Watershed Unit of Analysis	Analysis Unit Area (sq. km.)	1984 # of Active* Slides Along Streams	2000 # of Active* Slides Along Streams	1984 Indexed** Active Slides	2000 Indexed** Active Slides	% Change 1984-2000
Prairie Creek Subbasin	96.9	92	17	95	18	-82
Lost Man Creek	51.4	86	12	167	23	-86
May Creek	45.5	6	5	13	11	-17

**Index = (# slides/analysis unit area) X 100

Vegetation

Vegetation within the Prairie Creek Subbasin consists almost entirely of conifers (Table IV- 15 and Figure IV-11). These conifer stands are, for the most part, two different types. Areas of old growth redwood and Douglas-fir occupy most of the northern portion of the subbasin. Healthy, well-stocked second growth redwood forests are growing on the previously harvested lands in the subbasin. However, some of these second growth stands appear to be overstocked and may be loosing vigor due to competition.

Table IV- 15. Generalized cover type by subbasin and planning watershed.

Subbasin or Planning Watershed	Cover Type								
	Agriculture	Barren	Conifer	Hard-wood	Grass-land	Shrub	Developed	Water	Total
Prairie Creek Subbasin	0	132	24,173	604	387	36	27	0	25,359
May Creek	0	127	10,899	72	140	0	0	0	11,238
Lost Man Creek	0	5	13274	532	247	36	27	0	14,121

Redwood and redwood-Douglas-fir forest (21,999 acres in total) and Sitka Spruce-redwood forest (1,579 acres) comprise about 93% of the Prairie Creek subbasin. Douglas-fir forest covers just 51 acres, or less than 1% of the subbasin. One area (132 acres) classified as barren follows the newer section of Highway 101, commonly referred to as the "bypass."

Land Use

The great majority of lands within Prairie Creek Subbasin are managed by the RNSP. The RNSP land management strategies include: 1) perpetuation of the redwood forest and associated ecosystems as prime resources; 2) perpetuate ongoing natural influences on the basis of natural values and visitor use; and 3) protect threatened and endangered species and species of special concern (USDOI 1999). The private lands within the basin (approximately 460 acres) are in part used for livestock grazing

Timber Harvest

Timber harvests and other land use in the Prairie Creek Subbasin began soon after the local gold rush of the 1850s. The size of the huge redwood trees made them prized timber. Large-scale logging was soon underway and the once immense stands of redwoods began to disappear by the close of the 19th century.

In the early 1920s, the Save-the-Redwoods League purchased approximately 14,000 acres, creating a sanctuary of old growth coast redwood in the upper Prairie Creek watershed. Logging continued in those parts of the forests that were privately owned, accelerated by increased demand for timber during WW II, and the economic boom of the 1950s. It wasn't until 1968 that Redwood National Park was established, which secured some of the few remaining stands of uncut redwoods. In 1978, Congress added more land that included logged-over portions of Redwood Creek. Today, these lands are undergoing large-scale restoration by the Park resource managers.

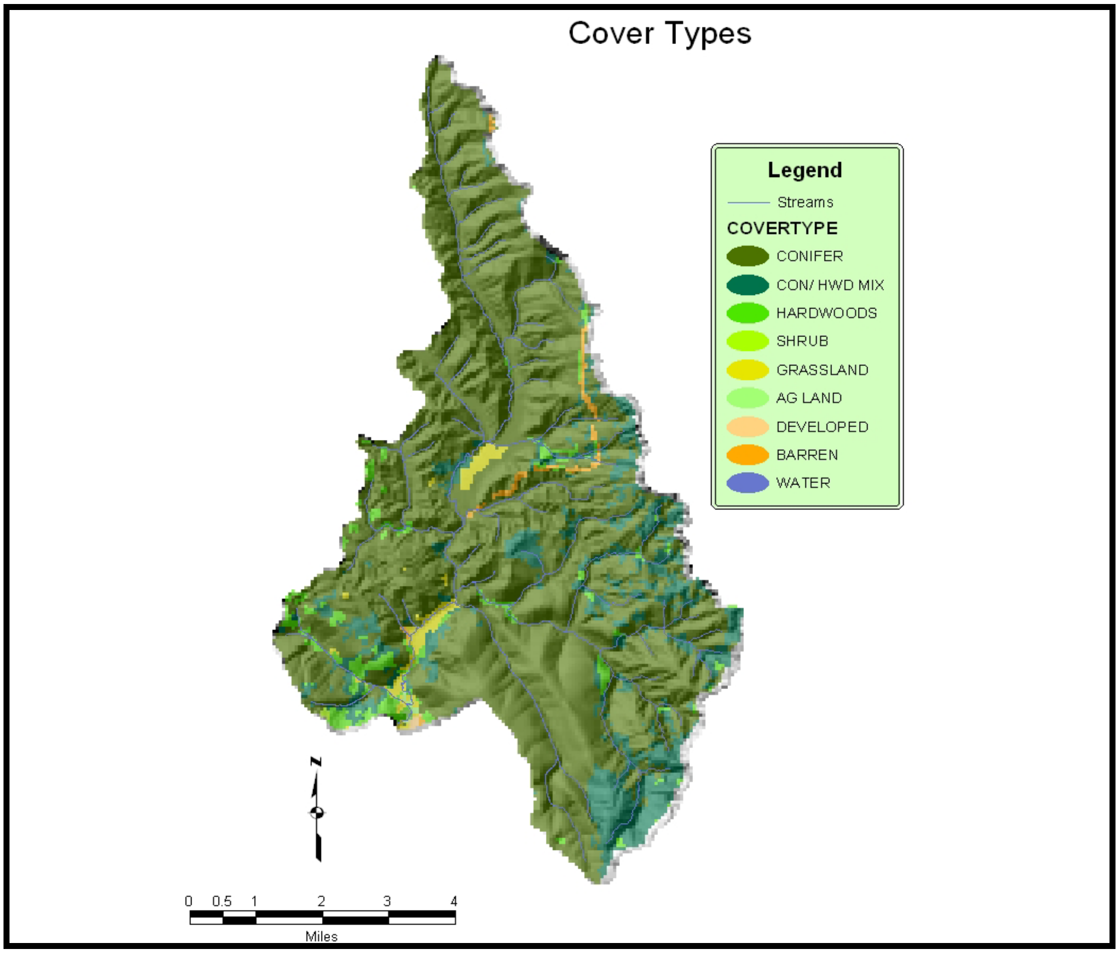

Figure IV- 11. Prairie Creek vegetation map showing cover types.

Before the expansion of Redwood National and State Park, over half of the watershed was logged. Timber harvests and associated road construction occurred in the May Creek, Boyes Creek, Lost Man Creek, and Skunk Cabbage Creek watersheds. Some early tractor logging started in the Prairie Creek Subbasin in the late 1930s, but did not become highly utilized until after World War II. By 1948 the use of tractors had become the primary mover during yarding operations.

A total of 13,542 acres were harvested within the private lands of Prairie Creek Subbasin from 1950 to 1978 (Table IV- 16, Figure IV- 12). Most the major harvest operations occurred between 1950 and 1964. These harvested areas now support stands of well-stocked young-growth forests. Approximately half of this area was partially logged. These areas now contain a mixed stand component of both old growth and second-growth trees.

With the Prairie Creek Subbasin now largely in state and national park ownership, there has been no timber harvest there since 1978. Approximately 460 acres in the subbasin, or about 1.8% of the area, is in private lands today. Any land use on these private lands should protect site-specific values of RNSP lands and consider potential cumulative effects to the subbasin.

Table IV- 16. Prairie Creek Subbasin timber harvest history, 1950-2000.

Subbasin or Planning Watershed	Harvest Acres by Period							
	1950-1964	1965-1974	1975-1983	1984-1992	1992-2000	Total Harvested	Total Acres	Percent Harvested
Prairie Creek Subbasin	11,236	1,387	919	0	0	13,542	25,305	53.5
May Creek	4,216	59	378	0	0	4,653	11,243	41.4
Lost Man Creek	6,426	1,288	475	0	0	8,189	12,704	64.4
Skunk Cabbage Creek Drainage	594	40	66	0	0	700	1,420	49.3

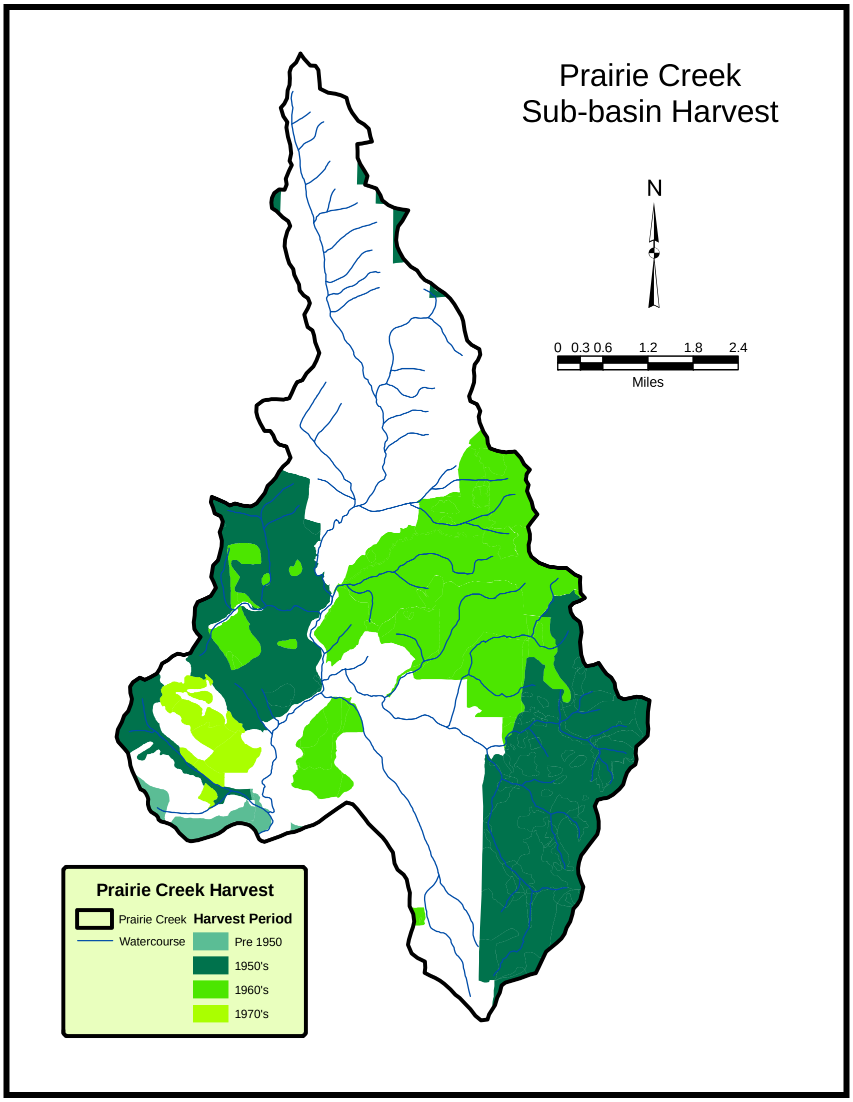

Figure IV- 12. Prairie Creek Subbasin timber harvest.

Roads

The Prairie Creek Subbasin has an estimated 108 miles of roads, or a road density of 2.7 road miles per square mile. An estimated 42% of the road miles are on areas of high or very high relative landslide potential. The bulk of the roads (66 of 108 miles) are in the Lost Man Creek planning watershed, which gives the planning watershed a road density of 5.5 road miles per square mile. The Skunk Cabbage Creek drainage has the lowest road density of 0.8 road miles per square mile.

The majority of the roads in the May Creek, Prairie Creek, Skunk Cabbage, and Lost Man Creek watersheds were constructed before 1950. After 1950 haul road systems, for the most part, followed the drainages themselves. Landings, some quite extensive, were also built in or along the watercourse channel. Roads and landings built in or adjacent to streams create major sediment sources that can result in significant sediment in stream systems and result in significant adverse impacts to fish habitat. The Redwood National and State Parks have removed streamside roads in these areas.

Additional adverse impacts during the construction of the Highway 101 bypass in 1989 from roads occurred. Winter rains eroded exposed soils and delivered large amounts of fine sediments to the headwaters of Prairie Creek tributaries. Salmonid spawning and rearing habitat of Brown, Boyes, and May Creeks were affected by the event. The reach of Prairie Creek downstream of Boyes Creek to the confluence with Redwood Creek was also impacted by the sediment transported downstream from the tributaries.

Fire and Fuels

Fuel ranks were developed for the Prairie Creek Subbasin (Table IV- 17 and Figure IV- 13). These rankings are based on vegetation and slope characteristics and rank potential fire behavior under an assumed constant set of weather conditions (see http://www.frap.cdf.ca.gov/data/fire_data/fuels/fuelsfr.html). Given the relatively cool, damp, marine-influenced weather of the Prairie Creek Subbasin, the fuel rankings alone likely overstate the actual fire risk.

The subbasin is dominated by areas in the high fuel rank, with 80% of the area falling into that class. An additional 4% of the subbasin is modeled as having a very high fuel rank. Small pockets of very high rank exist throughout the subbasin, with the largest area in the southern corner of the Lost Man Creek Planning Watershed. The Skunk Cabbage Creek drainage has relatively lower fuel ranks compared to the Lost Man and May Creek planning watersheds. Only under rare, severe fire weather conditions would the fuel conditions in the Prairie Creek Subbasin pose as high a risk as their rankings imply.

Table IV- 17. Fuel ranks summary for Prairie Creek Subbasin and planning watersheds.

Area of Analysis	Fuel Rank								Total Acres
	Moderate		High		Very High		Not Mapped		
	acres	%	acres	%	acres	%	acres	%	
Prairie Creek Subbasin	3,869	15	20,267	80	955	4	277	1	25,368
Lost Man Creek Planning Watershed	2,290	18	9,708	76	648	5	59	<1	12,705
May Creek Planning Watershed	951	8	9,838	88	239	2	215	2	11,243
Skunk Cabbage Creek Drainage	629	44	721	51	67	5	3	<1	1,420

Fluvial Geomorphology

Prairie Creek is the largest tributary to Redwood Creek. It occupies a narrow channel that is separated from a wide upper floodplain by clearly defined banks (Janda and others 1975). Streambed material is sandy-fine pebble gravel and accumulations of coarse organic debris have been described as sparse (Janda and others 1975). It flows southward along U.S. Highway 101 and drains approximately 40 square miles of redwood forest within RNSP and about 450 acres of privately owned land. Prairie Creek enters the mainstem Redwood Creek about a mile north of Orick.

The subbasin contains low-gradient streams having equal proportions of response and transport reaches. About 41% of the streams are response reaches and 43% transport reaches, 15% of the total reaches have channel gradients less than 1%, and 16% are source reaches steeper than 20% (Table IV- 18). Much of the subbasin, with its low-gradient streams, provides anadromous salmonid habitat.

Table IV- 18. Percent of stream length by stream gradient classes.

% Stream by Gradient	Prairie Creek Subbasin	Planning Watersheds		Skunk Cabbage Creek Drainage
		Lost Man Creek	May Creek	
	% stream length	% stream length	% stream length	% stream length
< 1% (Response Reach)	14.7	17.2	12.2	77.4
1-4% (Response Reach)	25.5	13.4	37.6	6.8
4-20% (Transport Reach)	43.8	54.2	33.3	11.6
>20% (Source Reach)	16.0	15.2	16.9	4.3

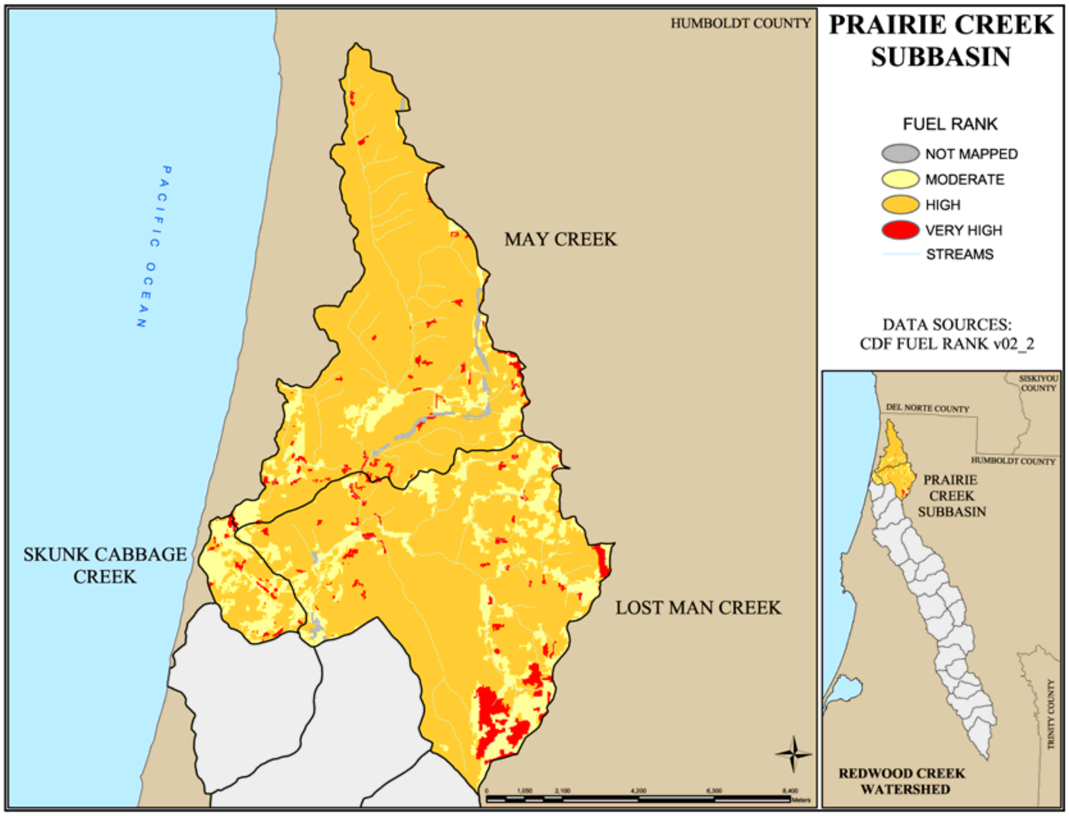

Figure IV- 13. Fuel ranking map of the Prairie Creek Subbasin.

Stream Disturbance

CGS mapped what appeared to be a thousand-foot reach of widened channel in Prairie Creek, just above its confluence with May Creek from air photos taken in 2000. This feature may be an accumulation of sediment that was contributed at least in part by the 1989 storm and consequent erosion of fine sediment from construction activities along the Highway 101 bypass.

However, between 1984 and 2000, negative stream features such as lateral bars, wide channels, and eroding banks decreased 88% from (3.13 mi to 0.37) miles by length in this subbasin (Table IV- 19). This is probably due to a lack of large storms and related erosion and a reduction of sediment inputs during the time interval, as well as to downstream transport of elevated sediment from previous storms. Overall the subbasin showed improvement in the 16-year period.

Table IV- 19. Length of negative stream features, negative stream feature index, and percent change for 1984 to 2000.

Subbasin or Planning Watershed Unit of Analysis	Analysis Unit Area (sq. km.)	Negative Features 1984 (m)	Negative Features 2000 (m)	Indexed Negative Features 1984*	Indexed Negative Features 2000*	% Change 1984-2000
Prairie Creek Subbasin	96.9	5,035	603	52	6	-88
Lost Man Creek	51.4	4,565	279	89	5	-94
May Creek	45.5	470	324	10	7	-31

* Index = (length of negative features in meters/area of unit of analysis in square kilometers)

Water Quality

Temperature

This subbasin contains optimal channel shade and climate conditions creating fully suitable water temperatures for salmonids. Existing data show maximum MWATs of 57°F at two locations on mainstem Prairie Creek from 1997-2001. Three tributaries to Prairie Creek had MWATs between 56 and 58°F with one recording of 64°F in

1974. The Prairie Creek subbasin is influenced by coastal fog and dense canopy cover provided by the redwood forest. Both the coastal climate and forest function to moderate air and water temperatures in the basin.

Maximum daily water temperatures recorded during the summers of 1997 through 2001 for the site in the Prairie Creek Subbasin ranged from 58 to 63ºF (Table IV- 20). These readings did not approach the lethal limit of 75ºF.

Table IV- 20. Prairie Creek Subbasin MWATs recorded between 1997 and 2001.

Site ID	Site	Subbasin	Period of Record	Max MWAT (ºF)	Seasonal Maximum (ºF)
10, Little Lost Man	Little Lost Man	Prairie	1974	57	
20, Lost Man	Lost Man	Prairie	1974	64	
20, Lmc	Lost Man	Prairie	2001	58	61
30, Ldc	Larry Dam Creek	Prairie	2000, 01	57	58
3015	Prairie Creek at Streelow Creek	Prairie	1997, 1999	59	61
3016, prw	Prairie Creek at Wolf Bridge	Prairie	1997-98, 01	60	63

Water Column Chemistry

Eight tributary stations in the Prairie Creek subbasin were monitored by USGS between 1973 and 1977. Data for dissolved oxygen ranged from 8-13mg/L (water quality objective >8mg/L), pH ranged from 6 to 8.3 (water quality objective 6.5-8.5), and conductivity ranged from 20-130umhos (water quality objective <220umhos). Water quality samples taken in Prairie Creek and its tributaries indicate compliance with Basin Plan objectives and no noticeable trends were observed. An assessment of current water chemistry conditions in the Prairie Creek Subbasin is lacking due to the absence of data post 1977. See Appendix C for water chemistry data from Prairie Creek.

In-Channel Sediment

Intensive fine and suspended sediment sampling occurred in Prairie Creek when the California Department of Transportation constructed a highway bypass (1988-90) around and through the watershed and for ten years after construction was completed. A storm in October 1989 eroded fine sediment from exposed areas along the construction site and large amounts of sediment entered Brown, Boyes, and May Creeks. Most of the monitoring from this incident developed from a violated water quality permit and was not a long-term sampling project to monitor and assess the health of Prairie Creek. Data collected under permit requirements showed that impacts to salmonid habitat did occur. Surveys by Welsh and Olliver (1998) in the affected streams found that densities of amphibians were significantly lower in the streams impacted by sediment compared to unaffected eastern tributaries of Prairie Creek of similar attributes. The same factors that may be decreasing stream amphibians could have hindered salmon production in these tributaries of Prairie Creek. The Highway 101 bypass sediment inputs may have also adversely effected salmonid egg survival during the early 90s. Meyer (1994) found that egg survival in the unaffected reach of Prairie Creek (located above Boyes Creek) was higher for both coho and Chinook during the 1991-93 water years compared to reaches that received sediments from the Highway 101 bypass construction. Detailed information about the Prairie Creek Highway 101 bypass project can be found in Rogers (1999), Coey (1998), Klein (1993), Roelofs (1999), Welsh (1999) and many others.

The only D_{50} particle size data in the Prairie Creek sub-watershed obtained for this assessment resulted from a study performed from 1989 to 1991 by the RNSP to monitor the recovery of a dam removal on Lost Man Creek. Due to the specifics of the study and lack of exact spatial locations, the data were not assessed in this report. Most of the samples were taken from a disturbed area; thus the data are not representative of the stream itself, nor does it accurately reflect the status of salmonid spawning habitat in that reach. More information about this study can be obtained from the RNSP.

Existing data for subsurface fine sediment in the Prairie Creek watershed was sampled from Lost Man and Little Lost Man Creeks in 1974 and 1987. Woods (1975) took McNeil core samples in Lost Man and Little Lost Man Creeks and analyzed the samples volumetrically. The 1974 results for the size class <0.85mm from Lost Man Creek was less than 26% and less than 18% from Little Lost Man Creek. Samples from both creeks exceeded the TMDL target of less than 14% fines <0.85mm. Little Lost Man Creek was sampled again in 1987 by the

RNSP, however the samples were analyzed after they had been dried. The 1987 sample can not be compared to TMDL targets nor can they be compared to the 1974 sample due to the different methods of analysis.

Salmonid Habitat Assessment

The Prairie Creek Subbasin supports populations of Chinook salmon, coho salmon, steelhead, coastal cutthroat trout, and other valuable fisheries resources. Streams of the Prairie Creek Subbasin provide approximately half of the tributary habitat (24 miles) available to anadromous salmonids in the Redwood Creek basin (Table IV-21). The Prairie Creek Subbasin is composed of a mix of old growth forest streams (upper Prairie Creek, Godwood Creek, Little Lost Man Creek) and streams impacted by logging, highway construction, and other land use (Lower Prairie Creek, Brown Creek, Boyes Creek, Lost Man Creek, and May Creek).

Table IV- 21. Prairie Creek Subbasin streams, species present, and number of stream miles accessible to anadromous salmonid.

Stream	Species Observed		Stream Length Access (mi.)	References
Prairie Creek	Chinook salmon Coho salmon coastal cutthroat trout steelhead trout chum salmon (rare) Pacific giant-salamander tailed frog	three-spine stickleback coast range sculpin prickly sculpin brook lamprey Pacific lamprey	11.8	CDFG 2001 surveys, Klatte and Roelofs 1999-1997, Neillands 1990, Brown and Anderson 1988
Lost Man Creek	Chinook salmon Coho salmon coastal cutthroat trout Steelhead trout	Pacific lamprey tailed frog Pacific giant-salamander	2.9	CDFG 2001 & 1966 Stream Surveys, carcass surveys 1984-1992, RPN/USFS barrier study notes, Neillands 1990, Brown 1988
Little Lost Man Creek	Chinook coho coastal cutthroat steelhead	Pacific lamprey sculpin sp. tailed frog larvae Pacific giant-salamander	2.0	Klatte and Roelofs 1997, D.J. Manning, et al. 1996, USFS/RNP barrier study 1995, RNP/USFS-RSL revisit of 1981 thesis sites field notes, Neillands 1990, Brown 1988
Brown Creek	Chinook coho coastal cutthroat steelhead trout pacific lamprey	Sucker sculpin sp. tailed frog red-legged frog Pacific giant-salamander	1.4	Klatte and Roelofs 1997, USFS/RNP barrier study 1995, Neillands 1990, Brown 1988, 1988 (referencing CDFG stream surveys)
Boyes Creek	Chinook coho coastal cutthroat steelhead	cutthroat/steelhead three-spined stickleback sculpin sp. Sucker	0.9	Klatte and Roelofs 1997, Brown 1988, 1988 (referencing CDFG stream surveys and Chuck Warren personal communication)
Streelow Creek	coho coastal cutthroat steelhead cutthroat/steelhead Pacific lamprey	sculpin sp. three-spined stickleback Pacific giant-salamander Frogs	1.3	RNP/USFS-RSL revisit of 1981 thesis sites field notes, Neillands 1990, Brown 1988
Godwood Creek	Chinook coho coastal cutthroat	Steelhead cutthroat/steelhead sculpin sp.	2.8	CDFG 2002, Klatte and Roelofs 1997, Neillands 1990, Brown 1988,
Skunk Cabbage Creek	coho steelhead	coastal cutthroat	0.6	Brown 1988
May Creek	coho coastal cutthroat steelhead Pacific giant-salamander	cutthroat/steelhead three -spined stickleback sculpin sp. Pacific lamprey Humboldt sucker	0.4	CDFG, 1980 & 76 stream surveys, Klatte and Roelofs 1997, USFS/ RNP barrier study notes 1995, Neillands 1990, Brown 1988 (ref. CDFG surveys, C Warren personal communication)

The Prairie Creek watershed has been the study area for several landmark reports, masters' thesis, and other studies of watershed conditions and fishery resources. Some of the earliest reports contain valuable descriptions of past habitat conditions and fishery resources.

Past Surveys

CDFG stream surveys in May and Lost Man creeks show differences in stream habitat conditions and fish populations before and after logging activity. The surveys share a common theme, both streams declined in stream habitat quality and also declined in fish abundance after "poor logging practices." Other streams of the Prairie Creek watershed that experienced timber harvests in the 1950s to the mid 1970s likely received similar impacts, as little or no protection was given to riparian and aquatic habitat systems. Changes found after logging included large increase in fine sediments in spawning gravels, numerous log jams, and a general reduction in the numbers of salmonids. Summaries of past stream surveys for May and Lost Man Creek are provided in Appendix D.

Present Surveys

In 2001, CDFG Stream habitat survey protocols were used to collect data describing stream habitat conditions from nine sample reaches located in the Prairie Creek Subbasin. The sites were selected using an equal probability random tessellation stratified survey design to develop a set of spatially balanced sampling reaches for the Prairie Creek and lower subbasins (Olsen 2000) (Figure IV- 14). These data represent site-specific attributes and do not necessarily characterize the entire reach of any stream.

The entire anadromous reach of Godwood Creek was surveyed in 2002 using CDFG survey protocols according to Flosi et al. (1998). Results from select stream habitat components are summarized below. Abbreviated stream reports generated from surveys conducted in the Prairie Creek watershed and summary comparisons between past and present surveys are provided in Appendix D.

Stream Reach Characteristics

Pool:Riffle:Run Relationships

***Significance*:** Productive anadromous streams are composed of a balance of pool, riffle and run habitat. Each plays an important role as salmonid habitat. The number of pools or pool frequency can be measured as a ratio of the number of bank full widths (BFWs) per pool in a stream reach. Using this metric, pool to pool spacing in many redwood forest streams ranges from approximately 2 to 7 BFWs and is often controlled by LWD (Keller and MacDonald 1981). In straight and meandering streams, pools are also often spaced more or less regularly at a repeating distance of 5 to 7 BFWs (Leopold 1994). A potential problem with using this metric is that BFWs may be widened from disturbance associated bank erosion during recent flood events. Since pool spacing is influenced by BFW, pools may be less frequent than pre-disturbance conditions if channels have widened, but appear within desirable ranges relative to present conditions.

The mean bank full width (BFW) to pool ratio for all Prairie Creek Subbasin sample sites combined was 5:1. The mean ratio of pool: riffle: run occurrence was 34% pool, 33% riffle and 31percent run habitat (Table IV-22). Together, these data suggest that the mean frequency of pool habitat in The Prairie Creek Subbasin is within desirable range for anadromous salmonid habitat. The mean percent length of pool, riffle, and run was 27: 35: 38 respectively, showing that the length of pool habitat is below the desired standard of 40% of stream length for anadromous fish habitat in Flosi et al. (1998). Individual sites listed in Table IV- 23 show the variation in stream reach characteristics among streams. Boyes Creek had the lowest percent of pools.

Figure IV- 14. Prairie Creek Subbasin Instream habitat sampling point.

Table IV- 22. Prairie Creek Subbasin bank full width (BFW) measured from sampling, site.

Stream Reach	Stream Order	Reach Length (feet)	Unit Count*	Estimated BFW (ft.)	BFW to Pool frequency ratio	Pool:Riffle:Run % occurrence	Pool:Riffle:Run % length	Dry % length
Boyes Creek Site 11	1	508	21	12.5	10 : 1	19 : 38 : 38	17 : 27 :52	4
Brown Creek Site10	1	512	17	15.9	6 : 1	29 : 47 : 24	21 : 62 : 17	0
May Creek Site 19	1	449	16	12	6 : 1	38 : 31 : 31	38 : 19 : 44	0
Lost Man Creek Site 15	2	634	21	31.3	3 : 1	32 : 32 : 27	22 : 38 : 38	2
Lost Man Creek Site 23	2	962	14	48	3 :1	43 : 14 : 43	14 : 5 : 81	0
Lost Man Creek Site 5	2	844	17	45.6	2 : 1	47 : 29 : 24	44: 34 : 23	0
Trib to Lost Man Creek Site 13	2	474	15	19.2	5 : 1	33 : 47 : 20	28 : 47 : 25	0
Prairie Creek Site 3	3	568	10	34	4 : 1	40 : 30 : 30	40 : 40 : 20	0
Prairie Creek Site 6	3	544	12	18	10 : 1	25 : 33 : 42	20 : 40 : 40	0
Mean values for Prairie Creek Subbasin sample sites		611	16	26	5 : 1	34 : 33 : 31	27 : 35 : 38	0.7
Godwood Creek	2	14,559	580	16	7 : 1	23 : 43 : 31	26 : 45 : 26	3

*Total number of pool, runs, and riffles counted.

Pool Depth

Significance: Deep pools are important for adult salmonid holding areas during spawning migrations and as year round habitat for rearing juvenile salmonids. Quantifying the amount of deep pool habitat in a stream reach is a useful indicator to assess stream conditions. Lack of deep pools may indicate a disruption to channel forming processes and/or elevated levels of sediments. Generally, the desirable length of a coastal anadromous stream reach should consist of approximately 30 – 40% pools with moderate maximum depths. Moderate maximum depths for the Redwood Creek streams are pools with maximum depths of from 2.0 to 2.5 feet for 1st and 2nd order streams, >3 feet for 3rd order streams and >4 feet deep for 4th order streams. These target values were developed to help assess the pool condition of anadromous salmonid habitat in typical North Coast California streams. However, shallow pool conditions are more likely in low gradient reaches within small watersheds that lack sufficient discharge to deeply scour the channel. Therefore, some smaller streams may not meet the general target values, but still provide important fish habitat.

Pools of the Prairie Creek Subbasin sample sites and Godwood Creek were often below target values for depth and percent of stream length in deep pools (Figure IV- 15). The deepest pools were found on undisturbed portions of Prairie Creek, and on a tributary to Lost Man Creek. The mean maximum depth for pools measured at sample sites were 1.8 ft. for 1st and 2nd order streams and 2.7 ft. for Prairie Creek (Table IV- 23).

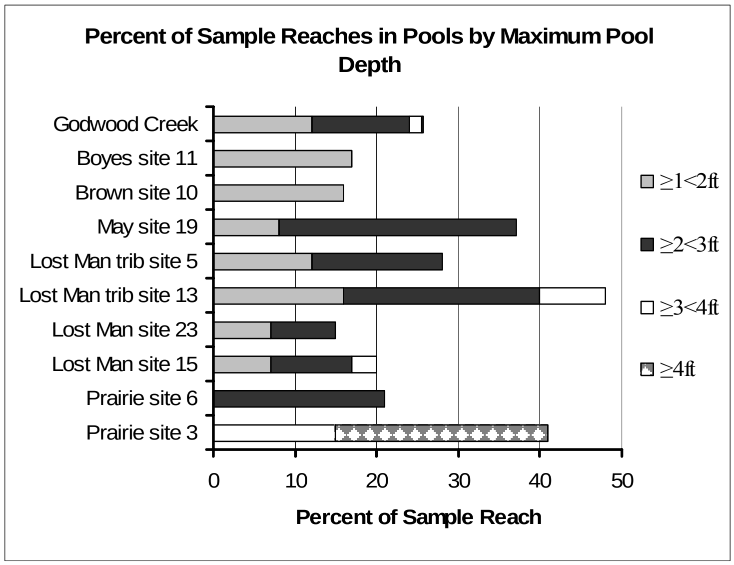

Figure IV- 15. Percent of sample reaches in pools grouped by maximum pool depth.

The sample size of pools shown in this figure range from four to eight pools per site. The sample reach length for each site is shown in Table IV- 23. The entire anadromous of Godwood Creek was surveyed.

Table IV- 23. Prairie Creek Subbasin mean maximum pool depths for sample reaches 2001 and Godwood Creek (2002).

Prairie Creek Subbasin	1st & 2nd Order Streams	3rd Order Streams	Godwood Creek (2nd Order)
Mean Maximum Depth	1.8	2.7	1.8
Mode	1.2	2.8	1.2
Minimum Max Depth	0.9	1.5	0.7
Maximum Depth	3.4	5.1	4.2
Standard Error	0.1	0.25	0.05
Number of Pools Measured	32	15	128

Pool Shelter

Significance: Salmonid abundance in streams increases with the abundance and quality of shelter of pools (Meehan 1991). According to a CDFG survey protocol, pool shelter complexity is rated by a relative measure of the quantity and composition of LWD, root wads, boulders, undercut banks, bubble curtain, and submersed or overhanging vegetation (Flosi et al. 1998). These elements serve as instream habitat, create areas of diverse velocity, provide protection from predation, and separates territorial units to reduce density related competition. The ratings range from 0-300, with ratings of ≥100 considered good shelter values. They do not consider factors related to changes in discharge, such as water depth.

Pool shelter ratings at the sample sites and Godwood Creek were generally below the 100 target value (Flosi et al. 1998) (Figure IV- 16). Cover in the tributaries and mainstem of Prairie Creek are mostly provided by woody debris undercut banks, and boulders (Table IV- 24). Cover in the tributaries and mainstem of Prairie Creek are mostly provided by woody debris and undercut banks. Boulders were dominant in the Lost Man Creek sampling sites.

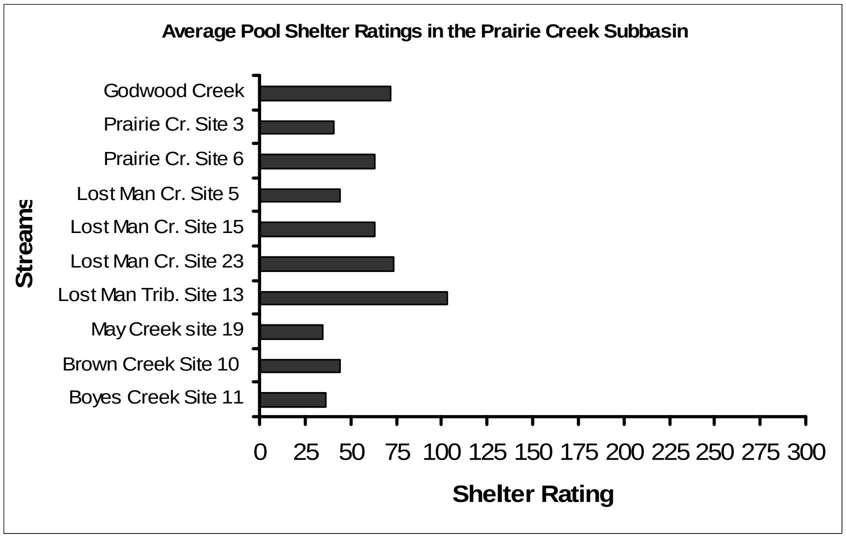

Figure IV- 16. Prairie Creek Subbasin average pool shelter ratings from CDFG sample reaches.

Average pool shelter ratings exceeding 100 are considered fully suitable and average pool shelter ratings less than 30% are unsuitable for contributing to shelter that supports salmonids.

Table IV- 24. Summary of mean percent cover.

Sample sites	Undercut Banks	Woody Debris	Terrestrial Vegetation	Aquatic Vegetation	White-water	Boulders	Bedrock Ledges
Boyes Creek site 11	2	1					
Brown Creek site 10	1					2	
Godwood Creek	2	1					
Lost Man Ck site 23		2				1	
Lost Man Ck site 5		1	2				
Lost Man Ck site 15		2				1	
Lost Man Ck trib site 13	2	1					
May Creek site 19	2	1					
Prairie Creek site 3	1	2					
Prairie Creek site 6	1	2					

Dominant (1) and Subdominant (2) Shelter Types in Pool and Flatwater Units in the Prairie Creek Subbasin. For details see figures in Appendix D.

Streamside Canopy Density

Significance: Stream side canopy density is an estimate of the percentage of stream channel that is shaded by riparian tree canopy. An effective tree canopy provides shade to reduce direct sun light from warming water. Generally management to increase shade canopy including re-vegetation projects are considered when canopy density is less than 80% (Flosi et al. 1998). A second attribute of stream side canopy data is the percent of coniferous and deciduous tree species providing the shade. The percent coniferous and deciduous component of the stream side canopy influences the potential for LWD loading. Streams flowing through mature conifer stands tend to have larger amounts of wood with larger average piece size than streams with younger riparian stands, which often are dominated by smaller deciduous species (Bilby and Bisson 1998). LWD produced by conifers is generally favored over deciduous wood because it tends to be larger and less likely to move downstream, it decays more slowly, and stays longer in stream systems.

Overall, the stream side canopy density is suitable for providing shade over the sample sites within the Prairie Creek subbasin (Figure IV- 17). The coniferous component providing shade was low at the Lost Man, May, and Boyes creek sites compared to sites on Godwood and Brown creeks. The Lost Man, May, and Boyes creek sites were located within areas that were harvested for timber in the 1950s-1960s whereas the Godwood and Brown Creek sites are in un-harvested areas. These data suggest a relatively slow re-growth of coniferous trees after timber harvests along riparian zones of Lost Man, May, and Boyes creek sites and may indicate a reduced potential for LWD inputs from conifers into these streams.

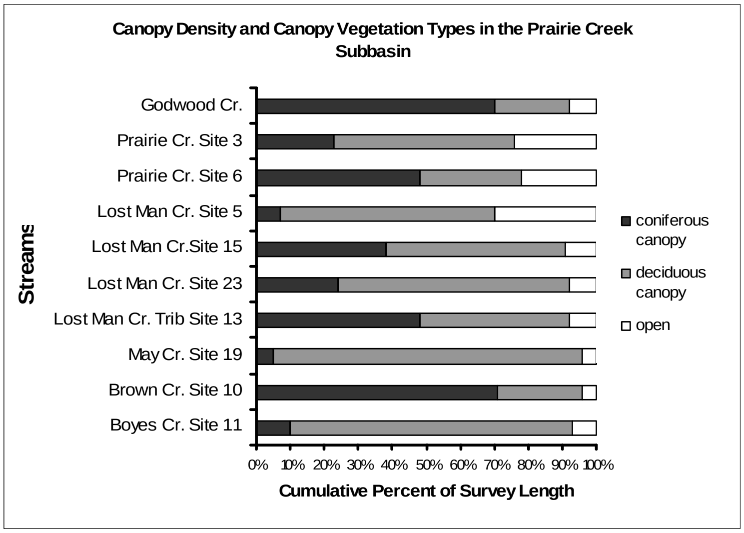

Figure IV- 17. Prairie Creek percent canopy density measurements and the percent vegetation type contributing to shade canopy.

Spawning Cobble Embeddedness

Significance: Cobble embeddedness is the percent of an average-sized cobble piece at a pool tail out that is embedded in fine substrate. Percent cobble embeddedness provides a measure of spawning substrate suitability for egg incubation, and fry emergence. Excessive accumulations of fine sediments reduce water flow (permeability) through gravels in redds, which may suffocate eggs or developing embryos. Excessive levels of fine sediment accumulations within gravel and cobble substrate may also alter aquatic insect species composition and may also reduce connectivity of flow between surface and subsurface stream flows needed to moderate water temperature.

High embeddedness ratings may indicate elevated levels of erosion occurring somewhere in the watershed due to natural and/or human causes. The potential for high levels of fine sediments is higher in watersheds like Prairie Creek where the geology, soils, precipitation, and topography cumulatively exacerbate erosional processes (Duncan and Ward 1985). Fine sediments are typically more abundant where land use activities such as road building or land clearing expose soil to erosion and increase mass wasting (Cederholm et al. 1981, Swanson et al. 1987, Hicks et al. 1991).

Cobble embeddedness varied between the sample sites (Figure IV- 18). The best embeddedness ratings were from site 19 on May Creek and site 3 located in the upper reach of Prairie Creek and Godwood Creek where little disturbance to the landscape has occurred. The absence of category 1 embeddedness values in Boyes and Brown creeks may indicate fine sediment delivery is still occurring from sources associated with the Highway 101 bypass construction or other land use.

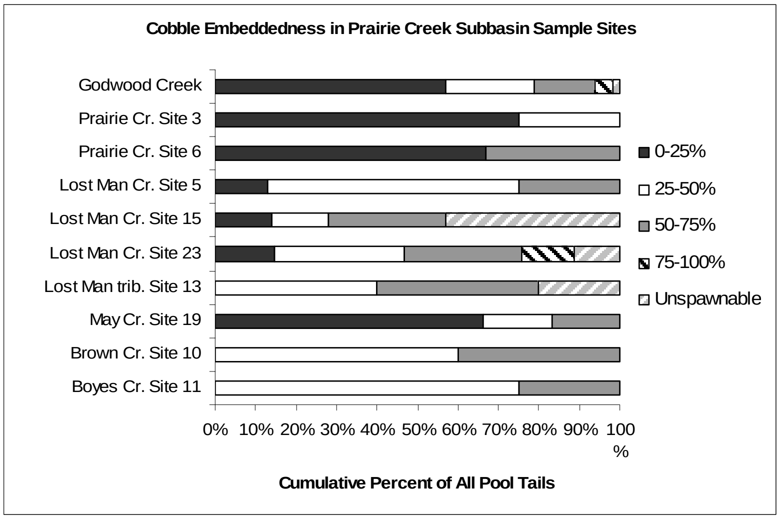

Figure IV- 18. Prairie Creek Subbasin average cobble embeddedness from sample sites.
Unspawnable is unsuitable for due to factors other than embeddedness (e.g. log, bedrock, boulders).

Salmonid Fishery Resources

Prairie Creek watershed is an excellent field laboratory that has produced numerous studies of California's anadromous salmonids and their habitat. Some studies have reported on life history strategies and carrying capacity (Hallock et al. 1952; Briggs 1953; DeWitt 1954; Burns 1971; Manning 2000; and Bell 2001), while others have focused on species distribution, abundance, and response to sediment inputs (Anderson 1988; Brown 1988; Klatte and Roelofs 1996 and 1997; Coey 1998; and Brakensiek 2002).

One of the first fish sampling efforts in Prairie Creek is presented in DeWitt (1954) and was part of a coastal cutthroat survey conducted in 1951. The results show a few (9) coastal cutthroat in the sample as well as numbers of other fish species collected (Figure IV- 19). Coastal cutthroat trout populations of Prairie Creek have been described as over fished and sensitive to changes in habitat (Van Kirk 1994 and Gerstrung 1996). In addition, note that coho were more abundant than steelhead in the sample reach.

Beginning in 1983, spawner surveys were conducted in the Prairie Creek Subbasin by RNSP staff and Humboldt State University (HSU). However, in some cases the same streams were not surveyed regularly or survey protocols were inconsistent. Logistical constraints such as lack of funding, limited personnel, and variable stream conditions contributed to irregularity of spawner surveys (D. Anderson, RNSP, personnel communication). In addition, the length of survey distances may vary between years and tributaries (Meyer 1994). Thus, deriving trends in redd, carcass and live fish counts from spawning surveys is problematic for most streams.

Weirs in Prairie Creek and Lost Man Creek were used to trap migrating salmonids for egg collection and propagation at the Prairie Creek Hatchery. Counts of fish were also made at the two weirs but, due to variability in effort, protocols, and locations it is difficult to interpret data and to identify trends over time. The most consistent adult trapping data for the Prairie Creek weir site are shown in Table IV- 25. Overall, counts of Chinook, coho and steelhead were highest at the Lost Man Creek weir possibly as a result of enhanced runs returning to the hatchery located on Lost Man Creek (Meyer 1994).

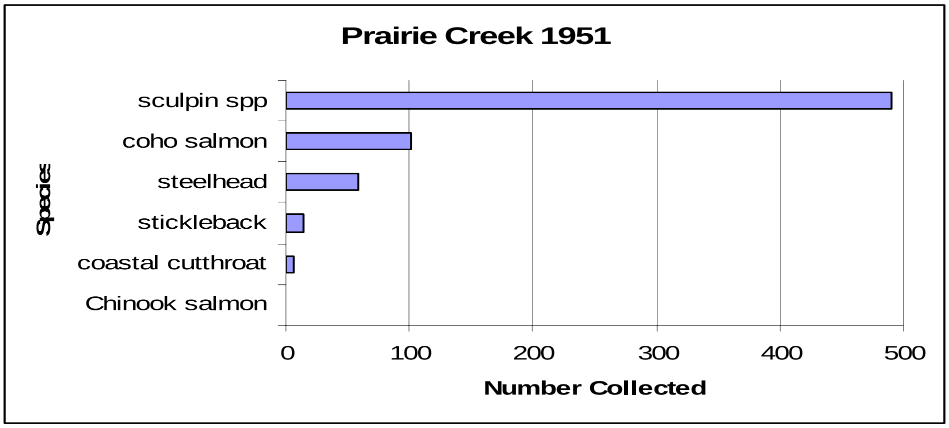

Figure IV- 19. Prairie Creek, 1951 sampling.

In September of 1951 a 779-foot section of Prairie Creek was cut-off by diverting the flow into an artificial channel. The cut-off section was seined, treated with rotenone, and re-seined. Two Chinook salmon were collected. "Scale readings of the nine cutthroat collected indicated that none had undergone any ocean or tidal growth. The ages of these fish varied from two to six years. No cutthroat-of-the-year were found in the cut-off section" (DeWitt 1954).

In contrast to the Prairie Creek spawner survey data, the weir trapping data shows that coho salmon usually were more abundant than Chinook salmon. Klatte and Roelofs (1996 and 1997) provided the most accurate counts of coho returning to Prairie Creek. A review of these data indicate that Lost Man Creek often had the most redds, carcasses and live fish per mile of all surveyed streams in the Prairie Creek Subbasin (Meyer 1994).

Table IV- 25. Adult salmonid counts at Prairie Creek Weir.

Spawning Year	Chinook				Coho				Steelhead			Total All Species
	Female	Male	Jack	Total	Female	Male	Jack	Total	Female	Male	Total	
1989-90 Nov 26, '89 to Mar 13, 90	13	19	25	57	22	15	115	152	9	18	27	236
1990-91 Nov 25, '90 to Jan 7, 91	19	30	17	66	34	29	16	79	0	0	0	145
1991-92 Nov 20, '91 to Mar 6, 92	7	26	7	40	23	35	12	70	12	19	0	141
1992-93 Nov 18, '92 to Jan 7, 93	19	33	10	62	18	26	23	67	0	1	31	130
1993-94 (dates not available)	28	41	10	79	45	32	1	78	2	8	1	167
1994-95 Nov 18, '94 to Feb 9, '95												
1995-96 Dec 1, '95 to Feb 28, '96	30	76		106	66	49		115				221
1996-97	33	80	37	113	45	79	10	124				237

Located between the confluences with Boyes and Streelow creeks, 1989 to 1996 (Meyer 1994 and Klatte and Roelofs 1996 and 1997). The trap was monitored 24 hours a day and seven days a week during 1996 and 1997.

Coho Salmon

The Prairie Creek Subbasin provides the most coho habitat and the likely largest coho population in the Redwood Creek Basin. Coho are found in Prairie Creek and at least eight other tributaries in the subbasin. Counts of live coho combined from Prairie Creek and Lost Man Creek weirs from 1973 to 1992 have ranged from less than 50 in 1978 to approximately 1800 fish in 1989 (Meyer 1994). The Lost Man Creek weir counts were usually much higher that the Prairie Creek site as coho production was enhanced by hatchery production. The most recent counts of 115 and 124 adult coho from the Prairie Creek weir site are for 1995-96 and 1996-97 spawning seasons respectively (Table IV- 25). The weir was located between Streelow and Boyes creeks and counts do not include coho that spawned in tributaries located downstream (such as Little Lost Man, Lost Man etc.) from the weir.

Recent spawner and carcass counts in Prairie Creek provide similar numbers as the weir counts (Figure IV- 20). Coho carcass counts yielded the highest numbers during the 1995-1996 spawning season and live coho counts peaked in 1997-98, and then declined during the next two years. For some years, it is unclear if the higher fish counts are due to a greater number of fish returning to Prairie Creek or a consequence of increased survey effort.

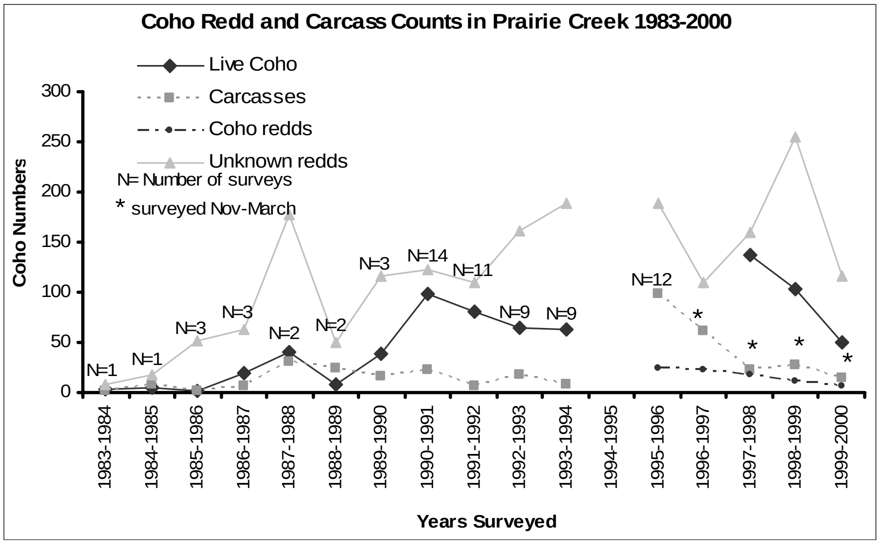

Figure IV- 20. Prairie Creek live coho, redd, and carcass counts, 1983 to 2000.
Information derived from Meyer (1994) and Redwood National and State Parks spawning and carcass surveys 1991 to 2000.

During 2001 electrofishing surveys, twenty-seven juvenile coho were captured over approximately 400 feet of sample site located in Lost Man Creek (Appendix D, attachment 1). No coho were captured from the sample sites located on the Unnamed Tributary to Lost Man Creek or Brown Creek in 2001. No electrofishing surveys were performed at the Prairie Creek sample sites to avoid interference with other studies in progress.

Chinook Salmon

Chinook salmon are found in most fish bearing streams of the Prairie Creek Subbasin. Chinook counts combined from Prairie Creek and Lost Man Creek weirs from 1973 to 1992 have ranged from less than 5 in 1973 and 1975 to approximately 175 fish in 1988 (Meyer 1994). As with the coho salmon counts, Chinook counts at the Lost Man Creek weir include fish that were returning to the hatchery located on Lost Man Creek. The most recent counts from the Prairie Creek weir site of 106 and 113 adult Chinook are from the 1995-96 and 1996-97 spawning seasons respectively (Table IV-25). Results from Prairie Creek spawner surveys 1983 to 1999 show a general increase in counts of live Chinook and carcasses since 1983, but also an increase in survey effort (Figure IV- 21). Spawner survey results show a peak of almost 500 Chinook counted in Prairie Creek in the 1998-99 spawning season. Within the past few spawning years (1995-2000) runs of adult Chinook have outnumbered coho by a sizeable margin, which is a reversal from the late 1980s and early 1990s when adult coho numbers outnumbered returning Chinook.

Steelhead

Most fish bearing streams of the Prairie Creek Subbasin support runs of winter run steelhead. However, the streams seem to favor production of coastal cutthroat and coho salmon rather than steelhead. Brown (1988) found that where they co-occurred with other salmonid species in the Prairie Creek Subbasin, steelhead were relatively less abundant compared to coastal cutthroat and coho salmon. The numbers of steelhead in the Prairie Creek watershed were enhanced by hatchery production beginning in the 1930's when steelhead from the Sacramento River system were introduced via the Prairie Creek Hatchery in an effort to supplement the sport fishery.

Steelhead counts combined from Prairie Creek and Lost Man Creek weirs from 1973 to 1992 have ranged from less than 25 in 1974 and 1975 to approximately 1200 fish in 1986 (Meyer 1994). During 2001 electrofishing surveys, 36 juvenile steelhead were captured from Lost Man Creek, three were captured from the Unnamed

Tributary to Lost Man Creek, and only one was captured in Browns Creek. These numbers of juvenile steelhead appear low in consideration of amount of habitat sampled.

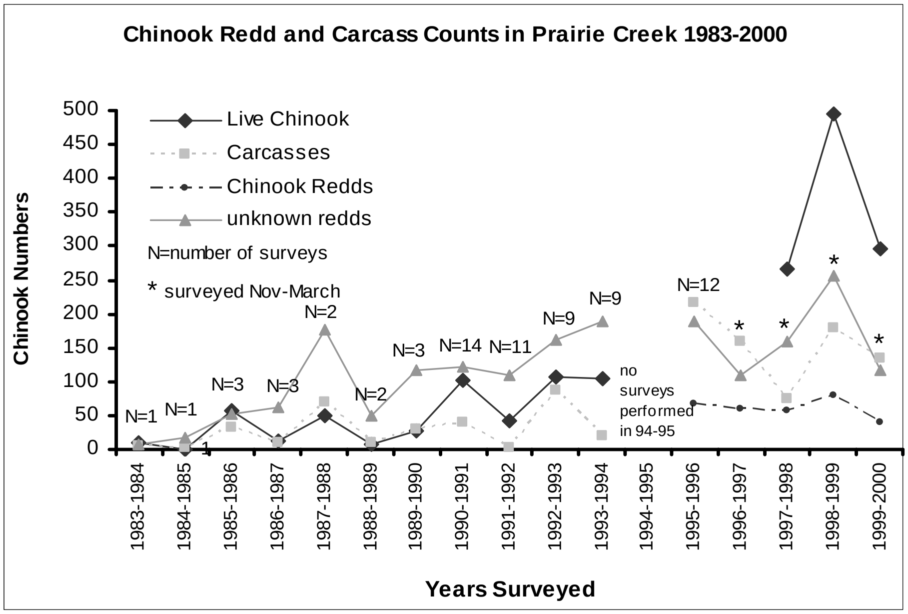

Figure IV- 21. Prairie Creek live Chinook, redd, and carcass counts 1983 to 2000.

Information derived from Meyer (1994) and Redwood National and State Parks Spawning and Carcass surveys 1991-2000. The 1997 through 2000 live, adult Chinook numbers may be inflated due to double counts of the same fish (Anderson personal communications 2002).

Coastal Cutthroat

The majority of the known sea run coastal cutthroat population of Redwood Creek basin resides in the Prairie Creek drainage. They can be found in nearly all tributaries of the subbasin (Gerstrung 1996). In the late 1800s and into the early 1900s, Prairie Creek watershed supported a large coastal cutthroat population which attracted many sport anglers (Snyder 1908, Dewitt 1954, USDI 1960, Van Kirk 1994). However, they were vulnerable to fishing pressure and by 1925 the coastal cutthroat population of Prairie Creek was over harvested by sportfishers (Van Kirk 1994). While populations continued to decline slowly, it was not until later that coastal cutthroat populations crashed in response to detrimental habitat changes during the 1950s to 1960s (Gerstrung 1996). Counts of coastal cutthroat from weir sites are not available. In the summer of 2001, CDFG survey crews collected only small numbers of coastal cutthroat during electrofishing surveys in Lost Man Creek, unnamed tributary to Lost Man Creek and Brown Creek (Appendix D, Attachment 1).

Prairie Creek Hatchery

The Prairie Creek Hatchery is located a few miles north of the town of Orick. The hatchery operated from 1927 until 1993. Throughout its years in operation, the hatchery propagated Chinook, coho, steelhead, rainbow trout, and coastal cutthroat trout. The fish were released mostly in the Redwood Creek watershed and other Humboldt County streams.

The Prairie Creek Hatchery supplied fish to multiple streams in and out of the Redwood Creek basin as well as several local lagoons, the Arcata Wastewater Facility, and Humboldt Bay until it closed in 1993. The coastal cutthroat fishery, for which the hatchery was originally intended, never returned to its former strength or popularity noted from the early 1900s (Van Kirk 1994). In its later years the hatchery provided fish to private programs such as Humboldt Fish Action Council and the Pacific Lumber Company. Salmonids from the hatchery were distributed rather freely to various watersheds without much consideration for the natal stocks. Eventually, stocking was limited to the Redwood Creek basin, surrounding lagoons, and the Humboldt Bay and Arcata Wastewater Facility for experimental studies for waste water treatment.

Total fish counts were not made during the first fifty years of hatchery operations. The hatchery operated along the guidelines of collecting the desired number of salmonid eggs for each year and then focused on hatching and releasing fry. Fish were only collected to meet demand for eggs from the early portion of the run. Late running fish were allowed to freely pass through the facility uncounted. Generally, fish were not trapped during high flows because of the trap being washed out. Therefore, for most years prior to the late 1980's, accurate, total yearly migrating adult salmon counts are not available.

From 1930 to 1936 the hatchery supplied an average of 324,174 coho salmon fry and 105,582 steelhead trout fry per year primarily to Prairie Creek and Lost Man Creek (Meyer 1994). An average of 54,289 Chinook salmon and 39,787 coastal cutthroats were planted per year during the early years of hatchery operations (Meyer 1994). In 1937, the hatchery was moved to Lost Man Creek. Hatchery production records from 1927 to 1993 are presented in Appendix D, Attachment 3.

Humboldt County officially took over the title and operation of the hatchery in 1961. The hatchery was closed in 1962 for extensive repairs (Meyer 1994 draft). In cooperation with Humboldt State University, the facility was improved to accommodate greater fish production. During the hatchery's peak production (mid- 1960s through mid-1970s) larger numbers of fish were being propagated and distributed to Humboldt county streams. For instance, in the 1971-1972 season, the hatchery produced approximately 1,462,919 fish totaling 35,087 pounds. The 1973-1974 season was another substantial year producing approximately 1,589,581 fish, totaling 31,603 pounds. The majority of these fish were Chinook and coho salmon. Steelhead propagation ceased temporarily from 1956 to the early 1970's, in part, due to closure and upgrade of the hatchery facility. Propagation of steelhead resumed during the 1972-1973 season, and became the dominant species produced through the 1980s. With the exception of steelhead, overall production decreased slightly during the 1980s and into the early 1990s. Approximately 25,000 Chinook, 81,000 coho, 94,000 steelhead yearlings were released during the ten-year period of 1981 through 1991. Some coho salmon stocks taken from out of the basin (Kalama River in Washington, Alsea River, Sooes River, Sandy River, and Trask Rivers in Oregon, and from California; Klamath River, Trinity River, Mad River, and Noyo River) during the years from 1978 to 1983 and were planted in Prairie Creek (Meyer 1994). After 1983, hatchery releases of coho and steelhead trout were produced from parental stocks collected from Lost Man or Prairie Creek (Meyer 1994). In addition, 300 to 400 coastal cutthroat yearlings were released into Lost Man Creek from 1988 to 1991.

During the period from 1977 to 1980 the percentage of trapped fish from Prairie Creek Hatchery stock was estimated for Chinook and coho salmon and steelhead trout. Steelhead trout had the highest percentage of the three species averaging 57% of fish trapped estimated from hatchery origin. Coho followed with 42% and Chinook with only 17% (Meyer, 1994). Although these percentages of steelhead and coho represent a substantial proportion of the runs, there is no discernible evidence that the hatchery consistently lead to improved numbers throughout the Prairie Creek watershed. Initially, returning adult steelhead numbers did raise when propagation resumed again in the early 1970s, but these numbers leveled off to resemble runs of the 1960s. Based on a comparison of proportional numbers of fry released to numbers of returning adults for respective years during the 1970s and early 1980s, adult coho numbers may never have benefited from hatchery production. Since the hatchery closed, numbers of salmonids in Prairie Creek have remained somewhat stable except for Lost Man Creek where recent carcass counts have declined. However, this could be based on a variety of factors other than closure of hatchery. Unlike Lost Man Creek figures, Prairie Creek spawner surveys have shown relatively consistent numbers of adult Chinook and coho since the closure of the hatchery.

Insufficient funds from Humboldt County caused the hatchery to rely on state funding sources during the 1980s. But, state funding became unavailable to the hatchery "because instream habitat was not being improved to support fish the hatchery produced" (Farley, 1992). With the termination of state funding, the county itself could not afford to maintain the hatchery operations and closed the facility in the spring of 1993

Prairie Creek Subbasin General Issues

RNSP management goals include the protection of natural resource values including anadromous salmonids and their habitat:

- The RNSP has done a significant amount of work to survey road systems, identify problems, and implement road removals and upgrades that should result in reducing erosion and sediment inputs into stream channels.

Before RNSP was expanded to include the great majority of the Prairie Creek Subbasin, approximately half of the subbasin was logged using timber harvest practices that resulted in excessive erosion, logging debris that clogged stream channels, and removal of valuable riparian forests:

- Impacts from past timber harvest still effect some riparian and stream habitat;
- Debris accumulations on Lost Man Creek may impede anadromous fish passage to upstream spawning grounds;
- Lost Man Creek watershed still has a relatively high density road network.

Impacts from Prairie Creek Hatchery operations.

Sediment impacts from the Highway 101 bypass are a concern.

Integrated Analysis and Cumulative Effects

The following section summarizes and integrates the above information to provide an interdisciplinary analysis of the subbasin condition. Summary tables facilitate the analysis of factors that cumulatively affect watershed processes and anadromous salmonid stream habitat. The tables include results from the EMDS sediment production and stream reach condition evaluations. A goal of the integrated analysis is to discern links or relations between geologic framework, watershed processes, land management activities, and stream habitat conditions.

The subbasin is divided by Prairie Creek into low gradient streams to the west (Skunk Cabbage, Streelow and Godwood creeks and others), and somewhat steeper streams to the east (including Lost Man, Little Lost Man, May creeks and others). Water temperatures in Prairie Creek measured by MWATs are usually below 60ºF which is considered desirable for cold water species like anadromous salmonids. The coastal climate in combination with old growth near stream forests over much of the area helps keep air and stream temperatures cool. The low gradient profile of Prairie Creek and reaches of most of the subbasin streams allows access to all four salmonid species found in the Redwood Creek basin, including coho salmon which are typically found in cool, low gradient stream reaches.

Approximately 14,000 acres located in the upper half of the Prairie Creek watershed and within the May Creek Planning Watershed were converted to State Parkland in the 1920s. These parklands in May Creek Planning Watershed still sustain nearly pristine old growth redwood forest conditions. The remaining lands, mostly within the Lost Man Creek Planning Watershed and Skunk Cabbage Creek, were subjected to timber harvests.

Approximately 56% of the land in the subbasin has a high or very high relative landslide potential. This relationship is nearly the same across the Prairie Creek Subbasin (Table IV- 26). However, Lost Man Creek Planning Watershed which covers 30% of the subbasin area has 279 acres of the 348 acres (80%) in historically active landslides (Table IV- 26 and Table IV- 27). Historically active and dormant landslide features in close proximity to streams were also highest in the Lost Man Creek Planning Watershed (Table IV-29). In addition, 86 of the 92 (93%) streamside landslides counted in the Prairie Creek Subbasin from 1984 aerial photographs were located in the Lost Man Creek Planning Watershed. The relatively high level of disturbance in the Lost Man Creek Planning Watershed is likely linked to the amount or roads located on areas of high or very high relative landslide potential (Table IV-27) and legacy impacts from past land use. Aerial photos from 2000 show that the number of active streamside landslides fell to 12 compared to 86 observed in 1984, indicating that conditions are improving.

When integrating land use, landslide potential, and active landslide data, a clear relationship becomes apparent. Lost Man Creek Planning Watershed has had the most land disturbance–measured by timber harvests and road density, and also the most area in active landslides and streamside landslides in the subbasin. It appears that land use has exacerbated landsliding in the Lost Man Creek Planning Watershed and the landscape has not fully recovered from past disturbances.

Table IV- 26. Acres and percent of area by relative landslide potential and land use or type classes.

Subbasin or Planning Watershed	Relative Landslide Potential[1]	Entire Subbasin or Planning Watershed		Woodland or Grassland[2]		Conifer Forest		Roads	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Prairie Creek Subbasin (25,305 acres) (110.2 road miles)	Very Low	3,492	13.8	360	1.4	3,068	12.1	28.6	26.6
	Low	3,017	11.9	3	0.0	2,989	11.8	14.5	13.5
	Moderate	4,565	18.0	8	0.0	4,526	17.9	19.2	17.8
	High	9,480	37.5	13	0.1	9,424	37.2	30.9	28.7
	Very High	4,750	18.8	4	0.0	4,731	18.7	14.4	13.4
	High/Very High Subtotal	14,230	56.2	17	0.1	14,155	55.9	45.3	42.1
	TOTAL	**25,304**	**100%**	**405**	**2%**	**24,738**	**98%**	**107.6**	**100%**
Lost Man Creek Planning Watershed (7,678 acres) (66.3 road miles)	Very Low	1,627	12.8	207	1.6	1,388	10.9	14.9	22.5
	Low	1,672	13.2	1	0.0	1,671	13.2	8.2	12.4
	Moderate	2,106	16.6	7	0.1	2,097	16.5	12.0	18.1
	High	4,288	33.8	9	0.1	4,279	33.7	20.4	30.8
	Very High	2,980	23.5	2	0.0	2,978	23.5	10.9	16.4
	High/Very High Subtotal	7,268	57.2	11	0.1	7,257	57.2%	31.3	47.2
	TOTAL	**12,673**	**100%**	**226**	**2%**	**12,413**	**98%**	**66.4**	**100%**
May Creek Planning Watershed (11,236 acres) (39.5 road miles)	Very Low	1,664	14.8	138	1.2	1,495	13.3	13.6	34.4
	Low	1,214	10.8	2	0.0	1,190	10.6	6.2	15.7
	Moderate	2,167	19.3	1	0.0	2,137	19.0	7.1	18.0
	High	4,538	40.4	0	0.0	4,496	40.0	9.1	23.0
	Very High	1,628	14.5	0	0.0	1,614	14.4	3.4	8.6
	High/Very High Subtotal	6,166	54.9	0	0.0	6,110	54.4	12.5	31.6
	TOTAL	**11,211**	**100%**	**141**	**1%**	**10,932**	**97%**	**39.4**	**100%**
Skunk Cabbage Creek Drainage (1,420 acres) (1.9 road miles)	Very Low	201	14.2	15	1.1	185	13.0	0.1	5.6
	Low	131	9.2	0	0.0	128	9.0	0.1	5.6
	Moderate	292	20.6	0	0.0	292	20.6	0.1	5.6
	High	654	46.1	4	0.3	649	45.7	1.4	77.8
	Very High	142	10.0	2	0.1	139	9.8	0.1	5.6
	High/Very High Subtotal	796	56.1	6	0.4	788	55.5	1.5	83.3
	TOTAL	**1,420**	**100%**	**21**	**1%**	**1,393**	**98%**	**1.8**	**100%**

[1] Refer to California Geological Survey appendix.
[2] Woodland and grassland include areas mapped in 1998 as grassland and non-productive hardwood.

Table IV- 27. Historically active and dormant landslides and selected geomorphic features[1] within 180' of a blue line stream.

Factor	Prairie Creek Subbasin		Planning Watersheds: Lost Man Creek		Planning Watersheds: May Creek		Skunk Cabbage Creek Drainage	
	% area	% stream length	% area	% stream length	% area	% stream length	% area	% stream length
Historically active and dormant landslide and selected geomorphic features[1] within 180' of a blue line stream.	2.6	8.0	3.7	0.2	1.1	0.6	0.9	0.0

[1] Landslide features and selected geomorphic features include earth flow, rock slide, debris slide, debris flow, debris slide slopes, disrupted ground, eroding banks and inner gorges.

Table IV- 28 provides an integrated information summary for the Prairie Creek subbasin. It provides the reader the opportunity to compare a large number of factors across the subbasin and to look at potential interactions between potential disturbance factors.

Table IV- 28. Prairie Creek Subbasin integrated information summary.

Factor	Prairie Creek Subbasin		Planning Watersheds				Skunk Cabbage Creek Drainage	
			Lost Man Creek		May Creek			
Relative Landslide Potentia1	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Very Low	3,492	13.8%	1,627	12.8%	1,664	14.8%	201	14.2%
Low	3,017	11.9%	1,672	13.2%	1,214	10.8%	131	9.2%
Moderate	4,565	18.0%	2,106	16.6%	2,167	19.3%	292	20.6%
High	9,480	37.5%	4,288	33.8%	4,538	40.5%	654	46.1%
Very High	4,750	18.8%	2,980	23.5%	1,628	14.5%	142	10.0%
High/Very High Subtotal	14,230	56%	7,268	57%	6,166	55%	796	56.1%
GRAND TOTAL	**25,304**	**100%**	**12,673**	**100%**	**11,211**	**100%**	**1,420**	**100.0%**
Landslide and Selected Geomorphic Features								
Historically Active Landslide Features Total[1]	**348**	**1.4%**	**279**	**2.2%**	**69**	**0.6%**	**0**	**0.0%**
Earthflow	13	0.1%	12	0.1%	1	0.0%		
Rock Slide	25	0.1%	16	0.1%	9	0.1%		
Debris Slide	161	0.6%	157	1.2%	4	0.0%		
Debris Flow	148	0.6%	94	0.7%	55	0.5%		
Dormant Landslide Features Total	**2,022**	**8%**	**1,758**	**13.9%**	**169**	**1.5%**	**95**	**6.7%**
Selected Geomorphic Features Total	**2,493**	**10%**	**1,454**	**11.5%**	**1,040**	**9.3%**		
Disrupted Ground	355	1%	355	2.8%	0	0.0%		
Debris Slide Slope	2,067	8%	1,083	8.5%	985	8.8%		
Inner Gorge (area)2	71	0%	16	0.1%	55	0.5%		
Total of all above features	**4,863**	**19%**	**3,490**	**27.5%**	**1,278**	**11.4%**	**95**	**6.7%**
Land Uses								
Grazing	230	0.9%	96	0.8%	134	1.2%		
Agriculture	1,393	5.5%						
Development	1,421	5.6%	28	0.2%				
Timber Harvest (1991-2000)	0	0	0	0	0	0	0	0
Road miles	110		66		40		2	
Road Density (miles/sq. mile)	2.7		3.4		2.3		0.8	
Density of Road Crossings (#/stream mile)	0.6		0.7		0.6			
Roads within 200' of Stream (miles/stream mile)	0.2		0.2		0.2			

[1]Areas of disrupted ground are not included as active landslide features in this analysis. These areas are likely underlain by earthflow or rockslide complexes. If so, this would substantially increase the miles of roads and area of land type and land use on active landslide features.

EMDS Potential Sediment Model Results

Tables IV-29 to IV-32 shows the results from the EMDS potential sediment model. The model assesses potential landscape factors that may generate and deliver sediment to streams. We remind the reader that this model was still under development at the time of this assessment. Results are based on sediment production potential of the Prairie Creek Subbasin and its planning watersheds in relation to all the other subbasins and planning watersheds of the Redwood Creek Basin. While the sediment production model has utility in its current state, we caution that it be interpreted only as being indicative of relative conditions and not as a definitive assessment of conditions of any specific planning watershed. Details of the EMDS sediment production model are provided in Appendix F.

Table IV- 29 presents the results from the EMDS sediment production model (All Sources) and shows the contributions to the result from natural sediment sources and management-related sediment sources. In essence, Table IV -29 provides the final synthesis of the results from Tables IV-29 to IV-32 and other finer scale model evaluations. Overall, the Prairie Creek Subbasin and its planning watersheds ranked relatively low for potential sediment production delivered to streams compared to the rest of the Redwood Creek Basin. Most of the potential sediment production identified by EMDS is from legacy impacts from past timber harvests, particularly management related sources in the Lost Man Creek Planning Watershed. Natural processes alone are not contributing much sediment to Prairie Creek Subbasin streams.

Table IV- 29. EMDS ratings for potential sediment inputs to streams; top three levels of model.

Subbasin or Planning Watershed	All Sources	Natural Processes				Management-Related Sources			
		All	Surface Erosion	Streamside Erosion	Mass Wasting	All	Surface Erosion	Streamside Erosion	Mass Wasting
Prairie Creek Subbasin	++	++	U	++	++	+	+	+	+
Lost Man Creek	+	++	U	++	++	-	-	+	+
May Creek	++	++	U	++	+++	+	+	+	++
Skunk Cabbage Creek Drainage	++	++	U	++	++	++	++	++	++

A 'U' represents data that lie in between suitable and unsuitable conditions, or there are data gaps.
The all sources column presents the cumulative results from all natural and Management-related sediment sources. The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---"score represents the most potential sediment delivery to streams.

Table IV- 30 provides more detail on management related potential surface sediment sources. It indicates that overall the subbasin is not generating much sediment from surface erosion that reaches streams. However, both roads proximate to streams and past timber harvests likely contribute some sediment to subbasin streams. Again, most of this is from the Lost Man Creek Planning watershed. Table IV-31 indicates the same problems with density of roads proximate to streams for management related streamside erosion sources in the Lost Man Creek planning watershed. Even though the Lost Man Creek Planning Watershed has been identified to have a high density of roads, the positive EMDS evaluation is due to its lower road density relative to other planning watersheds in the basin.

Table IV- 30. Potential sediment input to streams from management-related surface erosion sources.

Subbasin or Planning Watershed	All Mgmt.-Related Surface Sources	Road Related			Land Use Related	
		All Road Related	Density of Roads by Hillslope Position	Density of Roads Proximate to Streams	All Land Use Related	Timber Land Use
Prairie Creek Subbasin	+	+	++	+	+	-
Lost Man Creek	-	+	++	-	--	--
May Creek	+	+	++	+	++	+
Skunk Cabbage Creek Drainage	++	+	+++	++	++	-

The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---"score represents the most potential sediment delivery to streams.

Table IV- 31. Potential stream sediment production from management-related streamside erosion sources.

Subbasin or Planning Watershed	All Mgmt.-Related Streamside Sources	Road Related	
		Density of Roads Proximate to Streams	Density of Road Crossings
Prairie Creek Subbasin	+	+	+
Lost Man Creek	+	-	+
May Creek	+	+	+
Skunk Cabbage Creek Drainage	++	++	+++

The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---"score represents the most potential sediment delivery to streams.

Table IV-32 presents the EMDS potential sediment production model results for management related mass wasting sources. The table indicates that overall the Prairie Creek Subbasin is at low risk from management related mass wasting. While the relative rankings for most factors in the table look suitable, there are some less positive areas. For the Prairie Creek Subbasin overall, there is a somewhat low suitability ranking for timberland use, which is related to past harvesting activities on areas with higher relative landslide potential. Past timber management activities appear linked to active landsliding on the Lost Man Creek planning watershed and, to a lesser extent, on the Skunk Cabbage Creek drainage.

Table IV- 32. Potential stream sediment production from management-related mass wasting sources.

Subbasin or Planning Watershed	All Mgmt.-Related Mass Wasting Sources	Road Related				Land Use Related	
		All Road Related	Density of Roads Crossings	Density of Roads by Hillslope Position	Density of Roads on Unstable III-Slopes	All Land Use Related	Timber Land Use
Prairie Creek Subbasin	+	++	+	++	++	+	-
Lost Man Creek	+	++	+	++	+++	--	--
May Creek	++	++	+	++	+++	++	+
Skunk Cabbage Creek Drainage	++	++	+++	+++	-	++	-

The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---"score represents the most potential sediment delivery to streams.

EMDS Stream Reach Condition Results and Limiting Factors Analysis

The EMDS stream reach model evaluated sites in the Prairie Creek Subbasin as some of the best reaches for overall anadromous habitat suitability in the Redwood Creek Basin (Table IV- 33 and Figure IV- 22). The sample sites 3 and 6 located on Prairie Creek, Lost Man tributary Site 13, and both reaches of Godwood Creek received the highest overall evaluations. The Prairie and Godwood Creek sites are located in nearly pristine areas of the RNSP and retain much of their historic characteristics. There appears to be a link between areas with little disturbance and good quality salmonid habitat in the Prairie Creek Subbasin.

Factors that received negative scores by the EMDS (Table IV- 33) should be considered as limiting factors to anadromous salmonid production in the Prairie Creek subbasin. The sites on Lost Man, Brown, Boyes, and May creeks are all in areas that are influenced by past timber harvesting activities or road construction. These sites had the poorest evaluations for cobble embeddedness values which typically indicates erosion and sediment delivery to stream channels.

The lack of deep pools and poor shelter ratings were other factors often identified by EMDS that may limit anadromous salmonid production in the Prairie Creek Subbasin. A deficiency in the EMDS model likely contributed to negative evaluations of the pool depth attribute throughout the basin. However, shallow pool conditions are often found in low gradient reaches within small watersheds that lack sufficient discharge to deeply scour the channel. For example, some of the smaller fish-bearing stream channels (Godwood Creek, Prairie Creek Site 6), may not have the stream power to scour pools of the depth and frequency considered to be of high value, or "primary," pools by the Flosi et al. (1998) target values, or to be fully suitable according to EMDS. Therefore, some streams may not have the inherent ability to attain conditions that meet the suitability criteria or target values for pool depth. However, these streams may still be very important because of other desirable features that support valuable fishery resources.

Table IV- 33. Summary of the results from the Prairie Creek Subbasin EMDS Stream Reach Evaluation.

Stream	Reach Length (ft)	Reach number	Canopy Density	Pool Depth	Pool Shelter	Embeddedness
Lost Man Creek Site 5	844	1	+	- - -	- -	-
Lost Man Creek Site 23	962	2	+ + +	- - -	+	- -
Lost Man Creek Site 15	634	3	+ + +	- - -	-	-
Lost Man Tributary Site 13	474	1	+ + +	- - -	+ + +	- -
May Creek Site 19	449	1	+ + +	- - -	- -	+ +
Boyes Creek Site 11	508	1	+ + +	- - -	- -	-
Brown Creek Site 10	512	1	+ + +	- - -	- -	- -
Prairie Creek Site 3	568	1	+	+ ++	- -	+ + +
Prairie Creek Site 6	544	2	+ +	- - -	-	+
Godwood Creek	1701	1	+ + +	- - -	-	+ +
Godwood Creek	12,858	2	+ + +	- - -	+	+

+++ Fully Suitable ++ Moderately Suitable + Somewhat Suitable
\- Somewhat Unsuitable -- Moderately Unsuitable --- Fully Unsuitable

The scores* represent a range from fully suitable conditions to fully unsuitable conditions. Factors that received plus scores (+, ++, +++) should be considered to support anadromous salmonids and minus scores (-,--,---) should be considered as limiting factors to anadromous salmonid production at the sampling sites in Prairie Creek Subbasin.

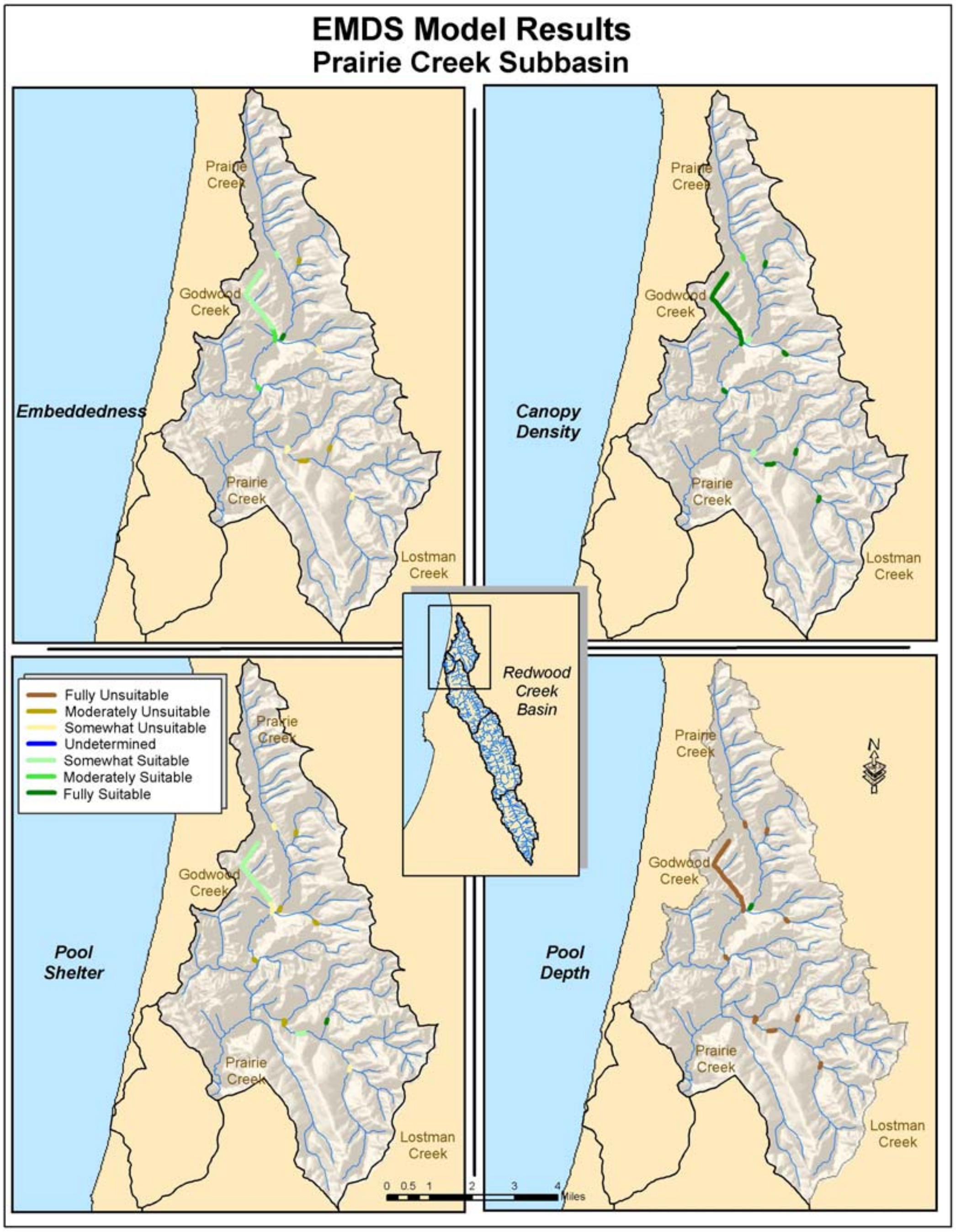

Figure IV- 22. Prairie Creek Subbasin EMDS map results for selected stream reach factors.

The colored coded areas represent the location of the sites sampled in the subbasin and the surveyed reaches in Godwood Creek.

Refugia Areas

The NCWAP interdisciplinary team characterized refugia habitat by using criteria developed for north coast watersheds. These criteria consider the status of watershed and stream ecosystem processes, stream habitat conditions, the presence and status of fishery resources, land uses, land ownership, potential risks from human activities, and other factors that may affect stream refugia quality. A detailed discussion of refugia habitat categories is presented in the Methods section of this report.

The high quality and high potential refugia designation for streams of the Prairie Creek Subbasin were largely based on the known presence and status of Chinook and coho salmon and cutthroat and steelhead trout, overall habitat conditions and the protection provided against future risk to habitat under RNSP management goals (Table IV- 34). It is believed that Lost Man, Brown, Boyes, and May creeks will increase to high habitat quality with time and/or management activities. Management activities that address limiting factors presented in Table IV- 34 will promote the advancement of these streams to the high quality refugia category.

Table IV- 34. Prairie Creek Subbasin anadromous salmonid refugia designations for streams.

Stream	Refugia Categories				Other Categories		
	High Quality	High Potential	Low Potential	Low Quality	Passage Barrier Limited	Critical Contributing Area/Function	Data Limited
Prairie Creek	X						
Lost Man Creek		X			X		
Little Lost Man Creek	X						
Brown Creek		X					
Boyes Creek		X					
Streelow Creek	X						
Godwood Creek	X						
Skunk Cabbage		X					X
May Creek		X			X		

Responses to Assessment Questions

<u>What are the history and trends of the size, distribution, and relative health and diversity of salmonid populations?</u>

- The Prairie Creek subbasin supports self sustaining populations of Chinook, coho, steelhead, and coastal cutthroat trout;
- The Prairie Creek Subbasin likely supports the largest coho salmon population of the Redwood Creek basin;
- Recent adult coho counts of 115 and 124 from the Prairie Creek weir site are for 1995-96 and 1996-97 spawning seasons respectively. These population counts are believed to be well below historic levels;
- Coastal cutthroats were once abundant in the Prairie Creek watershed, but today, are few in comparison to historic numbers. In 1925, over fishing was thought to be a leading cause of the initial decline of the coastal cutthroat population. In the following years their populations continued to decline;
- The historic abundance of steelhead in the Prairie Creek subbasin is not well described either by anecdotal information or the scientific literature. By the 1930s, steelhead were planted into Prairie Creek to supplement the declining coastal cutthroat fishery. These plantings occurred until into the 1990s and may have artificially increased the numbers of steelhead to equal or exceed historic levels in the Prairie Creek Subbasin.

<u>What are the current salmonid habitat conditions? How do these conditions compare to desired conditions?</u>

- The Prairie Creek Subbasin provides critical habitat for anadromous salmonids;
- Stream conditions range from almost pristine streams to reaches adversely impacted by past logging practices and excessive levels of fine sediment generated during highway construction;
- Water temperatures are within the optimum range (MWATs < 60°F) for salmonids based on data from 4 sites monitored from 1997 to 2001;
- Streams located in the undisturbed portion of the Prairie Creek Subbasin provide some of the best salmonid habitat in the Redwood Creek Basin due to the combination of beneficial riparian vegetation, cool water temperature, desirable pool characteristics, instream shelter and good spawning habitat;
- However, there are also sites in the Prairie Creek Subbasin that are lacking in one or more important habitat components. Sample sites within areas affected by past land use, Lost Man, Brown, and Boyes creeks were lacking in the amount of deep and complex pool habitat and lacked high quality spawning habitat;
- The most suitable spawning sites are located in undisturbed portions of Prairie Creek and Godwood Creek;

- Pool frequency and pool: riffle: run ratios are generally within desired ranges at all sites, however sites in Lost Man and Boyes creeks, the length of pool habitat is below a desired percent of reach length;
- All sites generally have good stream side canopy cover;
- Sites at Lost Man, Brown, and Boyes creeks lack stream side conifers as components of the shade canopy.

What are the past and present relationships of geologic, vegetative, and fluvial processes to stream habitat conditions?

- Geologically, the subbasin is dominated by a number of sub-parallel faults and folds in bedrock. These structural features appear to strongly influence the locations and orientations of the drainages, including Fern Canyon and Squashan, Little Lost Man, and Prairie Creeks;
- Drainages located west of Highway 101 have very gentle gradients at their heads and relatively broad, flat-floored valleys. Low-gradient, depositional stream reaches characterize much of the length of these streams. Small debris slides are the typically mode of failure on the hillslopes;
- The high rate of geologic uplift in the subbasin creates the potential for high natural sedimentation rates with a high potential for yielding a significant amount of relatively fine sediment that can be deleterious to fish and fish habitat;
- Franciscan rocks in the upper parts of Little Lost Man and Lost Man Creeks are resistant sandstone units, which form very steep slopes east of Highway 101. Mass wasting is characterized by debris flows, debris slides, numerous rotational slides, and earthflows. Such features tend to contribute sediment to streams when altered by landuses which may not be suitable to this type of terrain;
- While over half of the Prairie Creek Subbasin falls within the high to very high mass wasting potential category, historically active landslide features account for less than 1.5% of the subbasin area. That is the lowest percentage of active landslide features of all the subbasins;
- The number of active streamside landslides slides visible in aerial photographs decreased significantly between 1984 and 2000;
- Stream disturbance (measured from aerial photos) in Lost Man, Little Lost Man, and Brown Creeks decreased significantly between 1984 and 2000.

How has land use affected these processes?

- Land acquisition in the upper Prairie Creek Subbasin by Save the Redwoods League in the 1920s initiated protection of old growth redwood watershed processes and forest values;
- The maintenance and protection of natural resource values provided by RNSP is important to the recovery and expansion of anadromous salmonid populations of the Redwood Creek Basin;
- The habitat sample sites located in upper Prairie Creek, the unnamed tributary to Lost Man Creek and the survey reaches on Godwood Creek were ranked highest in overall stream habitat suitability by EMDS. These sites are located where there has been very little or no disturbance to the landscape;
- Approximately half of the Prairie Creek Subbasin was logged between 1950 and 1978. Most of the logging activity took place in the Lost Man Creek Planning Watershed;
- Nearly all of the active landslides were observed in the Lost Man Creek Planning Watershed, where the most timber harvesting and road construction has occurred. The effects of land use on stream habitat in the Lost Man Creek Planning Watershed have persisted for decades in some areas;
- Land use, has exacerbated landsliding and sediment delivery to streams in the Lost Man Creek Planning Watershed;
- Timber harvests and associated road construction occurred in the May Creek, Boyes Creek, Lost Man Creek, and Skunk Cabbage Creek watersheds. The activities resulted in soil erosion, landslides, sediment inputs, and large debris accumulations in the stream channels, which altered aquatic habitat. The affected landscape has not fully recovered from these past disturbances;

- Sediments and debris accumulations associated with legacy timber harvests are still stored in Lost Man Creek;
- Past CDFG surveys of May Creek and Lost Man Creek share a common theme, both streams were noted as in a disturbed condition and numbers of anadromous salmonids declined after logging activity;
- Surface and drainage alterations associated with the construction of the Highway 101 bypass resulted in the generation and delivery of large quantities of fine sediments into headwaters of tributary streams. Salmonid spawning and rearing habitat of Prairie, Brown, Boyes, and May Creeks were affected by the event.

Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?

- Elevated levels of fine sediment in spawning gravels in Lost Man, Brown, Boyes, and May creeks impair spawning habitat and may affect aquatic insect production needed as food for juvenile salmonids;
- The lack of deep pool habitat and instream shelter may limit salmonid production in sites located on Lost Man, Boyes, Brown and May creeks;
- A large debris accumulation likely impedes passage of spawning adults to upstream reaches on Lost Man Creek.

What watershed and habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

Barriers

- Modify large debris accumulation on Lost Man Creek to improve passage of spawning adults;

Flow and Water Quality Improvement Activities:

- Ensure that adequate streamside protection measures are used to maintain shade canopy in order to reduce moderate inputs to the lower reach of Prairie Creek and to maintain good water temperature in Lost Man Creek and other tributary streams;
- Water flow or water quality does not appear to be and issue at this time, but fish habitat requirements and channel maintenance flows should be considered prior to any water development projects.

Erosion and Sediment Delivery Reduction Activities:

- Continue road assessments and upgrades or removal of roads, especially in the Lost Man Creek planning watershed;
- Work with CalTrans to reduce sediment input potential to streams from HWY 101 activities;
- Consider bank stabilization projects in the Lost Man Creek watershed.

Riparian and Instream Habitat Improvement Activities:

- Ensure that any land management activities include protection and preservation of stream and riparian habitats;
- Restore riparian function in areas where vegetation removal or significant cattle impacts have been noted in lower Prairie Creek;
- Consider modifying debris accumulations in Lost Man Creek to facilitate fish passage;
- Consider adding pool enhancement structures to increase the number of pools or deepen existing pools in Lost Man Creek, May Creek, and Boyes Creek.

Supplemental Fish Rescue and Rearing Activities:

- The use of Prairie Creek hatchery can be considered to supplement fishery resources of Redwood Creek if populations fail to respond to current management strategies.

Education, Research, and Monitoring Activities:

- The wide range of habitat conditions within the watershed provides an opportunity to monitor channel and salmonid habitat recovery rates under various habitat improvement treatments within a variety of channel types and conditions;
- Humboldt State University and RNSP should continue and expand their salmonid population and continuous temperature monitoring tasks in the Prairie Creek subbasin. This includes the use of fish counting weirs, spawner and redd surveys and juvenile population studies;
- A long term, concerted monitoring effort between the land owners, interested parties and responsible agencies is needed to determine the status and trends of anadromous fish populations in the Prairie Creek Subbasin;
- Water temperature monitoring should occur at the confluence of Prairie Creek and the mainstem to determine the effects of colder Prairie Creek water on the mainstem and estuary;
- Nutrients contributed to streams from eggs and decaying carcasses has declined. Studies should be conducted to discern relationships between nutrient contributions from carcasses, stream productivity, and salmonid production;
- CalTrans should continue to monitor and reduce sediment delivery from the Highway 101 bypass.

Subbasin Conclusions

The Prairie Creek Subbasin supports self sustaining populations of Chinook and coho salmon, steelhead and coastal cutthroat trout. It is believed that the Prairie Creek Subbasin provides the most coho salmon habitat and supports the largest coho population of all subbasins in Redwood Creek. Recent counts of spawning Chinook and coho show an increase from the low numbers observed in the early 1980s. However, a review of available information concludes that salmonid populations are well below historic levels of abundance.

Physical factors including debris jams and sediment inputs that impair anadromous salmonid habitats are linked to past land use activities. In contrast, undisturbed areas of the subbasin generally maintain desirable conditions for anadromous salmonids. Overall, the best stream habitat of the subbasin was found in areas that received the least amount of land disturbance.

RNSP maintains and protects natural resources and refugia habitat that are important to the recovery and expansion of anadromous salmonid populations of the Redwood Creek Basin. In addition, the Prairie Creek Subbasin provides an excellent opportunity for planning and implementing management to maintain and improve stream habitat conditions and to strengthen anadromous stocks of Redwood Creek.

The Prairie Creek Subbasin is an excellent location to study watershed science and to observe responses of fish populations in disturbed versus undisturbed watersheds. These streams offer the opportunity to compare and contrast natural stream recovery with habitat improvement projects aimed at increasing aquatic habitat quality and fish abundance and diversity.

Lower Subbasin

The Lower Subbasin includes the area above the confluence of Redwood and Prairie creeks upstream to the confluence of Redwood and Devil's creeks including Devil's Creek watershed (Table IV- 35 and Figure IV-23). The Lower Subbasin includes the planning watersheds of McArthur Creek, Bond Creek, Bridge Creek, Copper Creek, and Devils Creek. The lands within the Lower Subbasin are in public ownership and managed by RNSP. Lower Subbasin streams support populations of Chinook, coho, steelhead and coastal cutthroat trout.

Table IV- 35. Lower Subbasin notable features.

Square Miles	69.51
Total Acreage	44,488
Private Acres	275
Public Acres	44,212
Principal Communities	none
Predominant Land Use	Park land
Predominant Vegetation Type	Redwood forest
Miles of Anadromous Stream	24.5
Low Elevation	~10 ft.
High Elevation	1,286

Geology

The Redwood Creek schist (KJfr) dominates the bedrock in the Lower Subbasin. The incoherent unit of Coyote Creek (KJfc) and the coherent unit of Lacks Creek (KJfl) form two relatively narrow bands immediately east of the Grogan Fault. The incoherent unit of Coyote Creek is relatively weak, pervasively sheared shale containing isolated intact blocks of sandstone/shale and other exotic rocks and forms the lower, earth flow-dominated slopes close to Redwood Creek. The coherent unit of Lacks Creek is a hard, competent package of interbedded sandstone and shale (turbidites). It stands steeply and creates rugged topography forming debris slide amphitheaters.

Seventy-one percent of the Lower Subbasin falls into the high- to very high mass wasting potential category (Table IV- 36). Most of the planning watersheds share the same proportional distribution of mass wasting potential, but Copper Creek has approximately twice the proportion of active landslides than the other planning watersheds in this subbasin. The number of active landslides appears to be driven by the incoherent unit of Coyote Creek underlying most of the eastern portion of the subbasin.

Dormant landslide features occupy approximately 12% of the subbasin and these occur primarily in the Bridge, Bond, and Copper Creek planning watersheds (Table IV- 36). The other planning watersheds have approximately 1 to 2% of their area involved in dormant landslide features. McArthur Creek appears to be more stable than the other planning watersheds in the subbasin and has a greater proportion of area in the very low to moderate mass wasting potential category. This mass wasting potential probably occurs because the upper portion of the planning watershed has a relatively flat-floored valley and marine terraces occupy the crests of the major ridges to the northwest and southeast (Plate A, Sheet 1, CGS appendix).

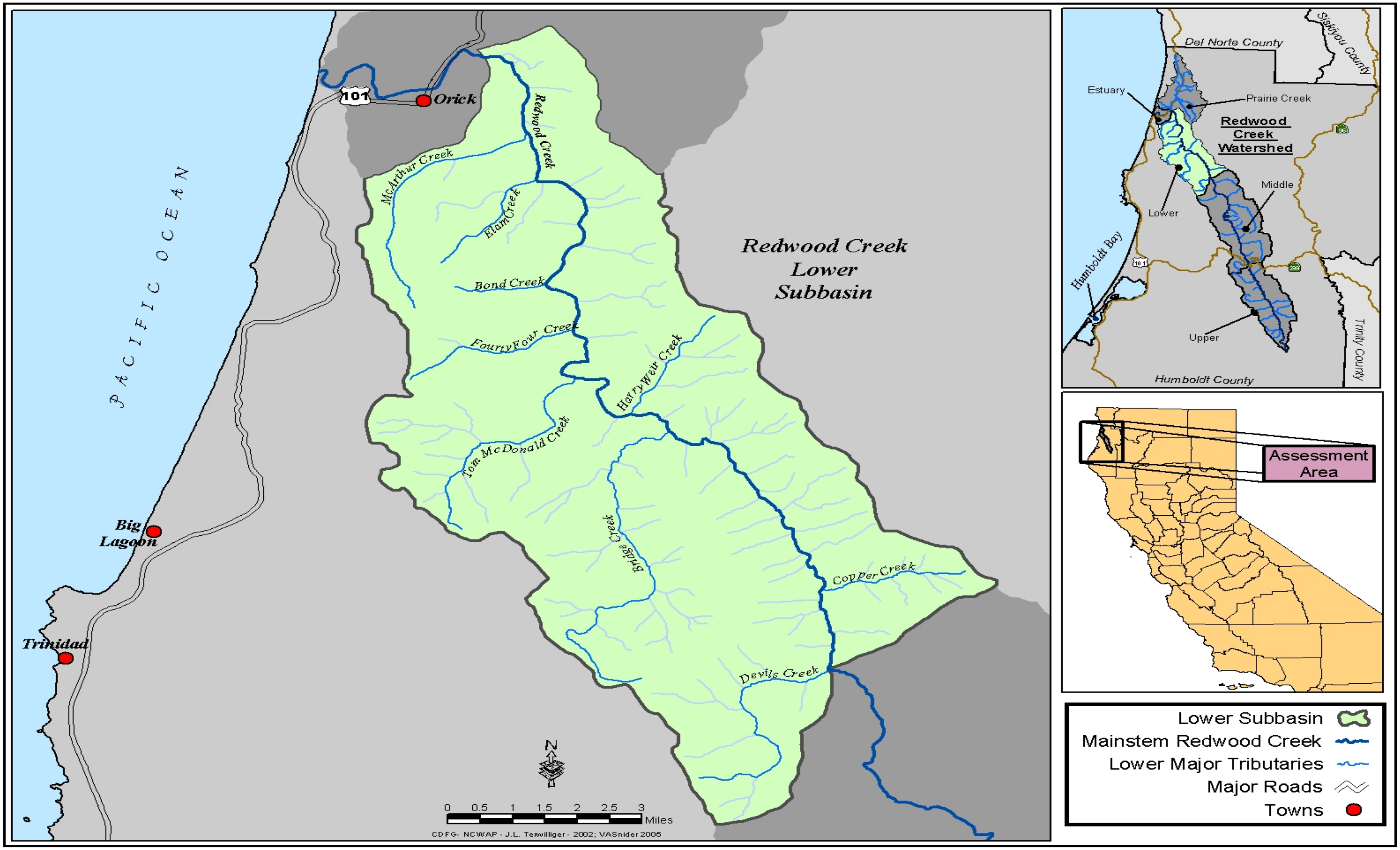

Figure IV- 23. Map of the Lower Subbasin of Redwood Creek.

Table IV- 36. Lower Subbasin summary of relative landslide potential and landslide features.

Factor	Subbasin		Planning Watersheds									
	Lower RC		Bond Creek		Bridge Creek		Copper Creek		Devil's Creek		McArthur Creek	
Relative Landslide Potential	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Very Low	2,666	6	389	4.8	780	5.2	266	2.7	226	5.1	1,005	14.8
Low	3,028	7	378	4.6	1,033	6.9	630	6.3	347	7.9	640	9.4
Moderate	7,259	16.3	1,273	15.6	2,326	15.5	1,740	17.4	738	16.7	1,182	17.4
High	17,431	39.2	3,359	41.1	6,146	40.9	3,239	32.4	2,087	47.3	2,600	38.2
Very High	14,033	31.6	2,783	34.0	4,731	31.5	4,134	41.3	1,011	22.9	1,374	20.2
High/Very High Subtotal	31,464	71	6,142	75	10,877	72	7,373	74	3,098	70.3	3,974	58
GRAND TOTAL	**44,417**	**100%**	**8,182**	**100%**	**15,016**	**100%**	**10,009**	**100%**	**4,409**	**100%**	**6,801**	**100%**
Landslide and Selected Geomorphic Features	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Historically Active Landslide Features Total [1]	2,662	6.0	477	5.8	985	6.6	1,149	11.5	8	0.2	43	0.6
Earthflow	1,762	4.0	271	3.3	363	2.4	1,126	11.3	2	0.0	0	0.0
Rock Slide	740	1.7	174	2.1	538	3.6					28	0.4
Debris Slide	82	0.2	21	0.3	29	0.2	19	0.2	4	0.1	9	0.1
Debris Flow	78	0.2	11	0.1	55	0.4	4	0	2	0	6	0.1
Dormant Landslide Features Total	5,263	11.8	1,296	15.8	2,101	14.0	1,683	16.8	104	2.4	79	1.2
Selected Geomorphic Features Total	5,540	12.5	898	11.0	1,017	6.8	2,244	22.4	671	15.2	709	10.4
Disrupted Ground	2,831	6.4	128	1.6	128	0.9	2,115	21.1	461	10.4	0	0.0
Debris Slide Slope	2,472	5.6	770	9.4	770	5.1	88	0.9	201	4.6	643	9.5
Inner Gorge (area)	236	0.5			119	0.8	41	0.4	10	0.2	66	1.0
Total of All Above Features	**13,465**	**30.3%**	**2,671**	**33%**	**4,103**	**27.3%**	**5,076**	**50.7%**	**783**	**17.8%**	**831**	**12.2%**

[1]Areas of disrupted ground are not included as active landslide features in this analysis.

Streamside Landslides

RNSP staff field mapped streamside landslides throughout the mainstem channel in 1980 at a scale of 1:6,000, using enlarged aerial photographs from 1978 (Kelsey and others 1981; Madej 1984a, b). Park staff also mapped storm landslides from 1997 aerial photos (1:6,000) following the 12-year storm of 1996/1997, to show landslides active during the storm. This was the largest storm event in Redwood Creek since 1975. "Although the number of landslides associated with roads was about the same as those not associated with roads, road-related landslides were larger and accounted for a much greater volume of sediment than non-road-related landslides." (M. Madej USGS, RNSP, Written Communication).

The Redwood Creek channel from Devils Creek to Bridge Creek is the area with some of the largest debris slides in the entire basin. These inner gorge debris slides were first noted in 1978 air photos and some extend 500 to 1000 feet upslope. The abundance of debris slides along the relatively straight reach may be related to a combination of steep slopes and a zone of weak, sheared rocks close to the Grogan fault. Another cause may be elevated groundwater levels, lowered evapotranspiration, and increased runoff related to extensive harvest operations which occurred immediately prior to this area's addition into the Park. Lower evapotranspiration, interception, and resultant higher groundwater may have combined with flooding during the 1975 storm season.

The northeast-facing slope above this section of channel stands strikingly out from the rest of the basin as it is relatively uniform and has few large landslides. The upper Bridge Creek channel may be structurally controlled because it closely follows a lineament (observed in aerial photographs) that extends south to Panther Creek.

Bond Creek showed a 64% increase in the number of small active landslides between 1984 and 2000; Copper Creek showed a 41% decrease in small active streamside landslides, while McArthur Creek did not change (Table IV- 37). If the number of active landslides were a simple predictor of future sediment storage in the channel, then Bond Creek would gain sediment in storage in its lower gradient reaches as a result of its high number of landslides in 2000. Bridge Creek contained the lowest density of small active landslides per acre or per unit length of stream, and showed little change between 1984 and 2000. Overall, there was a slight increase in streamside landslides in the subbasin. A simplified map of streamside landslides along a portion of the Lower Subbasin is presented in Appendix C.

Table IV- 37. Lower Subbasin active streamside slides, slide index, and change in index, 1984 and 2000.

Subbasin or Planning Watershed Unit of Analysis	Analysis Unit Area (sq. km.)	1984 # of Active* Slides Along Streams	2000 # of Active* Slides Along Streams	1984 Indexed** Active Slides	2000 Indexed** Active Slides	% Change 1984-2000
Lower Redwood Subbasin	180.1	249	260	138	144	4
Bond Creek	33.2	44	72	133	217	64
Bridge Creek	60.9	55	53	90	87	-4
Copper Creek	40.6	107	63	264	155	-41
Devil's Creek	17.8	0	18	0	101	∞
McArthur Creek	27.6	43	54	156	196	26

**Index = (# slides/analysis unit area) X 100

Vegetation

The Lower Subbasin contains 34,716 acres of forested landscape. The Lower Subbasin supports old growth and second growth redwood forests (16,663 acres or 37% of the subbasin) and mixed redwood /Douglas-fir (19,567acres or 44% of the subbasin) (Table IV- 38 and Figure IV- 24). Douglas-fir dominated stands (2,057 acres or 5% of the subbasin) are also present. Approximately 6,189 acres is grassland and 4,067 acres are stocked with hardwoods, mainly red alder. Areas of Oregon white oak are found along the upper ridges of the subbasin in association with grasslands. Timber stands within this area exhibit growth in the site II or site III classification for productivity. Areas classed as barren (408 acres) are located along the lower portion of Redwood Creek. These areas are mostly gravel bars, which do not support vegetation at this time.

Table IV- 38. Generalized cover type by subbasin and planning watershed.

Subbasin or Planning Watershed	Cover Type								
	Agriculture	Barren	Conifer	Hardwood	Grassland	Shrub	Developed	Water	Total
Lower Subbasin	0	408	39,037	3,805	1,244	19	5	0	44,518
Bond Creek	0	108	7,388	702	4	0	0	0	8,202
Bridge Creek	0	99	13,668	1,112	169	3	0	0	15,051
Copper Creek	0	66	8,110	795	1,059	3	0	0	10,033
Devil's Creek	0	8	4,129	270	0	4	0	0	4,411
McArthur Creek	0	127	5,742	926	12	9	5	0	6,821

Land Use

The land within the Lower Subbasin is managed by the RNSP. The RNSP land management strategies include: 1) perpetuation of the redwood forest and associated ecosystems as prime resources; 2) perpetuate ongoing natural influences on the basis of natural values and visitor use; and 3) protect threatened and endangered species and species of special concern (USDOI 1999).

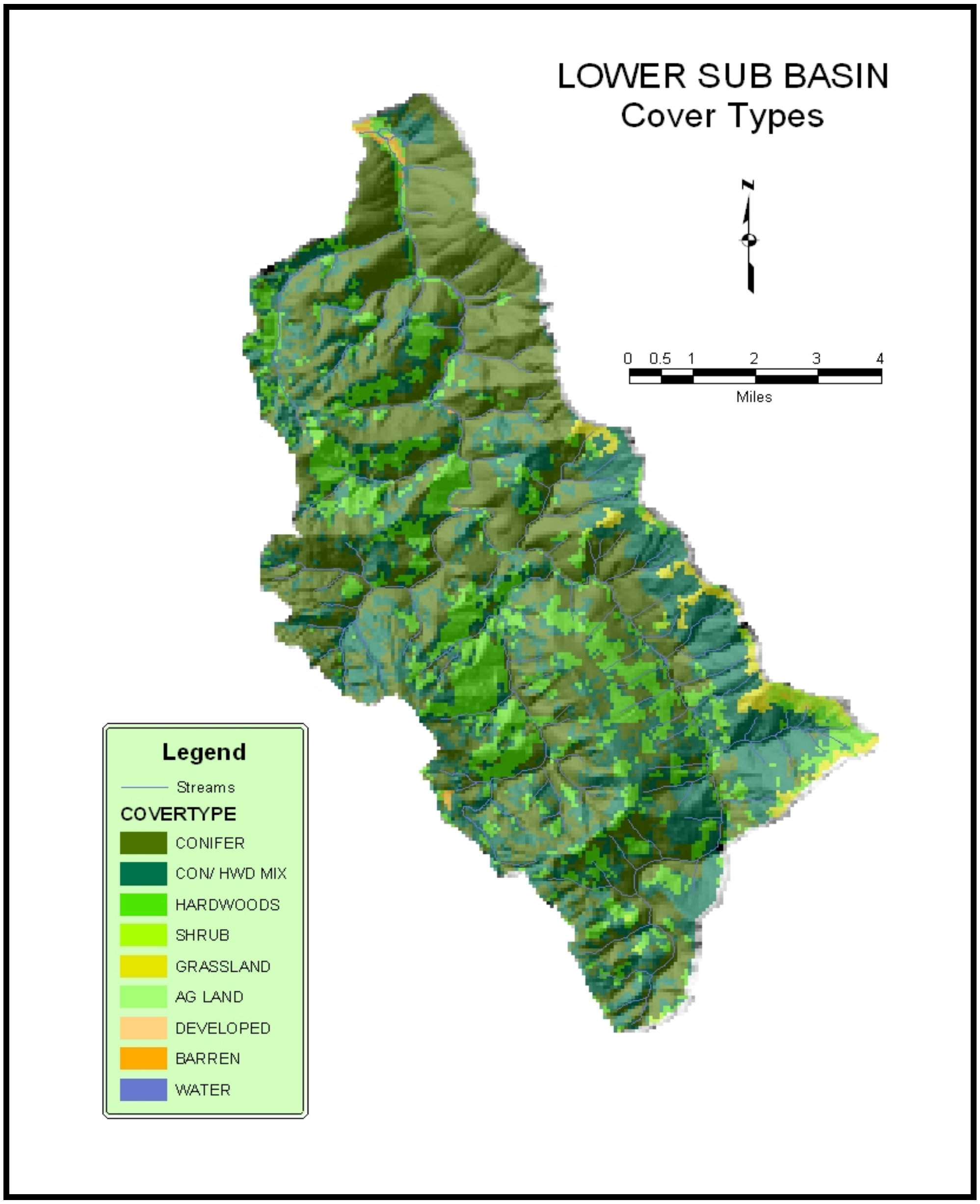

Figure IV- 24. Lower Subbasin vegetation map showing cover types.

Timber Harvests

Until 1978 the Lower Subbasin was under private ownership and was managed for timber production. Commercial timber harvests in the Lower Subbasin ended with the expansion of RNSP in 1978. Road removal, erosion control, and recreation are now major land use activities in the Lower Subbasin.

Approximately 30,215 acres of the Lower Subbasin were harvested between 1950 and 1978, or about 68% of the subbasin area (Table IV- 39 and Figure IV- 25). Prior to 1955, harvest rates were relatively low in the subbasin. Bridge Creek, Devil's Creek, and Bond Creek planning watersheds had the highest percentages of area harvested; McArthur Creek had the smallest.

Timber harvest technology and methods have evolved over the years as can be seen by inspection of time series air photos. Logging prior to 1942 in the headwaters of Devil's Creek and Panther Creek was mostly accomplished with the use of steam donkey skidding systems. Some harvest areas also used tractors including the area above Orick along the Bald Hills Road and areas of Tom McDonald Creek and Devils Creek. During the decades of the 1950s and 1960s, clear cuts were very large and extensive. The majority of these cuts employed tractor yarding. The use of tractor constructed skid trails is evident in aerial photographs, especially on steeper slopes. Ground disturbance resulting from these prolonged operations was extensive, with some areas showing over 75% of the ground disturbed. Clear-cut units in the mid 1970s and later were much smaller, with buffer zones between the cut blocks. With the introduction of cable systems in 1972 the road networks were built along the ridges and mid-slope locations. Although old roads were still located along channel bottoms, there was no new road construction in these areas.

Table IV- 39. Lower Subbasin timber harvest history, 1950-2000.

Subbasin or Planning Watershed	Harvest Acres by Period							
	1950 - 1964	1965 - 1974	1975 - 1978	1978 - 1992	1992 - 2000	Total Harvested	Total Acres	Percent Area Harvested
Lower Subbasin Total	12,470	13,436	4,308	0	0	30,214	44,505	67.9
Bond Creek	1,718	3,095	889	0	0	5,702	8,200	69.6
Bridge Creek	6,671	3,822	1,479	0	0	11,972	15,056	79.5
Copper Creek	2,216	2,625	837	0	0	5,678	10,028	56.6
Devil's Creek	848	1,539	725	0	0	3,112	4,407	70.6
McArthur Creek	1,017	2,355	378	0	0	3,750	6,814	55.0

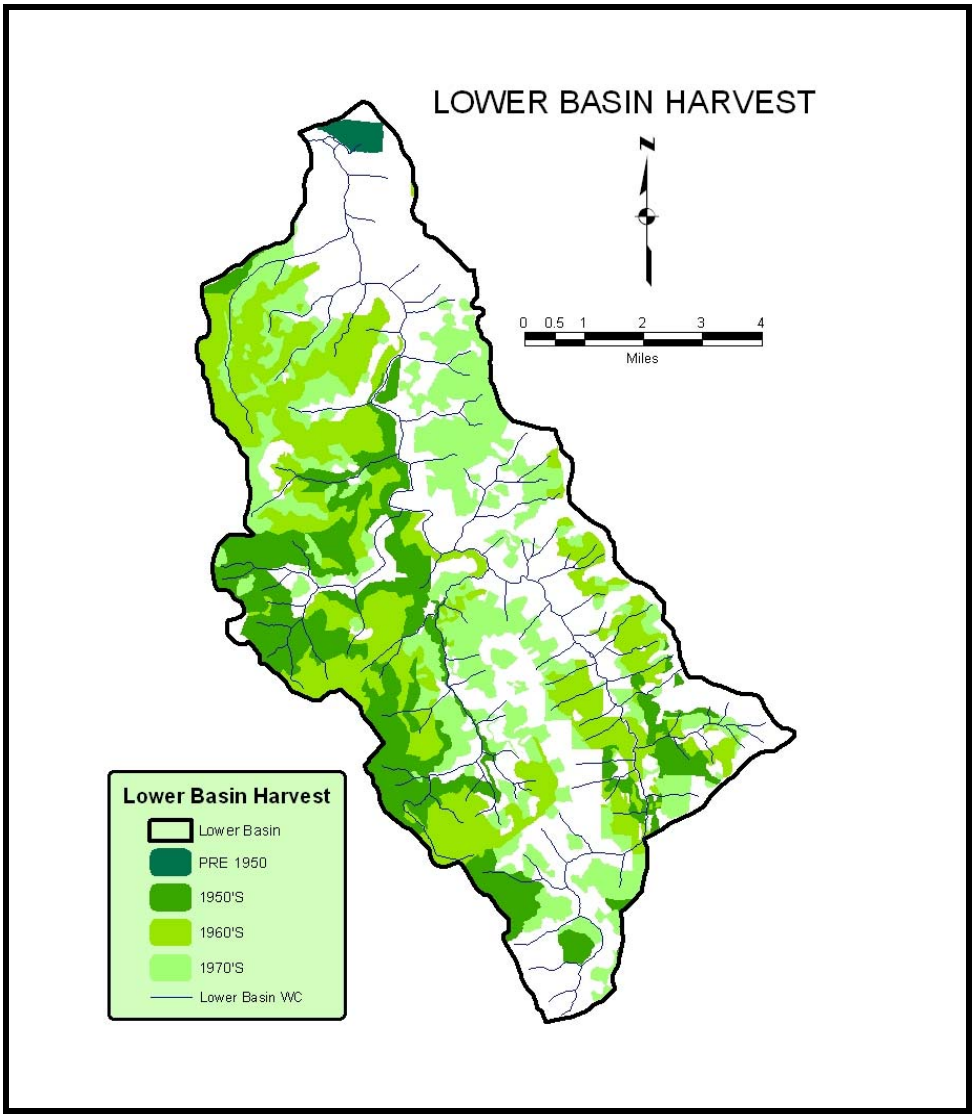

Figure IV- 25. Lower Subbasin timber Harvest.

Roads

As of 2001, the Lower Subbasin had an estimated 138 miles of roads, or a road density of about 2.0 miles of road per square mile. This low road density reflects the Park's aggressive efforts to remove roads in the subbasin. An estimated 76% of the road miles are on areas of high or very high relative landslide potential. The Copper Creek Planning Watershed has the lowest road density, at 0.6 road miles per square mile, and the Devil's Creek Planning Watershed has the highest, at 3.9 road miles per square mile. Recent road removal projects have reduced the number of road miles to near zero in the Lower Subbasin (Greg Bundros, RNSP, personal communication).

Fire and Fuels

Fire and fuels rankings in the Lower Subbasin (Table IV- 40 and Figure IV- 26) are dominated by areas in the high rank, with patches of small areas in the very high rank along the eastern border of the unit. The Copper Creek Planning Watershed stands out as having a relatively large percentage of area in the very high fuel rank, compared to the other planning watersheds on the subbasin. However, given the relatively cool temperatures and moist conditions of the Lower Subbasin, only under rare, severe weather conditions would fuel conditions pose as high a risk to fire as their rankings imply.

Table IV- 40. Lower Subbasin fuel ranks summary for planning watersheds.

Subbasin or Planning Watersheds	Fuel Rank								Total Acres
	Moderate		High		Very High		Not Mapped		
	acres	%	acres	%	acres	%	acres	%	
Lower Redwood Creek Subbasin	17,134	38	24,672	55	2,533	6	168	<1	44,507
McArthur Creek Planning Watershed	1,573	23	4,988	73	187	3	66	1	6,814
Bond Creek Planning Watershed	2,459	30	5,278	64	430	5	34	<1	8,201
Bridge Creek Planning Watershed	6,594	44	7,799	52	611	4	52	<1	15,056
Copper Creek Planning Watershed	4,503	45	4,382	44	1,133	11	11	<1	10,029
Devil's Creek Planning Watershed	2,005	45	2,226	51	171	4	5	<1	4,407

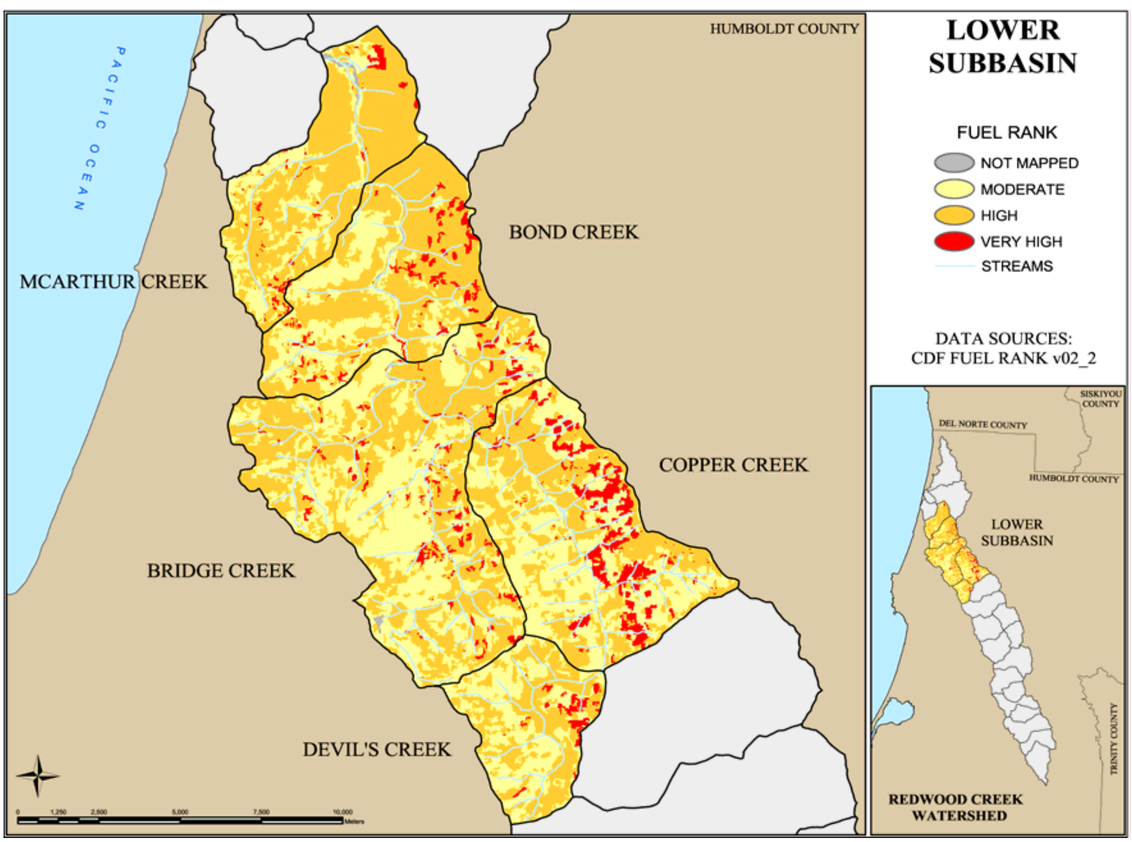

Figure IV- 26. Lower Subbasin fuel ranking map.

Fluvial Geomorphology

Within the Lower Subbasin, there are approximately 17 miles of mainstem Redwood Creek and 122 miles of blue line tributary stream channel (Table IV- 41). The lower reach of Redwood Creek is straight and follows the Grogan fault zone between confluences of Devil's Creek (~RM 21) and Dolason Creek (~RM 15). Streamside landslides are abundant along this reach within the fault zone. Below the mouth of Dolason Creek, the course of Redwood Creek veers westward into the Redwood Creek Schist. Below Bridge Creek, Redwood Creek widens. This lower, wider, and flatter stretch contains massive stream bars and some terraces, including the terrace of the Tall Trees Grove. Downstream, near the confluence with Prairie Creek the main stem makes its final westward bend toward the ocean.

The stream network in the lower part of Redwood Creek basin consists of roughly equal proportions of response, transport, and source reaches. Response reaches dominate the mainstem and provide the most habitat for anadromous fish. Source reaches dominate the tributaries, comprising about 44% of the total blue-line stream lengths of the whole subbasin. Sediment generated in the steeper reaches moves downstream and can be deposited in lower gradient, anadromous fish bearing habitat.

Studies show that the mainstem channel in the Lower Subbasin accumulated sediment from storms in 1955, 1964, 1972, and 1975 (RNSP 1999). Channel-bed elevations increased (Madej and Ozaki 1996) and the capacity of the channel to convey peak flows was reduced. The channel adjusted its width to accommodate flood peaks by eroding its banks (Janda and others 1975). As the locus of deposition of sediment shifted progressively downstream between 1974 and 1981, streambanks eroded along the lower reach (Nolan and Marron 1995) and streamside redwoods fell.

Table IV- 41. Lower Subbasin planning watershed area and miles of blue line streams.

Planning Watershed	Area (acres)	Miles of Blue-line streams	Miles of Redwood Creek Mainstem	Number of Blue-line Tributary Segments (Number of these that drain directly into Redwood Creek)
McArthur Creek	6,814	14.4	2.7	8 (6)
Bond Creek	8,200	18.4	4.6	12 (9)
Bridge Creek	15,056	45	3.1	37 (5)
Copper Creek	10,028	32.7	6.3	32 (19)
Devils Creek	4,407	11.8	0	8 (1)

Tall Trees Grove and the adjacent channel of Redwood Creek were affected by the storms as well as by the downstream movement of excess sediment from upstream roads and timber harvest areas. Aerial and ground photographs, channel cross sections, and interviews with lumber company workers employed during the 1940s through the 1970s (Milestone, J.F. 1979, Redwood National Park, written communication) all indicate that the channel bed near the grove aggraded by roughly 5 feet sometime after the 1955 flood. The channel banks eroded enough to endanger old-growth trees. In 1979, in the Tall Trees Grove, park staff mapped four fallen redwood trees and five redwoods with roots exposed by bank erosion (Milestone, J.F., Redwood National Park, written comm., 1979).

RNSP and the USGS began to monitor cross sections of mainstem Redwood Creek in the 1970s. Madej and Ozaki (1996) noted that the mainstem channel has aggraded and degraded across its entire active channel width including the thalweg and low unvegetated bars, rather than becoming incised and narrowing. Just below Panther Creek, channel width increases from 100 ft. to 160 ft. and channel gradient decreases from 1.4% to 0.3% along the reach that contains the first 14 cross sections in the Lower Subbasin. This reach, from Panther Creek to just below Harry Weir Creek, aggraded more than three feet after the 1975 flood. Within the next reach, between Harry Weir Creek and Tall Trees Grove, bankfull widths are as much as 500 ft. and channel gradient is 0.2%. Six cross sections have been monitored. The channel fluctuated between aggradation and degradation following the storms in the early 1970s. The third reach includes 10 cross sections, distributed along the mainstem channel from Tall Trees Grove downstream to Elam Creek. In this reach the mainstem channel aggraded during the entire period of monitoring discussed by Madej and Ozaki (1996). Bankfull width was 200-375 ft and channel gradient was reported as 0.2%. Downstream from the last park cross section, the river has fluctuated between aggradation and degradation due to the increase in width of the alluvial valley, construction of levees, and gravel extraction (Madej and Ozaki 1996). This information is discussed in more detail in Appendix E.

CDFG stream survey crews measured channel cross sections during 2001 in the tributaries and the mainstem of Redwood Creek. CGS compared channel parameters with regional curves developed by Rosgen and Kurz (2000, written communication) for North Coast streams. Areas along the lower mainstem of Redwood Creek do not fit predictions of the regional curves, which indicates that the lower mainstem channel is excessively wide with respect to its drainage area. Furthermore, CDFG crews in the field observed the excessive width of the channel in the spots they studied and recorded the observation in their field notes. Two specific locations were noted along the mainstem of Redwood Creek near the confluences with Tom McDonald Creek (392 ft. wide) and Bond Creek (308 ft. wide).

Stream Disturbance

In the Lower Subbasin, stream disturbance features showed a net decrease in overall length from 26.8 mi to 13.4 mi, between photo years 1984 and 2000. However, elevated sediment left steeper tributaries and accumulated in the mainstem channel, so the lowest part of the lower subbasin actually deteriorated with respect to stream disturbance features.

The changes in stream disturbance are discussed below by planning watersheds and by individual tributaries. This is important, because within a planning watershed, there were places of net improvement and places simultaneously showing net deterioration. The general trend between photo years 1984 and 2000 was for stream disturbance to decrease in tributaries and become confined to the mainstem of Redwood Creek.

Overall, the Lower Subbasin saw a decrease of 43% in disturbance features by length (Table IV- 42). Copper and Bridge Creeks show improvement in both negative stream features and streamside landslides, whereas McArthur Creek shows deterioration. Bond Creek shows an increase in streamside landslides, but a significant decrease in elevated sediment in the channel, suggesting that most sediment may be rapidly transported downstream.

Some planning watersheds straddle Redwood Creek, meaning that they include tributaries that enter the mainstem from both the east and the west. The Noisy Creek planning watershed in the upper subbasin, gained stream disturbance features. The gain was due solely to conditions on Noisy Creek, on the west side of the planning watershed. The tributaries on the east side improved, and the mainstem of Redwood Creek remained about the same.

Only McArthur Creek did not contribute to the improvement and showed an increase in the length of negative stream features. McArthur Creek may have been more affected by the 1996/1997 storm, which seems to have caused more erosion and sediment yield in that planning watershed. Correspondingly, the number of streamside landslides increased by 26% in McArthur Creek. Copper Creek saw a significant decrease of 71% in negative stream features.

Water Quality

Temperature

Temperature data in the Lower Subbasin were collected from 1997 to 2001 at four locations, two along the mainstem, and two at tributaries (Table IV-43). The tributary streams generally provide suitable water temperatures year-round for anadromous salmonids while the mainstem Redwood Creek has higher than desirable water temperatures during summer and early fall seasons. Cooler water refuge areas do provide habitat for juvenile salmonids in the mainstem over summer months when ambient stream temperatures may be highly stressful or preclude salmonids. A few thermally stratified pools form where cold intergravel flow, tributary flow, or springs seep into the stream channel (Ozaki 1988).

Table IV- 42. Length of negative stream features, negative stream feature index, and percent change for 1984 to 2000.

Planning Watershed	Creek Name	Stream Disturbance (m)		Stream Disturbance (ft)		Stream Disturbance (mi)		Stream Disturbance (%)	
		1984	2000	1984	2000	1984	2000	1984	2000
McArthur Creek	Hayes Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unnamed trib, east side, south of Hayes Creek	0.0	580.0	0.0	1902.9	0.0	0.4	0.0	2.5
	McArthur Creek	357.2	374.6	1172.0	1229.0	0.2	0.2	1.5	1.6
	Elam Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Redwood Creek	3159.6	5282.1	10370.0	28450.0	2.0	5.4	13.6	22.8
	Total	**3516.8**	**6236.7**	**11542.0**	**31581.9**	**2.2**	**6.0**	**15.1**	**26.9**
Bond Creek	Oscar Larson Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	East side trib unnamed, no blue line	427.4	0.0	1402.1	0.0	0.3	0.0	1.4	0.0
	Cloquet Creek	1514.5	0.0	4968.7	0.0	0.9	0.0	5.1	0.0
	Bond Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Miller Creek	2764.8	0.0	9070.9	0.0	1.7	0.0	9.3	0.0
	Fortyfour Creek	2306.0	360.3	7565.6	1182.0	1.4	0.2	7.8	1.2
	Cole Creek	1013.2		3324.1	0.0	0.6	0.0	3.4	0.0
	Redwood Creek	4298.6	3944.3	14103.1	12940.6	2.7	2.5	14.5	13.3
	Total	**12324.4**	**4304.6**	**40434.5**	**14122.7**	**7.7**	**2.7**	**41.6**	**14.5**
Bridge Creek	Tom McDonald Creek	3782.4	0.0	12409.4	0.0	2.4	0.0	5.3	0.0
	Harry Weir/Emerald Cr.	1560.6	0.0	5120.0	0.0	1.0	0.0	2.2	0.0
	Bridge Creek	4357.3	4587.5	14295.6	15050.8	2.7	2.9	6.1	6.4
	Redwood Creek	3817.6	2504.9	12525.0	8218.2	2.4	1.6	5.3	3.5
	Total	**13517.9**	**7092.4**	**44350.0**	**23269.0**	**8.4**	**4.4**	**18.8**	**9.9**
Copper Creek	Dolason Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	G Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Airstrip Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Slide Creek	1562.1	0.0	5125.1	0.0	1.0	0.0	3.0	0.0
	Maneze Creek	1236.1	0.0	4055.3	0.0	0.8	0.0	2.4	0.0
	Copper Creek	1719.2	1030.5	5640.4	3381.0	1.1	0.6	3.3	2.0
	Lyons Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Elf Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Redwood Creek	8786.1	2953.0	28825.8	9688.4	5.5	1.8	16.7	5.6
	Total	**13303.5**	**3983.5**	**43646.7**	**13069.4**	**8.3**	**2.5**	**25.3**	**7.6**
Devils Creek	Devils Creek	452.7	0.0	1485.3	0.0	0.3	0.0	2.4	0.0
	Total	**452.7**	**0.0**	**1485.3**	**0.0**	**0.3**	**0.0**	**2.4**	**0.0**

The NW/SE aspect of the basin and lack of riparian shading have a large influence on mainstem water temperature in this subbasin. On the mainstem Redwood Creek, maximum weekly average temperature (MWAT) cools slightly from approximately 72ºF above the confluence with Lacks Creek in the Middle Subbasin to a range of 67 -70ºF , near the confluence of Tom McDonald Creek, 15 miles downstream. MWATs are consistently slightly cooler in the Lower Subbasin than in the Middle Subbasin, but temperature data from the past four years exceed the desirable range for salmonids even with contributions from cold water tributaries and fog influence. Redwood Creek flows through patches of giant trees in this part of the subbasin, however this does not significantly lower water temperature because the mainstem channel is often too wide for trees to provide shade over the flowing stream or create a microclimate. The coastal fog belt does not influence water temperature for much more than a mile upstream the confluence with Prairie Creek. Contributions from cool water tributaries also may reduce water temperature in localized patches of the mainstem. These confluence sites may provide small, thermal refuge areas for salmonids during hot summer months.

Tributaries have cooler MWATs than the mainstem. For example, Bridge Creek has steadily resided between 60º and 61ºF MWAT from 1996 to 2001. This consistent MWAT may be a result of canopy and channel protection and restoration by the RNSP. Water temperature in Tom McDonald Creek had an MWAT of 58ºF in 2001.

Table IV- 43. Lower Subbasin streams MWATS.

Site ID	Site	Subbasin	Period of Record	Max MWAT year	Max MWAT (F)
40, Tmcd	Tom McDonald Creek1	Lower	2001	2001	58
3014, RwTtg	*RedCrk upstm Tom McD Crk5, 1	Lower	1997-99, 2001	1998	70
3002, Bri	Bridge Creek5, 1	Lower	1996-2001	1999	61

Maximum daily temperatures recorded during the summers of 1996 to 2001 for the sites in the Lower Subbasin were between 70 and 75ºF along the mainstem and 60 and 65ºF on the tributaries. These readings indicate that at least one day during the hottest part of the year, temperatures in the lower mainstem approach the lethal limit of 75º F and may remain hot for some hours thus causing stress and damage to salmonids.

Water Column Chemistry

USGS monitored 26 sites in the Lower Subbasin between 1970 and 1980. Most of the sites were sampled from 1974-1975. Three sites were along the mainstem and 23 sites on tributaries. Samples collected from the lower watershed area show near compliance for all parameters with Basin Plan current water quality objectives and no noticeable trends were observed. Data for dissolved oxygen ranged from 7-13mg/L (water quality objective >8mg/L), pH ranged from 5.5 to 8.5 (water quality objective 6.5-8.5), and conductivity ranged from 25-250umhos (water quality objective <220umhos), slightly exceeding objective goals. See Appendix C for water chemistry data from Lower Subbasin.

In-Channel Sediment

In-channel sediment was sampled by RNSP for median particle size (D_{50}) and percent of fine materials at five sites in the mainstem of Redwood Creek of the Lower Subbasin from 1979 to 1995. Median particle size of in-channel sediment was sampled by RNSP on a point bar just downstream of the confluence with Miller Creek in 1982, 1985, 1988, and 1991. See Appendix C for the D_{50} data. These data showed a large increase in D_{50} particle size from 3 to 21mm between 1985 and 1988. The minimum TMDL target of >37mm for D_{50} was not met between 1982 and 1991 at this site. Information from the CGS fluvial geomorphology assessment shows the point bar grew from 1984 to 2000, suggesting that sediment was stored here during that time. The assessment also notes an excess of sediment in the Miller and Fortyfour creek tributaries from the RNSP examination of 1980 and 1997 air photos. The in-channel sediment data, along with the CGS and RNSP fluvial geomorphology assessment confirm an elevated amount of sediment on the mainstem at the confluence with Miller Creek from 1980 to 2000.

Another mainstem site in this subbasin sampled for in-channel sediment by RNSP is located upstream from the confluence with Harry Wier (Emerald) Creek (approx. RM 14). Data show the D50 size increasing from 11mm in 1979 to 16mm 1982. The minimum TMDL target of >37mm for D_{50} was not met between 1979 and 1982 at this site. See Appendix C for the D_{50} data. There was a streamside slide and tributary fan evident in 1993 photos at the mainstem confluence with Bridge Creek, which is upstream of the sample site. Data show a peak in D_{50} particle size in 1995 perhaps reflecting this slide. CGS fluvial geomorphology analysis located this site at the downstream end of a stream bar. Their photo analysis showed the bar eroded slightly at the sample site and enlarged at the opposite end between 1984 and 2000. This site is also opposite and downstream of mainstem slides that were mapped in 1980 photos by the RNSP. These slides could have contributed to the shaping and formation of the stream bar at the sample site. Comparisons of in-channel sediment data with the fluvial geomorphology assessment by CGS help to create a picture of sediment transport in this reach. See the fluvial geomorphology section of the CGS appendix (Appendix E) for more detailed information about this cross section.

The Lower Subbasin of Redwood Creek was sampled in 1979 and 1994 at 6 sites to determine the amount of fine materials present in the channel by the RNSP and USGS. Unfortunately, due to different methods of analysis the RNSP and USGS data cannot be compared to TMDL targets at this time (See the In-Channel Sediment section of Part 2 for more information). However, the gravimetrically measured data presented in Appendix C shows that the <2mm size class fluctuated the most between 1979 and 1994. Without current data it is difficult to make conclusions from these studies about the distribution of in-stream sediments and how they impact salmonid habitat in the lower subbasin.

Salmonid Habitat

Fish Habitat Relationship

The Lower Subbasin supports populations of Chinook salmon, coho salmon, steelhead, and coastal cutthroat trout (Table IV- 44). The entire lower reach of Redwood Creek (17 miles) is used by anadromous salmonids for upstream and downstream migrations and is also used for seasonal spawning and rearing habitat.

Within the 14 known fish bearing tributary streams in the Lower Subbasin, only 9.5 miles of habitat is accessible to anadromous salmonids (Brown 1988). The steep channel gradient limits access to anadromous salmonids to only the lowermost reaches of these tributary streams. The most important tributary streams (based on amount of available habitat) in the Lower Subbasin for anadromous salmonids are Bridge, Emerald (Harry Weir), Tom McDonald, and McArthur Creeks. These four creeks comprise 78% of the tributary stream habitat available to anadromous salmonids in the Lower Subbasin. Resident populations of coastal cutthroat and rainbow trout are found upstream of anadromous tributary reaches. It is unclear how these resident populations interact with anadromous stocks.

Table IV- 44. Lower Subbasin stream species present, and number of stream miles accessible to anadromous salmonids.

Stream	Species Observed		Stream Length Access (mi.)	References
Bridge Creek	Chinook coho coastal cutthroat steelhead sculpin sp.	Pacific lamprey yellow-legged frog western toad Pacific giant salamander	4.5	CDFG 2001 & 1966 Stream Surveys, Brown 1988 (Hofstra personal communication), USFS/RNSP barrier study notes.
Emerald (Harry Wier)	steelhead coastal cutthroat coho	Sculpin spp. Pacific giant salamander	1.8	Ridenhour and Hofstra 1994, Brown 1988, and RNSP/USFS-RSL revisit of 1981 thesis sites
Tom McDonald Creek	Chinook coho steelhead cutthroat/steelhead coastal cutthroat	pacific lamprey sculpin spp. Pacific giant salamander	1.30	RNP 2000 surveys, , Neillands 1990, Brown 1988, RNP/USFS-RSL revisit of 1981 thesis sites field notes, CDFG 1966 stream survey
McArthur Creek	coho steelhead coastal cutthroat cutthroat/steelhead sculpin spp.	Pacific giant salamander tailed frog yellow-legged frog	0.50	RNSP 2001, Forest Science Project 2000, RNSP/USFS-RSL barrier study - 1995 notes, Neillands 1990, Brown 1988
Copper Creek	steelhead		0.31	Brown 1988
Elam Creek	coho coastal cutthroat steelhead	cutthroat/rainbow sculpin sp.	0.31	RNSP 2001, Forest Science Project 2000, Neillands 1990, Brown 1988
Cloquet Creek	coastal cutthroat steelhead sculpin sp.	tailed frog yellow-legged frog	N/A	RNSP 2000
Devils Creek	steelhead Pacific giant salamander	tailed frog yellow-legged frog	0.19	Neillands 1990 and Brown, 1988
Fortyfour Creek	cutthroat trout steelhead sculpin sp.	Pacific giant salamander	0.19	USFS/RNSP barrier study notes, CDFG 2001 stream surveys, Neillands 1990, Brown 1988
Hayes Creek	steelhead coastal cutthroat	Pacific giant salamander yellow-legged frog		USFS/RNSP Barrier study notes 1996
Bond Creek	coastal cutthroat steelhead	cutthroat/rainbow trout	0.12	Neillands 1990, Brown 1988
Slide Creek	steelhead		0.12	Brown 1988
Dolason Creek	steelhead		0.12	Brown 1988
Miller Creek	steelhead		0.12	Brown 1988
Redwood Creek	Chinook coho coastal steelhead	steelhead eulachon	17.2	CDFG 2001 Stream Surveys, Gerstrung 2001, RNSP 2001, 1989, Anderson 2000, Ridenhour and Hofstra 1994, Brown 1988, Hallock et al. 1952.

Past Surveys

Based on review of air photos, CDFG reports, and anecdotal accounts, it is clear that historic conditions of the Lower Subbasin were quite different than today. In the past, the mainstem channel was cooler, narrower and riparian forests containing large redwoods lined the riverbanks. Shade from these large trees likely worked in combination with cool tributary inflows, a cooler mainstem from upstream sources, and other cool water sources to provide desirable water temperatures for summer rearing salmonids. The large trees also provided a source of LWD to help maintain channel diversity, complexity, and nutrient inputs to the aquatic ecosystem.

Hallock et al. (1952) described how the lower mainstem was once a productive year round salmonid nursery area. In an effort to collect juvenile coho salmon for a three-state fingerling marking program, they noted that "Little River and Redwood Creek were both excellent silver (coho) salmon streams, but were not seined extensively because in the few places where they could be reached by road, the pools were so deep as to make netting impractical". "However, these streams made good planting places and received more fish than were taken from them." More than 10,000 marked YOY coho were released (May 14 through July, 21 1951) into the mainstem Redwood Creek (Hallock et al. 1952). This information suggests that juvenile coho were rearing during summer in the lower mainstem Redwood Creek. Water temperature in Redwood Creek was cold enough to support coho salmon in July 1951, and that pools along the lower reach of Redwood Creek were deep. This is a significant difference compared to present conditions.

Following the major flood of December 1964, conditions in Redwood Creek changed drastically. Fisk et al. (1966) stated that the lower mainstem of Redwood Creek was "in a severely damaged condition" and was "largely unsuitable" as a nursery for young salmon and steelhead. As a result of sediment deposition, "the streambed has widened and rose" and pools were filled.

In 1966, CDFG surveyed the lower four miles of Bridge Creek and reported that fish presence was limited to a few steelhead and cutthroat trout in lower reach. There was a "moderate abundance of resident cutthroat in last mile of survey." The lower three miles contained scarce pools, logging debris in the channel, little streamside canopy, and the bottom was 26-50% covered by silt. The upper mile contained better habitat conditions. There was a low abundance of aquatic insects. A large debris jam located approximately 0.8 miles up stream of the confluence with Redwood Creek blocked anadromous fish passage for the remaining 3.7 miles of anadromous fish habitat. Similar to other debris jams in the basin, a large store of sediment had accumulated behind the structure (in 1971 over 20,000 cubic yards was estimated). Prior to the jam formation, timber harvest activities occurred along upper reaches of Bridge Creek. Roads were built along the stream bank, and logs were tractor yarded through the channel (RNSP staff personal communication). Modifications to remove the debris jam were made between 1971 and 1990. The final treatment in 1990 consisted of the development of a fishway, removal of seven feet of debris to moderate movement of sediment downstream into salmonid spawning habitat, and placement of LWD at four sites to scour excessive sediments stored above the debris jam and develop pool habitat. During spawner surveys conducted in the fall of 1990, adult Chinook and coho salmon were seen above the former migration barrier. The presence of anadromous salmonids above the former barrier showed successful removal of a passage barrier and return of lost habitat to the fish. Additional past stream survey summaries of Lower Subbasin tributaries are provided in Appendix D.

Present Surveys

Stream habitat inventories were conducted in September 2001 at nine randomly selected sampling sites located in the Lower Subbasin. Three sites were located on tributary streams (Bridge, Elam, and Fortyfour creeks) and six sites were located along the mainstem Redwood Creek (Figure IV- 28). The sampling sites were inventoried using CDFG protocols, sampling 100% of the selected reach. Unlike the typical CDFG stream inventory of anadromous reaches (Flosi et al. 1998), these data only attribute specific to sample sites and not entire stream reaches available to anadromous salmonids. Results from select stream habitat components for Redwood Creek and tributary sites are summarized below. Further discussions of present conditions of Lower Subbasin streams are provided in Appendix D.

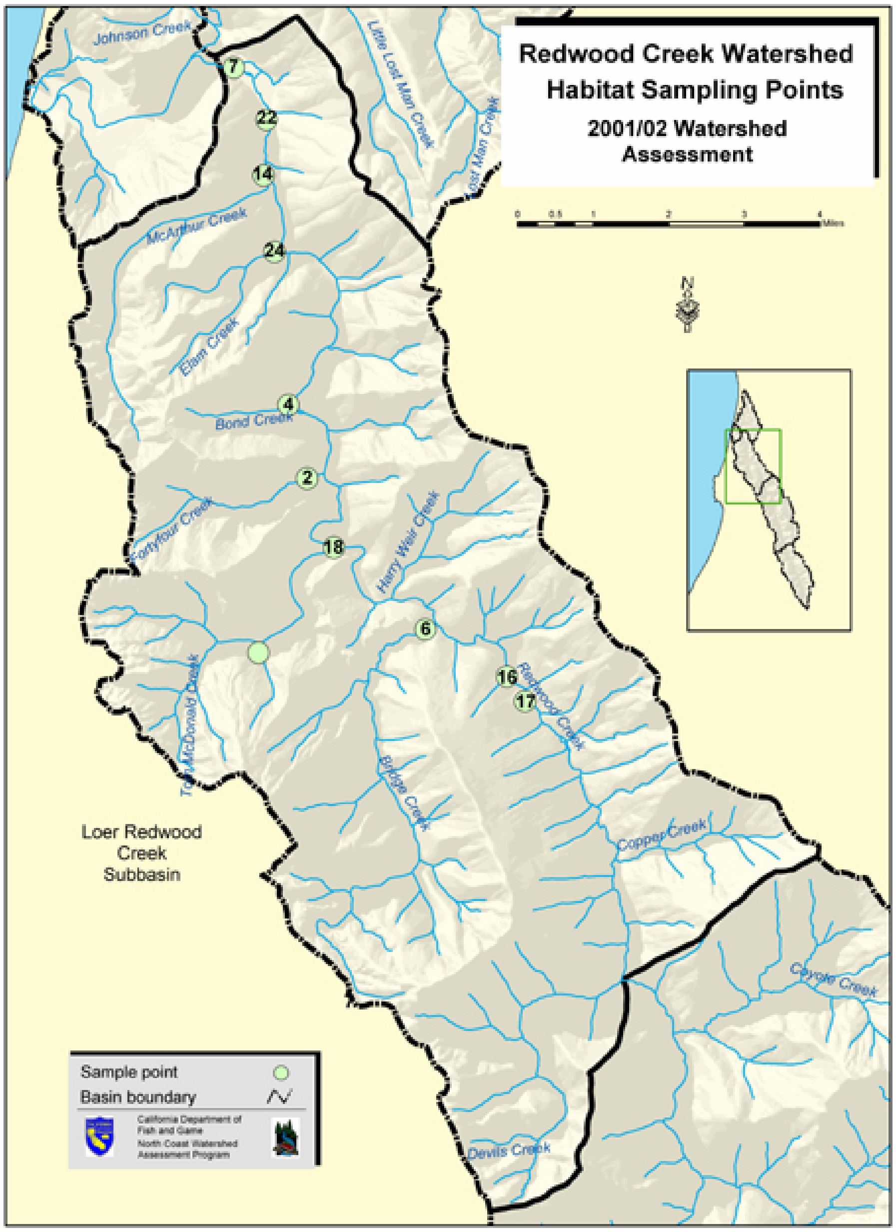

Figure IV- 27. Lower Subbasin instream habitat sampling points.

Stream Reach Characteristics

Pool:Riffle:Run Relationships

Significance: Productive anadromous streams are composed of a balance of pool, riffle and run habitat and each plays an important role as salmonid habitat. Looking cumulatively at pool, riffle, and run relationships and bank full width (BFW) to pool frequency ratios helps characterize the status of these habitat types and also provides a measure of stream habitat diversity and suitability for fish. A pool: riffle ratio of approximately 1:1 is suggested as a desirable condition for most wadable, anadromous, fish bearing streams, but it is not applicable for evaluating salmonid suitability of all stream reaches and channel types (Rosgen 1996). However, pool:riffle relationships showing an over abundance of riffles or runs that may indicate aggraded channel conditions or lack of scour objects needed for pool formation. Pool frequency can be measured as a ratio of the number of bank full widths (BFW) per pool in a stream reach. Pool to pool spacing in many redwood forest streams ranges from approximately 2 to 7 BFWs and is often controlled by LWD (Keller and MacDonald 1981). In straight and meandering streams, pools are also often spaced more or less regularly at a repeating distance of 5 to 7 BFWs (Leopold 1994).

In mainstem Redwood Creek sample reaches, run type habitat was the most abundant habitat type. The mean percent length for the Redwood Creek sites was 16% pools, 10% riffle, 57% run, and 15% dry (Table IV- 45). Sites 4 and 17 had the largest amount of pool habitat of all the Redwood Creek sites of the Lower Subbasin. The other sites showed a general lack of pool habitat. The stream survey team found that the lowermost Redwood Creek sample site 7 was completely dewatered on September 16, 2001. This is likely due to a low water year and the aggraded channel conditions. The BFW to pool ratios generally appear within a desirable range, however BFW to pool ratios may be perplexed, due to the present widened condition of the mainstem Redwood Creek influencing the ratio calculations.

The three tributary sampling sites in the Lower Subbasin yielded a mean length of 27% pool, 37% riffle, and 35% run habitat (Table IV- 45). The 27% of stream length in pools is below a desirable range for amount of pool habitat (40%) according to Flosi (1998). The pool frequency of approximately 31% of habitat units by occurrence and the mean BFW to pool ratio of 4:1 for tributary sample sites are within the desirable range suggested by the NCWAP team. These data suggest that the number of pools is within a desirable range, but the pools are somewhat short in length.

Table IV- 45. Lower Subbasin percent occurrence and percent by length of pool, run, riffle, and dry habitats in the.

Stream Reach	Stream Order	Reach Length (ft.)	Pool, Rifle, Run% Occurrence	Pool: Riffle: Run% total length	Estimated BFW (ft)	BFW to Pool ratio	Dry (% total length)
Bridge Creek Site 8	3	1,249	31 : 36 :31	29 : 38 : 32	61	2 : 1	0
Elam Creek Site 24	2	513	31 : 23 : 46	30 : 21 : 49	16	4 : 1	0
Fortyfour Creek Site 2	2	597	32 : 41 : 27	19 : 50 : 31	21	4 : 1	0
Tributaries Mean			**31 : 33 : 35**	**27 : 37 : 35**		**3 : 1**	**0**
Redwood Creek Site 14	4	1,819	25 : 0 : 75	14 : 0 : 86	78	23 : 1	
Redwood Creek Site 7	4	1,500	Dry channel	-	NA*	-	100
Redwood Creek Site 22	4	2,065	17 : 33 : 50	3 : 17 : 80	NA	-	
Redwood Creek Site 4	4	1,608	35 : 24 : 41	41 : 19 : 40	308	0.4 : 1	
Redwood Creek Site 18	4	1,566	23 : 41 : 26	8 : 18 : 74	392	1 : 1	
Redwood Creek Site 17	4	1,508	27 : 14 : 59	32 : 6 : 61	105	2 : 1	
Redwood Creek Mean			**25 : 22 : 50**	**16 : 10 : 57**		**7 :1**	**15**

* BFW Not Available

Pool Depth

***Significance*:** Pool depth and frequency are fundamental attributes of channel morphology and are largely dependent on the presence of large roughness elements such as large woody debris (LWD), bedrock, and boulders in addition to channel type, stream gradient, sinuosity, and channel width. Evaluating the amount of deep pool habitat in a stream reach helps assessment of important channel characteristics for salmonids. Deep pools are especially important as year round rearing habitat for coho salmon, summer steelhead, coastal cutthroat trout and holding habitat for adult salmonids of all species (especially summer steelhead) returning to spawn. Lack of deep pools in forest streams may indicate a disruption to channel forming processes by a lack of LWD and/or elevated levels of stored sediments.

The percent of stream reach of the mainstem Redwood Creek composed of moderately deep pools was below the desirable range at all sample sites in the Lower Subbasin (Figure IV- 28 and Table IV- 46). The mean maximum depth for all pools measured on Redwood Creek was 3.4 feet. The deepest pool (11.8 ft.) was found at Redwood Creek site 17. Redwood Creek site 7 was surveyed as a dry channel, therefore no pools were measured. Redwood Creek site 4 had the most pool type habitat, but the majority of pools were less than 3 feet maximum depth.

The mean maximum depth for all pools measured from the 2nd order tributary sites was 1.9 feet. However the Elam Creek site had two pools greater than 3 feet maximum depth which accounted for approximately 18% of the survey length. Bridge Creek, a 3rd order site, had a mean maximum pool depth of 2.9 feet. The shortage of deep pool habitat is indicative of channel aggradation due to accumulations of sediments and a deficiency of LWD, boulders or other scour objects to create and maintain desirable pool habitat. Some stream reaches may not meet the general target values for pool depths, but still may provide important fish habitat.

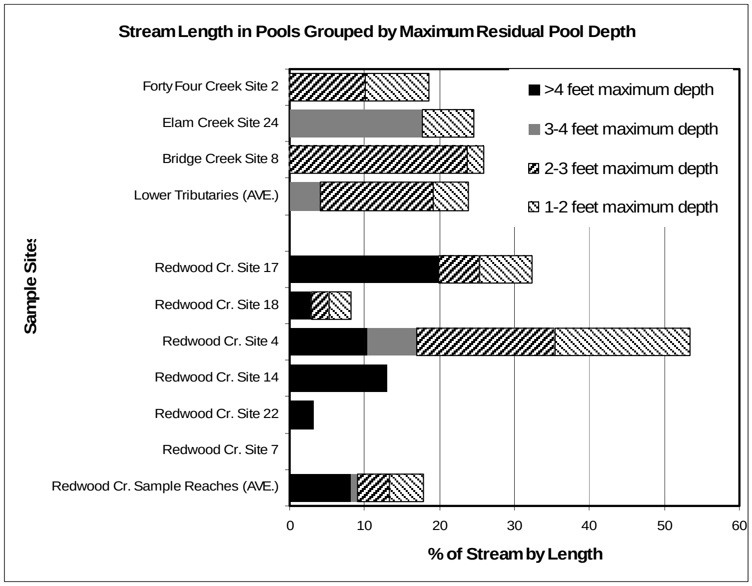

Figure IV- 28. Lower Subbasin percent of sample reaches in pools.

Grouped by maximum residual pool depth and tributaries combined and all sample sites on lower Redwood Creek combined.

Table IV- 46. Lower Subbasin mean maximum pool depths for sample reaches 2001.

Lower Subbasin Maximum Pool Depths	1st & 2nd Order streams (Elam and Fortyfour)	3rd Order stream (Bridge Creek)	4th Order stream (Redwood Creek)
Mean Maximum Depth	1.9	2.25	3.4
Standard Error	0.230	0.128	0.4196
Minimum Max Depth	0.9	1.5	1.3
Maximum Depth	3.2	2.9	11.8
Number of Pools Measured	13	10	28

Pool Shelter

***Significance*:** The pool shelter rating is a relative measure of the quantity and percent composition of LWD, root wads, boulders, undercut banks, bubble curtains, and submersed or overhanging vegetation in pool habitats. These elements serve as instream habitat, create areas of diverse velocity, provide protection from predation, and separate territorial units to reduce density related competition. The ratings are measured in pool and flatwater habitat units. The rating does not consider factors related to changes in discharge, such as water depth.

Sampling sites located in Elam, Fortyfour Creeks, and Redwood Creek sample sites were generally lacking in pool shelter complexity (Figure IV- 29). The Bridge Creek sample site had the highest amount of shelter elements. The pool shelter elements were dominated by woody debris and boulders (Table IV- 47). Stream habitat improvement work was recently done in Bridge Creek to increase pool habitat and shelter complexity, but this work was not within the sampling site boundaries.

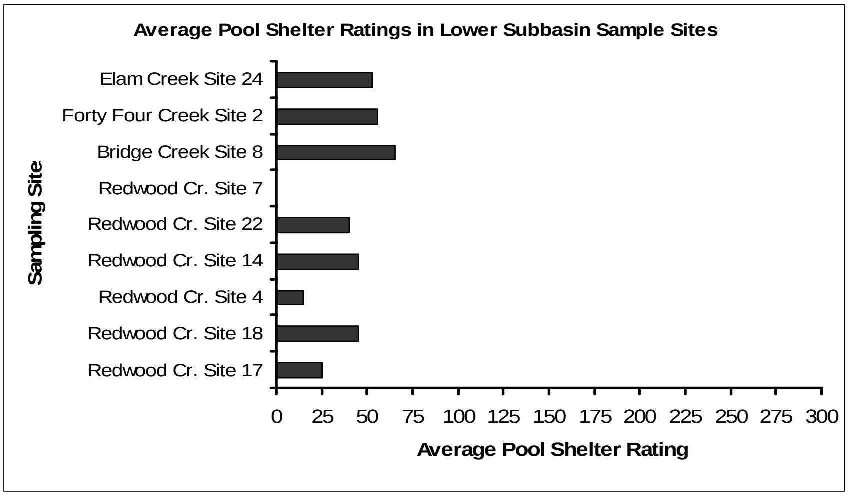

Figure IV- 29. Average pool shelter ratings.

From CDFG Sample Reaches, Lower Subbasin. Average pool shelter ratings exceeding 100 are considered desirable and average pool shelter ratings less than 30 are viewed as unsuitable.

Table IV- 47. Summary of mean percent cover.

Lower Subbasin	Undercut Banks	Woody Debris	Terrestrial Vegetation	Aquatic Vegetation	White-water	Boulders	Bedrock Ledges
Tributary Streams							
Bridge Creek		2				1	
Elam Creek		1	2				
Fortyfour Creek		1				2	
Mainstem Redwood Creek							
Redwood Ck site 18	2	1				2	
Redwood Ck site 17					2	1	
Redwood Ck site 4		2				1	
Redwood Ck site 22		1				2	
Redwood Ck site 14	2					1	

Dominant (1) and subdominant (2) shelter types in pool and flatwater units in the Lower Subbasin. See figures located in Appendix D for detailed explanation.

Streamside Canopy Density

***Significance*:** Streamside canopy density is a measure of the percentage of wetted stream that is shaded by riparian tree canopy. Tree canopy provides shade to reduce direct sun light from warming water, provides a source of nutrients in the form of terrestrial insects, organic debris, and leaf litter, and contributes to LWD loading to stream channels. The roots of riparian vegetation also help maintain soil and stream bank stability. Generally, riparian management projects are considered when canopy density is less than 80% or when a low percent of the canopy is composed of coniferous trees in forested streams (Flosi et al. 1998).

The average canopy density over the mainstem Redwood Creek was only 30% (Figure IV- 30). The wide channel of the mainstem and the historical harvest of streamside conifers have prevented the riparian canopy from providing shade on large areas of Redwood Creek. Early timber harvest typically removed large and shade producing near stream conifers. The lack of old growth Douglas-fir and redwood resulted in less shade along the channel and contributed to increasing water temperatures (Urner and Madej 1998). The low percent of canopy from coniferous trees along the Redwood Creek mainstem and in Elam Creek also means the future supply of coniferous LWD to the channel will be low. Conifers are preferred LWD because hardwoods that fall into stream channels are smaller, decay faster, and are less capable of providing enduring stream forming structures. However, the riparian corridor is undergoing recovery as trees become re-established and grow within the near stream forests. But many years are needed for conifers to achieve the large size need to provide shade and LWD that will function in the mainstem.

The average stream canopy density at the Bridge Creek, Elam Creek, and Fortyfour Creek sites are all above the 80% standard considered sufficient to moderate the direct heating from direct sunlight on stream water (Figure IV- 30).

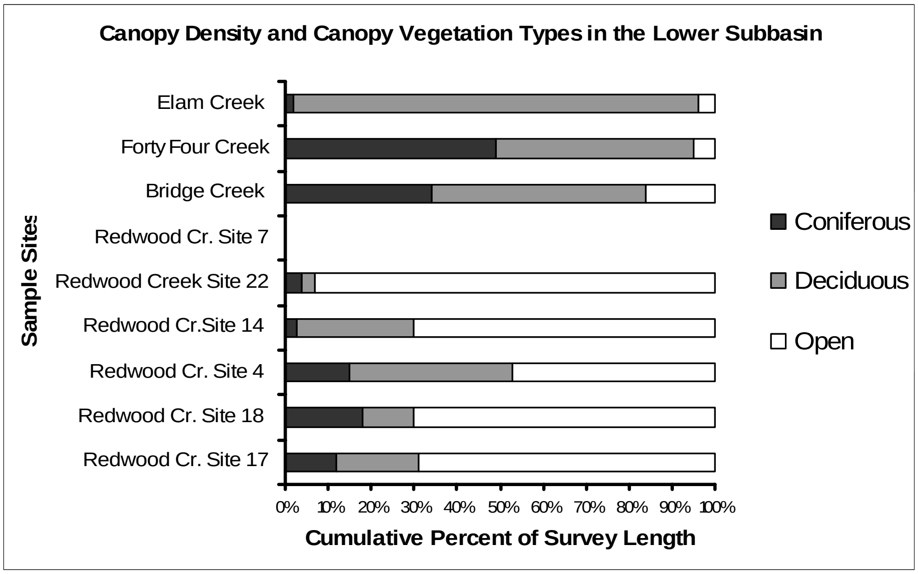

Figure IV- 30. Lower Subbasin percent stream canopy density and percent vegetation type contributing to shade canopy.

Spawning Cobble Embeddedness

Significance**:** Percent cobble embeddedness estimates substrate suitability for spawning, egg incubation, and fry emergence. Generally, cobble embeddedness of 0-25% is considered good quality for spawning (Flosi et al. 1998). Excessive accumulations of fine sediments (>50%) reduce water flow (permeability) through gravels in redds which may suffocate eggs or developing embryos. Excessive levels of fine sediment accumulations over gravel and cobble substrate also may alter insect species composition and food availability for growing fish. High embeddedness ratings also may indicate elevated levels of erosion occurring in the watershed. The percent of fine sediments is higher in watersheds where the geology, soils, precipitation, or topography favor erosional processes (Duncan and Ward, 1985). Fine sediments also are typically more abundant where land use activities such as road building or land clearing expose soil to erosion and increase mass wasting (Cederholm et al. 1981; Swanson et al. 1987; Hicks et al. 1991). Sedimentation resulting from land use activities is recognized as a fundamental cause of salmonid habitat degradation (FEMAT, 1993). Other factors such as bed mobility are also important to determine the quality of spawning substrate.

The majority (> 70%) of pool tails measured from the mainstem Redwood Creek sites were in the 25 to 50% cobble embeddedness range (Figure IV- 31). Only one pool tail sampled from the Redwood Creek sites was in favorable condition and considered good salmonid spawning habitat as measured by embeddedness estimates. This pool tail was located in site 14.

Only 10% of pool tails in Bridge Creek are considered in favorable condition. All of the pool tails sites sampled in Fortyfour Creek were either in poor condition with highly embedded, small gravels or unusable for spawning because of the presence of bedrock substrate. The relatively highly embedded substrate observed from pool tails in tributary sample sites are indicative of excessive fine sediments entering tributary stream channels. These sediment sources should be identified and treated to reduce sediment generation and delivery to streams. Other tributary streams in the subbasin may have similar cobble embeddedness levels and they also may need sediment reduction treatments.

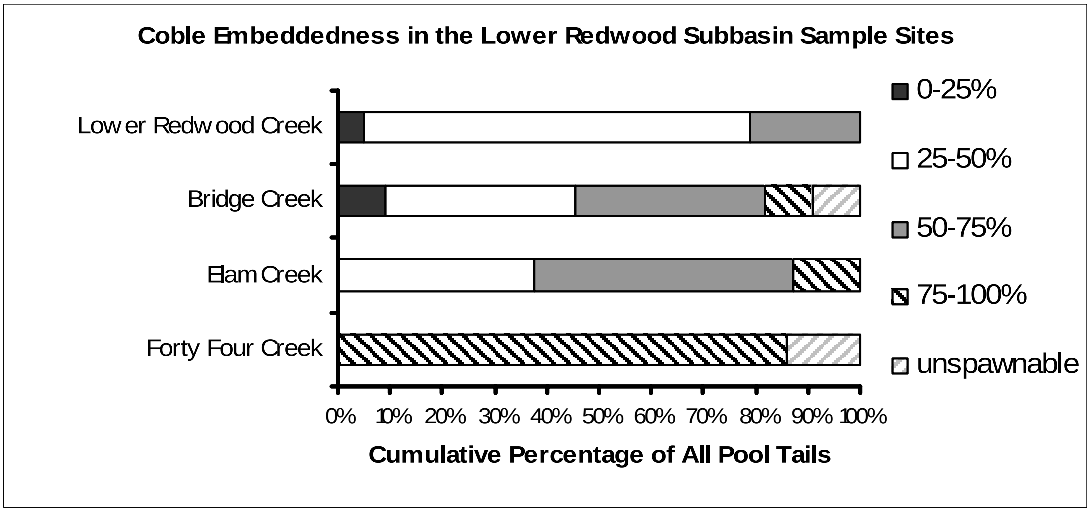

Figure IV- 31. Lower Subbasin cobble embeddedness categories measured at pool tail crests, sampling sites. Unspawnable is due to factors other than embeddedness (e.g. logs, sand substrate, or bedrock).

Salmonid Fishery Resources

Chinook Salmon

Chinook salmon were observed throughout spawning survey efforts performed on Bridge and Tom McDonald creeks by RNSP staff from 1982- 1994 (Table IV- 48 and

Table IV- 49). The greatest numbers of live Chinook were counted in the 1985/1986 and 1987/1988 seasons, 272 and 94 respectively. The 1985/86 counts of Chinook reflect large returns of Chinook coast wide. As noted in the Prairie Creek Subbasin, Chinook numbers observed during spawner surveys in the Lower Subbasin declined during the drought years of 1988 through 1994 when from 0 to 20 Chinook were observed. No recent spawner surveys have been conducted in these streams.

Small numbers of YOY Chinook salmon were noted by IFWM survey crews in the lower portions of Bridge and Tom McDonald Creeks in 2001 and 2002 surveys (D. McCanne and B. Reisberger, IFWM personal communication). Four YOY Chinook were observed from Bridge Creek August 22, 2001 and seven were observed on September 18, 2002. Four YOY Chinook were observed on Tom McDonald Creek July 3, 2001 and ten were noted on August 27, 2002 (D. McCanne and B. Reisberger personal communication). Juvenile Chinook rearing in streams over summer is a behavioral strategy that has been recently observed in few streams of Redwood Creek. These fish may have been too small to perform downstream migrations in the spring. The importance of this behavior is unclear, however maintaining diversity of juvenile life history strategies, such as over summer rearing, helps to insure survival of any given year class and may be important to sustain the species.

Steelhead

Steelhead are the most widely distributed salmonid species in the Lower Subbasin. They are found in all fourteen anadromous fish bearing tributary streams in the subbasin and in the mainstem Redwood Creek. CDFG crews conducting stream surveys for NCWAP in 2001 reported that juvenile steelhead densities appeared relatively low in Lower Subbasin sampling sites located in Fortyfour Creek (site 2), Bridge Creek (site 8), and Elam Creek (site 24) (Appendix D). Currently there is little known about population abundance or population trends for steelhead of the Lower Subbasin.

Coho Salmon

Generally coho populations appear depressed in Lower Subbasin streams. Past surveys have produced varying numbers of juvenile coho salmon in Bridge, Emerald Tom McDonald, McArthur, Elam, and Redwood creeks. Fish surveys conducted in 2001 by the CDFG and the Institute for Forest and Watershed Management (IFWM) using CDFG ten-pool-protocol observed 536 juvenile coho salmon in Tom McDonald Creek and 280 in 2002. In Bridge Creek, juvenile population estimates using single pass snorkel counts were 24 in 2001 and 1,264 ± 513 in 2002 (D. McCanne, IFWM personnel communication).

During adult spawner surveys conducted on Bridge Creek only three live adult coho were seen in twelve seasons (1985/86 – 1992/93) and only two live coho were observed on Tom MacDonald Creek (Table IV- 48 and Table IV- 49). No coho carcasses were noted 1982-1993 in either stream. Spawner surveys have not been conducted from 1994 to 2001 on Tom McDonald Creek. Bridge Creek was surveyed once on December 3, 1997 and March 4, 1998 (D. Anderson, RNSP, personal communications). During that survey one female coho carcass was found at the mouth of Bridge Creek. Little is known about population abundance or population trends for coho of the Lower Subbasin.

Table IV- 48. Bridge Creek spawning survey results 1982-1994.

Spawning Season	# of Surveys	Live Fish				Carcass Type												Redds	
						Chinook			Coho			Steelhead			Unknown				
		Chin	Coho	Shd	Unk	F	M	Unk	F	M	Unk	F	M	Unk	F	M	Unk	Def	?
1982/1983	3	8			12	1	2											1	
1983/1984	4	19		33		4	1	4										4	
1984/1985	11	16		126			1							1			2	6	
1985/1986	8	272		6		23	20	4							4			4	
1986/1987	2	6		4		1	1											6	
1987/1988	9	94		4	5	15	5							1			7	16	
1988/1989	5	6		12		1		1									1	8	
1989/1990	4			7													1	7	1
1990/1991	4	8		8	1	1	1											5	3
1991/1992	3	1	1	7	3	1	1	1					1					15	6
1992/1993	4	4		8	4			1										10	1
1993/1994	4	20	2	1	17	1	1											22	3

chin = Chinook salmon, Coho = coho salmon, Shd = steelhead trout, Unk = unknown species or sex; F = female, M = male, and Unk = unknown sex; Def = definite and ? = questionable
Summarized from RNSP surveys.

Table IV- 49. Spawning survey results for Tom McDonald Creek, 1982-1994.

Spawning Season	# of Surveys	Live Fish				Carcasses				Redds
		Chin	Coho	Shd	Unk	Chinook	Coho	Steelhead	Unknown	
1982/1983	3	4	0	0		0	0			1
1983/1984	2	4	0	0		7	0			0
1984/1985	1	1	0	0		1	0			0
1985/1986	0	No surveys performed								
1986/1987	0	No surveys performed								
1987/1988	3	3	0	3		3	0			4
1988/1989	0	No surveys performed								
1989/1990	0	No surveys performed								
1990/1991	0	No surveys performed								
1991/1992	2	0	0			0	1			16
1992/1993	1	0	0	2		0	0			7
1993/1994	3	0	2			0	0	1		9

chin = Chinook salmon, Coho = coho salmon, Shd = steelhead trout, Unk = unknown species or sex; F = female, M = male, and Unk = unknown sex; Def = definite and ? = questionable Summarized from RNSP surveys.

Lower Subbasin General Issues

The current land use is primarily for preservation and protection of natural resource values and recreation:

- The Lower Redwood Creek Subbasin was made part of the Redwood National and State Park system in 1978.

Prior to 1978, approximately 68% of the landscape was harvested for timber resources:

- Adverse impacts from legacy timber harvests are still affecting mainstem and tributary stream habitat.

The lower reach of Redwood Creek is a low gradient, depositional reach which accumulates excessive sediments derived from upstream sources:

- The aggraded channel condition contributes to elevated water temperatures, a widened channel, and an overall lack of channel diversity and complexity in Redwood Creek;
- During the summer months of recent low rain years (2001 and 2002) the lowermost reach of Redwood Creek became intermittent or dry from the Highway 101 bridge up to the confluence with Hayes Creek, loosing connection with the estuary. In a recent newspaper article in the McKinleyville Press (2002), it was noted by a local resident since 1945 that Redwood Creek has never been so low.

Impairments to freshwater habitat needed to complete salmonid freshwater life cycles have been identified as a leading factors in the decline of Redwood Creek's anadromous salmonids:

- Mainstem Redwood Creek water temperatures exceed favorable limits for salmonid production;
- Anecdotal accounts by long time residents indicate that water temperature was much colder in Redwood Creek before 1964;
- Lower Subbasin tributaries provide water temperature that supports salmonids;
- A lack of instream large woody debris (LWD) contributes to poor aquatic habitat structure including a low number of deep, complex pools;
- LWD recruitment potential to Lower Subbasin appears low at most locations;
- Stream habitat conditions in the Lower Subbasin can be improved.

Integrated Analysis and Cumulative Effects

Between 1950 and 1978 approximately 70% of the Lower Subbasin was harvested for timber and many miles of poorly designed road were constructed. The subbasin has been managed by RNSP since 1978, so no recent timber harvests have occurred. Removal of haul roads has been a major focus of RNSP management activities. Although these treated roads still show evidence of erosion features, sediment yields to streams are less than from the abandoned roads prior to treatments (Madej 2000).

Comparisons of the planning watersheds shows historically active landslide features are not evenly distributed across the subbasin (Table IV- 50). The characteristics of the underlying bedrocks units on each side of the Grogan Fault are factors influencing the distribution and type of landslide features. The Copper Creek Planning Watershed has almost twice the percentage of area in historically active landslide features as the subbasin as a whole. These are primarily earth flows which are not considered as significant contributors of sediments to streams over the short term. However land use on earth flows can exacerbate debris flows and debris slides which are believed the source of most recent sediment delivery to streams. In total, about 160 acres (0.4%) of the subbasin was identified as debris flows and debris slides. The Bridge Creek Planning Watershed has the largest area (84 acres) in debris flows and debris slides in the subbasin. Bridge Creek and Copper Creek planning watersheds had the most land in timber harvests prior to the park expansion suggesting a link between land use activities and debris flow and debris slides occurrence.

Table IV- 50. Acres and percent area of historically active landslide features associated with land type or use.

Subbasin or Planning Watershed	Historically Active Landslide Feature[1]	Entire Subbasin or Planning Watershed		Woodland and Grassland[2]		THPs 1991 – 2000		Timberland, No Recent Harvest		Roads [3]	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Lower Redwood Creek Subbasin (44,479 acres) (137.9 road miles)	Earthflow	1,762	4.0	270	0.6	0	0.0	1,485	3.3	3.7	2.7%
	Rock Slide	740	1.7	0	0.0	0	0.0	740	1.7	2.9	2.1%
	Debris Slide	82	0.2	3	0.0	0	0.0	75	0.2	0.2	0.1%
	Debris Flow	78	0.2	0	0.0	0	0.0	77	0.2	0.1	0.1%
	All Features	2,662	6.0	274	0.6	0	0.0	2,377	5.3	7.0	5.0%
Bond Creek (8,196 acres) (27.2 road miles)	Earthflow	271	3.3		0.0		0.0	271	3.3	1.9	7.2%
	Rock Slide	174	2.1		0.0		0.0	174	2.1	0.7	2.5%
	Debris Slide	21	0.3		0.0		0.0	19	0.2	0.1	0.2%
	Debris Flow	11	0.1		0.0		0.0	11	0.1	0.0	0.0%
	All Features	477	5.8	0	0.0	0	0.0	475	5.8	2.7	9.9%
Bridge Creek (15,047acres) (40.1 road miles)	Earthflow	363	2.4		0.0		0.0	363	2.4	1.1	2.9%
	Rock Slide	538	3.6		0.0		0.0	538	3.6	2.1	5.2%
	Debris Slide	29	0.2		0.0		0.0	28	0.2		0.0%
	Debris Flow	55	0.4		0.0		0.0	55	0.4	0.0	0.1%
	All Features	985	6.5	0	0.0	0	0.0	984	6.5	3.3	8.2%
Copper Creek (10,022 acres) (8.6 road miles)	Earthflow	1,126	11.2	270	2.7		0.0	849	8.5	0.6	7.6%
	Rock Slide		0.0		0.0		0.0		0.0		0.0%
	Debris Slide	19	0.2	3	0.0		0.0	14	0.1	0.0	0.1%
	Debris Flow	4	0.0	0	0.0		0.0	3	0.0		0.0%
	All Features	1,149	11.5	274	2.7	0	0.0	867	8.7	0.7	7.6%
Devil's Creek (4,404 acres) (27.2 road miles)	Earthflow	2	0.0		0.0		0.0	2	0.0%		0.0%
	Rock Slide		0.0		0.0		0.0		0.0%		0.0%
	Debris Slide	4	0.1		0.0		0.0	4	0.1%	0.1	0.5%
	Debris Flow	2	0.0		0.0		0.0	2	0.0%		0.0%
	All Features	8	0.2	0	0.0	0	0.0	8	0.2%	0.1	0.5%
McArthur Creek (6,810 acres) (34.9 road miles)	Earthflow		0.0		0.0		0.0		0.0%		0.0%
	Rock Slide	28	0.4		0.0		0.0	28	0.4%	0.2	0.5%
	Debris Slide	9	0.1		0.0		0.0	9	0.1%		0.0%
	Debris Flow	6	0.1		0.0		0.0	6	0.1%	0.0	0.1%
	All Features	43	0.6	0	0.0	0	0.0	42	0.6%	0.2	0.6%

[1] Refer to Plate 1 and California Geological Survey appendix. Areas of disrupted ground are not included as active landslide features in this analysis. These areas are likely underlain by earthflow or rockslide complexes. If so, this would substantially increase the miles of roads and area of land type and land use on active landslide features.
[2] Woodland and grassland includes areas mapped in 1998 as grassland and non-productive hardwood.
[3] Table IV- 50 does not accurately represent the present number of road miles in the subbasin. Most of the logging roads in the Lower Subbasin have been removed by the RNSP (G. Bundros RNSP, personal communication).

Areas of high and very high relative landslide potential comprise about 71% of the subbasin (Table IV- 51). The vast majority occurs on forestlands (68%). Looking across the subbasins, McArthur Creek stands out for having a relatively low percentage (58.4%) of its area in the high and very high landslide potential classes.

Table IV- 51. Lower Subbasin acres and percent of area by relative landslide potential and land use or type classes.

Subbasin or Planning Watershed	Relative Landslide Potential[1]	Entire Subbasin or Planning Watershed		Woodland or Grassland[2]		THPs 1991 – 2000		Timberland, No Recent Harvest[3]		Roads	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Lower Redwood Creek Subbasin (44,479 acres) (137.9 road miles)	Very Low	2,666	6.0	92	0.2			2,172	4.9	17.7	12.8
	Low	3,028	6.8	96	0.2			2,905	6.5	14.0	10.2
	Moderate	7,259	16.3	96	0.2			7,144	16.1	30.6	22.2
	High	17,431	39.2	676	1.5			16,734	37.6	49.7	36.0
	Very High	14,033	31.5	25	0.1			13,468	30.3	26.0	18.9

Subbasin or Planning Watershed	Relative Landslide Potential[1]	Entire Subbasin or Planning Watershed		Woodland or Grassland[2]		THPs 1991 – 2000		Timberland, No Recent Harvest[3]		Roads	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
	High/Very High Subtotal	31,464	70.7	701	1.6			30,202	67.9	75.7	54.9
	TOTAL	44,417	100%	985	2%	0	0%	42,423	95%	138.0	100%
Bond Creek (7,678 acres) (27.2 road miles	Very Low	389	4.7	1	0.0			295	3.6	2.0	7.3
	Low	378	4.6	1	0.0			374	4.6	1.7	6.2
	Moderate	1,273	15.5	0	0.0			1,267	15.5	5.4	19.8
	High	3,359	41.0	1	0.0			3,353	40.9	10.7	39.2
	Very High	2,783	34.0		0.0			2,778	33.9	7.5	27.5
	High/Very High Subtotal	6,142	74.9	1	0.0			6,131	74.8	18.2	66.7
	TOTAL	**8,182**	**100%**	**3**	**0%**	**0**	**0%**	**8,067**	**98%**	**27.3**	**100%**
Bridge Creek (15,047 acres) (40.1 road miles)	Very Low	780	5.2	8	0.1			647	4.3	6.0	15.0
	Low	1,033	6.9	18	0.1			999	6.6	4.6	11.5
	Moderate	2,326	15.5	5	0.0			2,313	15.4	12.0	29.9
	High	6,146	40.8	129	0.9			6,002	39.9	10.7	26.7
	Very High	4,731	31.4	9	0.1			4,708	31.3	6.9	17.2
	High/Very High Subtotal	10,877	72.3	138	0.9			10,710	71.2	17.6	43.9
	TOTAL	**15,016**	**100**	**169**	**1%**	**0**	**0%**	**14,669**	**97%**	**40.2**	**100%**
Copper Creek (10,022 acres) (8.6 road miles)	Very Low	266	2.7	73	0.7			143	1.4	1.7	19.8
	Low	630	6.3	73	0.7			551	5.5	1.3	15.1
	Moderate	1,740	17.4	89	0.9			1,648	16.4	1.6	18.6
	High	3,239	32.3	540	5.4			2,697	26.9	2.8	32.6
	Very High	4,134	41.2	14	0.1			3,609	36.0	1.2	14.0
	High/Very High Subtotal	7,373	73.6	554	5.5			6,306	62.9	4.0	46.5
	TOTAL	**10,009**	**100**	**789**	**8%**	**0**	**0%**	**8,648**	**86%**	**8.6**	**100%**
Devil's Creek (4,404 acres) (27.2 road miles)	Very Low	226	5.1	5	0.1			224	5.1	0.8	2.9
	Low	347	7.9	2	0.0			344	7.8	2.0	7.4
	Moderate	738	16.8	1	0.0			736	16.7	5.6	20.6
	High	2,087	47.4	3	0.1			2,086	47.4	14.1	51.8
	Very High	1,011	23.0	1	0.0			1,001	22.7	4.6	16.9
	High/Very High Subtotal	3,098	70.3	4	0.1			3,087	70.1	18.7	68.8
	TOTAL	**4,409**	**100%**	**12**	**0%**	**0**	**0%**	**4,391**	**100%**	**27.1**	**100%**
McArthur Creek (6,810 acres) (34.9 road miles)	Very Low	1,005	14.8	5	0.1			863	12.7	7.2	20.6
	Low	640	9.4	2	0.0			637	9.4	4.4	12.6
	Moderate	1,182	17.4	1	0.0			1,180	17.3	6.0	17.2
	High	2,600	38.2	3	0.0			2,596	38.1	11.4	32.7
	Very High	1,374	20.2	1	0.0			1,372	20.1	5.8	16.6
	High/Very High Subtotal	3,974	58.4	4	0.1			3,968	58.3	17.2	49.3
	TOTAL	**6,801**	**100%**	**12**	**0.1%**	**0**	**0%**	**6,648**	**98%**	**34.8**	**100%**

[1] Refer to Plate 1 and California Geological Survey appendix.
[2] Woodland and grassland includes areas mapped in 1998 as grassland and non-productive hardwood.
[3] Area of timberlands that were not contained in a THP during the 1991 to 2000 period.
The number of miles of roads in this table does not accurately reflect present conditions in all listed planning watersheds. The majority or in some planning watersheds all of roads in the Lower subbasin have been removed by RNSP.

Table IV- 52 provides an integrated information summary for the lower Redwood Creek subbasin and its planning watersheds. It provides the reader the opportunity to compare a large number of factors across the watershed and subbasins and to look at potential interactions between disturbance factors and instream fish habitat.

Table IV- 52. Lower Subbasin integrated information summary.

Factor	Lower Redwood Subbasin		Planning Watersheds									
			Bond Creek		Bridge Creek		Copper Creek		Devil's Creek		McArthur Creek	
Relative Landslide Potential[1]	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Very Low	2,666	6%	389	4.8%	780	5.2%	266	2.7%	226	5.1%	1,005	14.8%
Low	3,028	7%	378	4.6%	1,033	6.9%	630	6.3%	347	7.9%	640	9.4%
Moderate	7,259	16.3%	1,273	15.6%	2,326	15.5%	1,740	17.4%	738	16.7%	1,182	17.4%
High	17,431	39.2%	3,359	41.1%	6,146	40.9%	3,239	32.4%	2,087	47.3%	2,600	38.2%
Very High	14,033	31.6%	2,783	34.0%	4,731	31.5%	4,134	41.3%	1,011	22.9%	1,374	20.2%
High/Very High Subtotal	31,464	71%	6,142	75%	10,877	72%	7,373	74%	3,098	70.3%	3,974	58%
GRAND TOTAL	**44,417**	**100%**	**8,182**	**100%**	**15,016**	**100%**	**10,009**	**100%**	**4,409**	**100%**	**6,801**	**100%**
Landslide and Selected Geomorphic Features	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Historically Active Landslide Features Total	2,662	6.0%	477	5.8%	985	6.6%	1,149	11.5%	8	0.2%	43	0.6%
Earthflow	78	0.2%	11	0.1%	55	0.4%	4		2		6	0.1%
Rock Slide	82	0.2%	21	0.3%	29	0.2%	19	0.2%	4	0.1%	9	0.1%
Debris Slide	1,762	4.0%	271	3.3%	363	2.4%	1,126	11.3%	2	0.0%	0	0.0%
Debris Flow	740	1.7%	174	2.1%	538	3.6%					28	0.4%
Dormant Landslide Features Total	5,263	11.8%	1,296	15.8%	2,101	14.0%	1,683	16.8%	104	2.4%	79	1.2%
Selected Geomorphic Features Total	5,540	12.5%	898	11.0%	1,017	6.8%	2,244	22.4%	671	15.2%	709	10.4%
Disrupted Ground	2,831	6.4%	128	1.6%	128	0.9%	2,115	21.1%	461	10.4%	0	0.0%
Debris Slide Slope	2,472	5.6%	770	9.4%	770	5.1%	88	0.9%	201	4.6%	643	9.5%
Inner Gorge (area)2	236	0.5%			119	0.8%	41	0.4%	10	0.2%	66	1.0%
Total of All Above Features	**13,465**	**30.3%**	**2,671**	**33%**	**4,103**	**27.3%**	**5,076**	**50.7%**	**783**	**17.8%**	**831**	**12.2%**
Other Land Uses	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Grazing	29	0.1%					29	0.3%				
Agriculture	0	0.0%										
Development	4	0.0%									4.1	0.1%
Timberland, No Recent Harvest	38,032	85.6%	8,067	99%	14,669	98%	8,648	86%			6,648	98%
TOTAL	**38,065**	**85.7%**	**8,067**	**99%**	**14,669**	**98%**	**8,677**	**87%**	**0**	**0.0%**	**6,652**	**98%**
Roads[5]												
Road Density (miles/sq. mile)	2.0		2.2		1.7		0.6		4.0		3.3	
Density of Road Crossings (#/stream mile)	0.1		0.1		0.1		0.1		0.3		0.4	
Roads within 200' of Stream (miles/stream mile)	0.1								0.1		0.2	
Factor	**Lower Redwood Subbasin**		**Planning Watersheds**									
			Bond Creek		**Bridge Creek**		**Copper Creek**		**Devil's Creek**		**McArthur Creek**	
Streams	**% stream length**		**% stream length**		**% stream length**		**% stream length**		**% stream length**		**% stream length**	
% Stream by Gradient												
< 1% (Response Reach)		17.8%		18.9%		7.7%		26.7%		0.0%		35.2%
1-4% (Response Reach)		10.4%		5.3%		14.1%		9.5%		0.0%		19.4%
4-20% (Transport Reach)		31.7%		47.3%		41.9%		30.5%		70.9%		32.2%
>20% (Source Reach)		40.1%		29.2%		36.2%		33.3%		29.1%		13.1%
Historically Active and Dormant Landslide and Selected Geomorphic Features[4]	% area	% stream length	% area	% stream length	% area	% stream length	% area	% stream length	% area	% stream length	% area	% stream length
Within 180' of Blue Line Stream	4.2%	16.1%	2.1%	0.0%	5.1%	21.9%	7.8%	11.1%	1.9%	7.3%	1.0%	36.7%

[1] Refer to California Geological Survey appendix for landslide map (Plate 1), relative landslide potential map (Plate 2) and description. Areas of disrupted ground are not included as active landslide features in this analysis. These areas are likely underlain by earthflow or rockslide complexes. If so, this would substantially increase the miles of roads and area of land type and land use on active landslide features.

[2] Area based on inner gorges captured as polygons plus inner gorges captured as linear features, which are treated as having an average width of 100 feet.

[3] Category 1 includes clearcut, rehab, seed tree step, and shelterwood seed step prescriptions; Category 2 includes shelterwood prep step, shelterwood removal step, and alternative prescriptions; Category 3 includes selection, commercial thin, sanitation salvage, transition, and seed tree removal step prescriptions.

[4] Landslide features and selected geomorphic features include earthflow, rock slide, debris slide, debris flow, debris slide slopes, disrupted ground, eroding banks and inner gorges.

[5]The number of miles of roads in this table does not accurately reflect present conditions in all listed planning watersheds. The majority or in some planning watersheds all of roads in the Lower subbasin have been removed by RNSP.

EMDS Potential Sediment Production Results

Table IV- 53 to IV- 56 present the results of the EMDS potential sediment production model for the Lower Subbasin. While we believe that this model has utility in its current state, we caution that it be interpreted only as indicative of relative conditions and not as a definitive assessment of absolute conditions.

Table IV- 53 presents results from the top three levels of the EMDS sediment model. Natural sources of sediments are potentially high in Copper Creek Planning Watershed due to a relatively large amount of its area close to streams in active landslide features and due to the amount of area in the very high landslide potential classes. Subsequent tables looking deeper into the model will help to provide more insight into the sources of these condition rankings. The results in Table IV- 54 suggest that roads in the Lower Subbasin are less a factor for concern relative to other subbasins for road related surface erosion. The Park's aggressive work to remove roads and to upgrade remaining roads likely is a major factor in these favorable relative ratings. However, the effects from past timber harvest activities may still contribute to surface erosion, particularly in Bridge and Bond creek planning watersheds.

Table IV- 53. EMDS ratings for potential stream sediment production; top three levels of model.

Subbasin or Planning Watershed	All Sources	Natural Processes				Management-Related Sources			
		All	Surface Erosion	Streamside Erosion	Mass Wasting	All	Surface Erosion	Streamside Erosion	Mass Wasting
Lower Redwood Subbasin	+	+	U	+	+	+	-	++	+
Bond Creek	+	+	U	+	+	+	-	++	+
Bridge Creek	+	+	U	-	+	+	-	++	-
Copper Creek	-	--	U	--	-	+	-	++	+
Devil's Creek	++	++	U	++	+++	+	+	++	+
McArthur Creek	++	++	U	++	+++	+	+	+	++

A 'U' represents there is a lack of data to categorize.
The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---" score represents the most potential sediment delivery to streams.

Table IV- 54. Potential stream sediment production from management related surface erosion sources.

Subbasin or Planning Watershed	All Mgmt.-Related Surface Sources	Road Related			Land Use Related	
		All Road Related	Density of Roads by Hillslope Position	Density of Roads Proximate to Streams	All Land Use Related	Timber Land Use
Lower Redwood Subbasin	-	+	++	++	-	--
Bond Creek	-	++	+++	+++	--	--
Bridge Creek	-	++	+++	+++	---	---
Copper Creek	-	++	+++	+++	--	+
Devil's Creek	+	+	+	++	+	-
McArthur Creek	+	+	++	+	+	-

The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---"score represents the most potential sediment delivery to streams.

Table IV- 55 looks at potential sediment production from road related streamside erosion. These relative ratings show that the lower Redwood Creek subbasin and its planning watersheds are in favorable condition for management related streamside erosion.

Table IV- 55. Potential stream sediment production from management related streamside erosion sources.

Subbasin or Planning Watershed	All Management-Related Streamside Sources	Road Related	
		Density of Roads Proximate to Streams	Density of Road Crossings
Lower Redwood Subbasin	++	++	++
Bond Creek	++	+++	+++
Bridge Creek	++	+++	+++
Copper Creek	++	+++	+++
Devil's Creek	++	++	++
McArthur Creek	+	+	++

The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---" score represents the most potential sediment delivery to streams.

Table IV- 56 examines potential sediment production from management related mass wasting. The column combining all management related mass wasting shows at least somewhat favorable relative conditions for the entire subbasin and all planning watersheds except Bridge Creek. As in the other EMDS sediment results for this subbasin, roads have a favorable relative rating throughout the subbasin, while land uses—timber land use, legacy effects from tractor logging in particular—appear to have a high likelihood to produce sediment from mass wasting processes. Timber land use has these relatively unfavorable rankings at the subbasin level and for all the planning watersheds except Copper Creek.

Table IV- 56. Potential stream sediment production from management related mass wasting sources.

Subbasin or Planning Watershed	All Mgmt. Related Mass Wasting Sources	Road Related				Land Use Related	
		All Road Related	Density of Roads Crossings	Density of Roads by Hillslope Position	Density of Roads on Unstable Slopes	All Land Use Related	Timber Land Use
Lower Redwood Subbasin	+	++	++	++	++	-	--
Bond Creek	+	++	+++	+++	++	--	--
Bridge Creek	-	+++	+++	+++	+++	---	---
Copper Creek	+	+++	+++	+++	+++	--	+
Devil's Creek	+	+	++	+	+	+	-
McArthur Creek	++	++	++	++	++	+	-

The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---" score represents the most potential sediment delivery to streams.

Stream Reach Condition EMDS Results and Limiting Factors

The overall reach condition of the sample sites located in the Lower Subbasin were all rated "somewhat unsuitable" for salmonid production by EMDS (Table IV- 57 and Figure IV- 32). Readers should refer back to the Fish Habitat Relationships section above for detailed information describing physical factors affecting salmonid habitat.

Canopy density evaluations were "fully suitable" at the Elam Creek and Fortyfour Creek sites. On the mainstem Redwood Creek, canopy density was generally unsuitable for providing shade benefits to salmonid habitat. The wide channel of the mainstem Redwood Creek and the historical harvest of streamside conifers have prevented the riparian canopy from providing shade on large areas of the stream. However, it is likely that the riparian corridor is undergoing recovery as trees become re-established and grow within the near stream forests.

The somewhat unsuitable rating for stream condition is largely due to the lack of deep, complex pools observed from the tributary sites (Elam, Bridge, and Fortyfour Creeks), a lack of high quality spawning substrate, and the lack of deep, complex pools and lack riparian canopy density affecting the lower mainstem Redwood Creek sites. A deficiency in the EMDS model likely contributed to negative evaluations of the pool depth attribute throughout the basin. However, shallow pool conditions are often found in low gradient reaches within small watersheds that lack sufficient discharge to deeply scour the channel. Assessments of the amount of deep pools are also discussed in the Fish Habitat Relationships section above.

Overall, warm summer water temperature is a primary limiting factor to salmonid production in the mainstem Redwood Creek in the Lower Subbasin. In addition, habitat factors that received negative evaluation scores by the EMDS should be considered as potential limiting factors to salmonid production in the Lower Subbasin.

The average embeddedness ratings for the five sample sites in Redwood Creek and three tributary sample sites indicate that overall pool tail spawning substrate contains more than the desirable levels of fine sediment. Although, site 14 located on Redwood Creek received a "fully suitable" evaluation by EMDS, the result was due to only one pool tail measured in the sample reach. Pool tail substrate at Sites 22 and 18 located on Redwood Creek were generally 25-50% embedded with fines which places them into the EMDS "undetermined" evaluation category. All tributary sites evaluated to "moderately unsuitable" for pool tail embeddedness. Excessive sediments in pool tails is an indicator of upslope erosion and sediment inputs to stream channels.

Table IV- 57. Summary of results from the Lower Subbasin EMDS stream reach evaluation.

Stream	Reach Length (ft)	Reach Condition	Canopy Density	Pool Quality	Residual Pool Depth	Pool Shelter	Embeddedness
Elam Creek site24	513	-	+++	- -	- -	-	- -
Fortyfour Creek Site 2	597	-	+++	- -	- - -	-	- - -
Bridge Creek Site 8	1373	-	++	- -	- - -	0	- -
Redwood Creek Site 7	1500	*	*	*	*	*	*
Redwood Creek Site 22	2065	-	- - -	- -	- - -	- -	0
Redwood Creek Site 14	1819	-	- - -	- -	- - -	- -	+ + +
Redwood Creek Site 4	1608	-	- -	- - -	- - -	- - -	- -
Redwood Creek Site 18	1566	-	- - -	- -	- - -	- -	0
Redwood Creek Site 17	1508	-	- - -	- - -	- - -	- - -	-

+++ Fully Suitable ++ Moderately Suitable + Somewhat Suitable
- - - Fully Unsuitable - - Moderately Unsuitable - Somewhat Unsuitable 0 Uncertain * Dry reach, not sampled

The stream habitat components are categorized with respect to suitability for anadromous salmonid production. The scores* represent a range from fully suitable conditions to fully unsuitable conditions. These overall scores provide a general overview of current stream conditions and may be used to identify limiting factors and focus on areas for habitat improvement strategies.

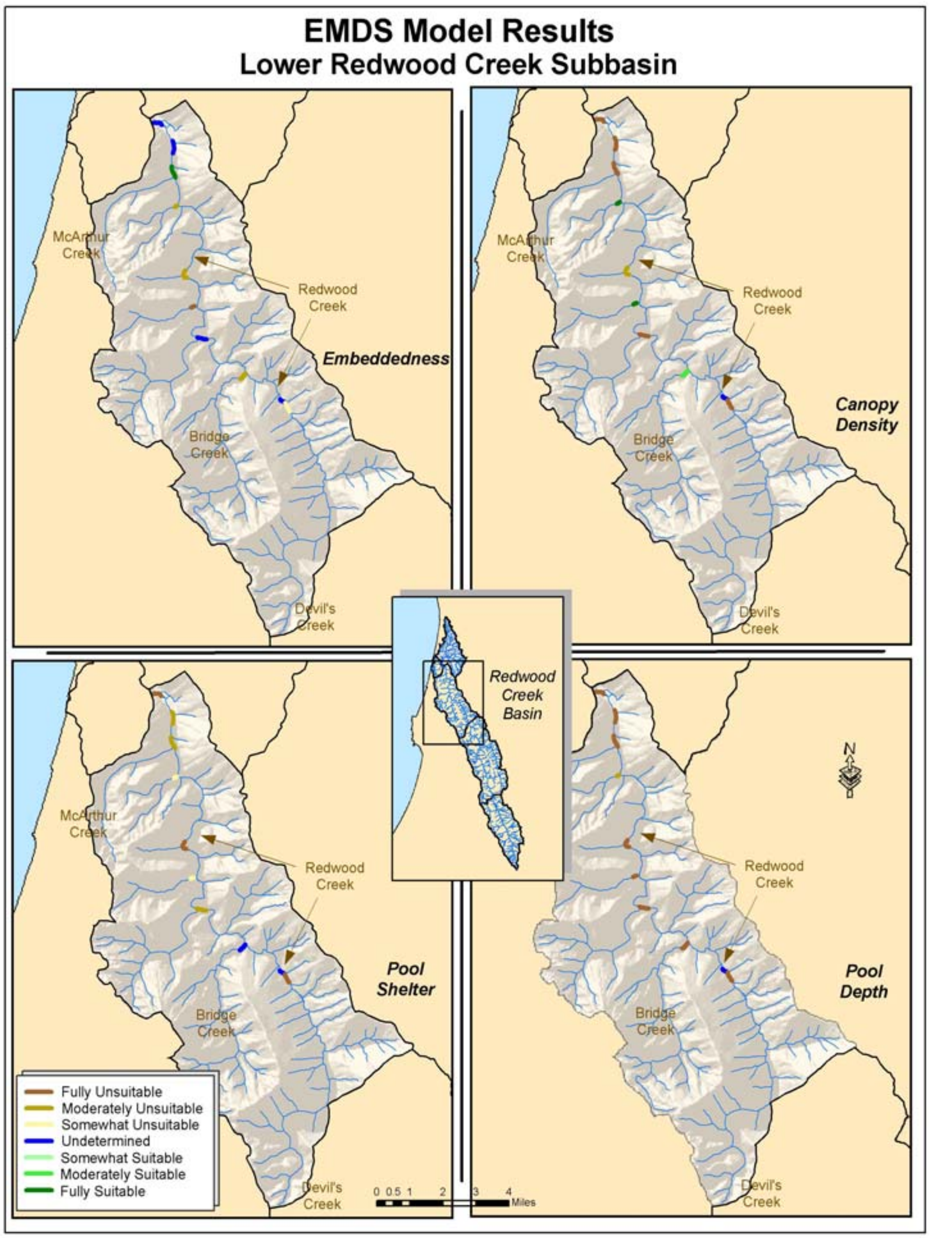

Figure IV- 32. Lower Subbasin EMDS results for selected stream reach factors.

Refugia Areas

The NCWAP interdisciplinary team characterized refugia habitat in the Lower Redwood Creek subbasin by using criteria developed for north coast watersheds. The majority of fish bearing tributary streams of the lower subbasin received designations as high potential refugia habitat or critical contributing areas (Table IV- 58). The high potential refugia designations were based on the presence of more than one species of anadromous salmonid in the watershed, low risk from future human caused disturbance, cool water temperatures in tributaries, and a high propensity for improvement. The critical contributing areas are known to contribute cool water to the lower reach of the mainstem. Redwood Creek received a potential refugia designation as problems with water temperature, habitat structure, and the likelihood of improvement potential lowered its refugia value.

Table IV- 58. Lower Subbasin anadromous salmonid refugia designations.

Stream	Refugia Categories				Other Categories		
	High Quality	High Potential	Potential	Low Quality	Passage Barrier Limited	Critical Contributing Area/Function	Data Limited
Bridge Creek		X					
Emerald Creek (Harry Weir)		X					
Tom McDonald		X					
McArthur Creek			X				
Copper Creek		X					
Elam Creek		X					
Cloquet Creek							X
Devils Creek						X	
Fortyfour Creek		X				X	
Hayes Creek						X	
Bond Creek		X				X	
Slide Creek						X	
Dolason Creek							X
Miller Creek							X
Redwood Creek			X				

Responses to Assessment Questions

<u>What are the history and trends of the size, distribution, and relative health and diversity of salmonid populations?</u>

- The Lower Subbasin supports populations of Chinook and coho salmon and steelhead and coastal cutthroat trout;
- Anadromous salmonid populations are believed to be well below historic levels of abundance and less widely distributed than in the past;
- Indications that the lower mainstem of Redwood Creek was once a productive salmonid nursery area is found in a discussion in Hallock et al. (1952). They noted that “Redwood Creek was an excellent silver (coho) salmon stream.” Coho salmon have not been observed rearing in the mainstem during the summer months for decades;
- A review of spawner survey data collected 1982-1994 in Tom McDonald and Bridge creeks indicates small runs of Chinook and coho are returning to spawn in Lower Subbasin tributary streams;
- Although no quantitative estimates are available, juvenile salmonid densities appear relatively low in Bridge, Elam, and Fortyfour creeks;
- Juvenile coho have been recently identified in Bridge, Harry Wier (Emerald), Tom McDonald, Elam, and McArthur creeks;
- Steelhead and coastal cutthroat are present in the majority of the lower Redwood Creek tributaries and in the mainstem;

- Resident populations of coastal cutthroat and rainbow trout are found above the upstream limits of anadromous fish in tributary reaches. The status of these resident populations is unknown.

What are the current salmonid habitat conditions? How do these conditions compare to desired conditions?

- The Lower Subbasin provides critical habitat for anadromous salmonids;
- Fish habitat conditions in the Lower Subbasin differ between mainstem Redwood Creek and tributary streams;
- Water temperatures in mainstem Redwood Creek are generally too warm to support juvenile salmonids (especially coho) during summer months. A few cool water patches form where cold intergravel flow, tributary flow, or springs seep into the Redwood Creek channel. These thermally stratified pools or other forms of cool water refugia provide habitat for juvenile steelhead and possibly adult summer steelhead during summer months;
- Tributary streams have suitable summer water temperatures for rearing salmonids. In general, streams with cool water (MWAT below 64°F) provided habitat for coho salmon. These include Bridge Creek, Elam Creek, Fortyfour, and Tom McDonald Creek;
- Deep, complex pools are lacking in sample reaches in Redwood, Bridge, Elam, and Fortyfour Creeks;
- There is a low amount of instream LWD in mainstem Redwood Creek;
- The existing streamside shade canopy and the future supply of LWD and is limited by a lack of large, nearstream conifers along mainstem Redwood Creek;
- Streamside tree canopy providing shade over the water was generally suitable for the tributary reaches. However, the supply of LWD needed to maintain channel diversity and complexity may be limited by a general lack of large conifers growing near the Lower Subbasin tributaries;
- High embeddedness levels in spawning gravels in Bridge, Elam, and Fortyfour Creeks potentially limit successful egg incubation and the development and emergence of salmonid fry;
- The relatively highly embedded substrate observed from pool tails in the tributary sample sites are indicative of excessive fine sediments entering their stream channels;
- In-channel sediment data from mainstem Redwood Creek at the confluence with Miller and Harry Wier (Emerald) creeks show that median stream bed particle size did not meet minimum TMDL targets between 1982 and 1991 at Miller Creek and between 1979 and 1995 at Harry Wier (Emerald) Creek.

What are the past and present relationships of geologic, vegetative, and fluvial processes to stream habitat conditions?

- Through air photo interpretation, review of CDFG reports, and anecdotal accounts, it is clear that historic conditions of the lower reach of Redwood Creek were quite different than we see today. In the past, riparian forests containing large redwoods lined the riverbanks and deep pools and complex flatwaters supported salmonids (including coho) year round;
- Past descriptions of lower Redwood Creek suggest that water temperature in Redwood Creek was cold enough to support coho salmon. Pools along the lower reach of Redwood Creek were numerous and deep;
- Excessive sediment accumulation and changes in stream morphology and near stream forest condition have had adverse and long-lasting effects on salmonid habitat in lower Redwood Creek;
- Following the major flood of December 1964, the lower mainstem of Redwood Creek was in a severely damaged condition and became largely unsuitable as a nursery for young salmon and steelhead;
- Sediment transported from tributaries and from upstream reaches has contributed to a substantial accumulation of sediment in the Redwood mainstem channel;

- Chronic erosion from upstream hillslopes contributes to prolonged turbidity and high suspended sediment loads;
- The Redwood Creek stream channel is anomalously wide, as compared to regional curves of channel width vs. drainage area;
- The lack of large Douglas-fir and redwood results in less overstory shade along the channel and contributes to high water temperatures along the mainstem of Redwood Creek;
- Conifers large enough to provide LWD to the channel formation processes are absent in many anadromous fish bearing reaches;
- The flow of warm water from upstream reaches, combined with the wide condition of the stream channel and lack of large conifers providing shade contribute to elevated water temperatures of Redwood Creek;
- The relatively highly embedded substrate observed from pool tails in the tributary sample sites are indicative of excessive fine sediments entering the stream channels;
- The number of active landslides appears to be driven by the incoherent unit of Coyote Creek and land use;
- The largest streamside debris slides in the subbasin were observed along the Redwood Creek channel between Devils and Bridge Creeks, where the mainstem of Redwood Creek coincides with the Grogan fault. The abundance in number and volume of debris slides coincides with the zone of weak, sheared rocks of the Grogan fault;
- Although Bond Creek shows an increase in streamside landslides, it also shows a significant decrease in disturbance features in the channel, suggesting that most sediment is rapidly transported downstream;
- The lack of stream flow in lower Redwood Creek in 2001 and 2002 is likely a cumulative impact from low rainfall in spring and aggraded channel condition.

<u>How has land use affected these natural processes?</u>

- Past logging activities, particularly the construction of roads and skid trails and the removal of vegetative ground cover, have been a major factor contributing to erosion and sediment delivery to streams;
- As a result of land use, the lower reach of Redwood Creek has accumulated sediments, the channel has widened, aggraded and lost channel diversity;
- Large clear cut areas of the past resulted in accelerated runoff rates and increased suspended sediment loads;
- Legacy impacts from non-engineered side cast roadway fills constructed on marginally stable ground delivered large amounts of sediment into the stream network in Bridge Creek and possibly other streams;
- Many road watercourse crossings were poorly constructed and lacked backup drainage structures to prevent the diversion of runoff when culverts overflowed. Stream diversions often carve large gullies and transport scoured sediments to streams. These gullies may still be a source of sediment inputs to streams;
- The harvest of near stream, large conifers contributed to a loss of shade needed to help cool water temperature;
- The harvest of near stream, large conifers has contributed to reduced LWD loading potential. Reduced amounts of organic debris has likely impacted nutrient cycles and food web dynamics.

<u>Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?</u>

- Elevated water temperature is the most significant factor limiting salmonid production in the lower Mainstem Redwood Creek;
- Lack of channel diversity and adequate supply of shelter elements also are factors that limit juvenile anadromous salmonid use of the lower reaches of the mainstem Redwood Creek;

- The lack of diverse and complex aquatic habitat and shelter elements likely limits anadromous salmonid production in the Lower Subbasin tributaries;
- The supply of LWD needed to maintain channel diversity and complexity is limited by a general lack of large conifers growing near the Lower Subbasin streams;
- Elevated levels of fine sediment reduce the amount of suitable spawning habitat and may limit or impair survival of developing salmon eggs and embryos in both the mainstem and tributary streams of the lower subbasin;
- Nutrients levels needed to fuel the aquatic food web, contributed by decaying organic debris and salmonid carcasses, are likely below historic levels;
- The decline in abundance of salmonids has likely caused a corresponding decrease in reproductive potential. Populations will likely require several years to rebuild.

What watershed and habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

Barriers to Fish Passage

- Modify or remove potential barriers such as deltas or boulder and/or debris accumulations that may impede upstream fish passage into tributary streams for spawning.

Flow and Water Quality Improvement Activities:

- Promote near stream conifer growth to reduce solar radiation and to moderate air temperatures along stream corridors. This will reduce heat inputs to Redwood Creek and its tributaries and help to keep water cool.

Erosion and Sediment Delivery Reduction Activities:

- Any reduction of sediment from upstream sources will benefit the lower mainstem Redwood Creek;
- In order to reduce sediment delivery to Redwood Creek and its tributaries RNSP should continue efforts such as road improvements (e.g., upgrading crossings, rocking native surface roads, outsloping, ensuring surface drainage does not flow directly into watercourses, etc.) and decommissioning (e.g., removing unstable fills, removing drainage structures and fills, restoring natural contours, blocking vehicle access, etc.) throughout the Redwood Creek Basin;
- To address accumulations of fine sediments observed in Elam, Bridge, and Fortyfour creeks, Sediment sources from eroding stream banks and adjacent hillslopes should be identified and treated.

Riparian and Stream Habitat Improvement Activities:

- Where appropriate, land managers should use tree planting, thinning from below, and other vegetation management techniques to promote the development of large near stream conifers along mainstem Redwood Creek, Bridge Creek or other stream reaches with a low coniferous component in the riparian zone. Thinning to encourage conifer growth should be done with consideration of maintaining adequate shade canopy over stream channels;
- Instream LWD is needed for channel maintenance and shelter complexity;
- Strategically add wood into pools and flatwater units to increase pool depth and overall shelter complexity in Bridge, and Elam, Fortyfour creeks and other streams within the subbasin that lack deep complex pools;
- Consider adding shelter complexity with wood to existing cool temperature refuge sites on Redwood Creek, and lower reaches of tributary sites. This could be done even on a temporary basis using small woody debris to provide escape cover for juvenile salmonids during summer season. The cool patches may be located in temperature stratified pools or adjacent to cool water inputs from tributary flows at Bridge Creek or near springs, and seeps.

Education, Research, and Monitoring Activities:

- The range of habitat conditions within the Lower Subbasin provides an opportunity to monitor channel and salmonid habitat recovery rates using habitat improvement treatments within a variety of channel types and conditions;
- Perform stream habitat surveys in tributaries throughout the Lower Subbasin to identify excessive erosion areas, assess salmonid stream habitat, identify deltas or boulder and/or debris accumulations that may impede passage for spawning, and to identify potential sites for improving habitat with restoration techniques;
- Monitoring in-channel sediment by measuring sediment size distribution, turbidity, V*, photo points should be increased; tracking of streambed levels with stream channel cross sections should be continued along the mainstem reach of lower Redwood Creek;
- A long term, concerted monitoring effort between the land owners, interested parties and responsible agencies is needed to determine the status and trends of anadromous fish populations in Lower Subbasin streams;
- Land managers and responsible agencies should increase continuous temperature monitoring efforts along the mainstem and at additional tributary locations to determine the impact of cold-water inputs from tributary and ground water sources;
- Although there were no formal stream reach surveys for LWD; observations of crews and findings regarding pool complexity indicate that there is limited instream LWD. Formal surveys for LWD loadings could be done to verify these observations.

Subbasin Conclusions

The lower mainstem of Redwood Creek is an important migratory route for anadromous salmonids as it provides access to Lower Subbasin tributaries and upstream spawning areas. The mainstem also may serve as spawning habitat for Chinook salmon during low water years. Elevated water temperature and lack of channel complexity are factors most limiting juvenile anadromous salmonid use of the lower reaches of the mainstem Redwood Creek during the summer months.

Juvenile Chinook, coho, steelhead, and coastal cutthroat have been observed in Lower Subbasin tributaries. These streams provide important salmonid spawning and year round rearing habitat. Water temperature is generally suitable in the tributaries year round. However, tributary streams lack sufficient area in deep, complex pools. Spawning gravels were moderately to highly embedded in fine sediments, which is considered unfavorable for successful incubation salmonid eggs.

The Lower Subbasin offers opportunities for both implementing and effectiveness monitoring of stream and riparian habitat improvement activities. Based on the survey sample sites, appropriate stream habitat improvement activities for Lower subbasin streams include reducing sediment inputs by stabilizing stream bank and hillslope erosion, increasing depth and complexity to existing pool habitats, promoting near stream conifer growth, and adding shelter complexity to cool water refuge sites.

Middle Subbasin

The Middle Subbasin includes the area above the confluence of Redwood and Devil's creeks, up to the confluence of Redwood and Lupton creeks, including the Lupton Creek watershed (Table IV- 59 and Figure IV-33). The predominant land use in the Middle Subbasin is timber production and in addition, some livestock grazing occurs in Redwood Valley. The Middle Subbasin includes the following Planning watersheds:

Coyote Creek	Panther Creek	Lower Lacks Creek	Upper Lacks Creek
Roaring Gulch	Toss-up Creek	Minor Creek	Lupton Creek

Principal features within the Middle Subbasin include coniferous forestland, the Park Protection Zone, and rural developments in Redwood Valley. The Park Protection Zone was established on private lands in 1978 and includes lands within Coyote, Panther, and Upper and Lower Lacks creek planning watersheds. The Park protection zone enables RNSP staff to participate in the State's timber harvest plan process and to develop cooperative relationships with private land owners. Approximately 2,300 acres in the Lacks Creek watershed is managed by the Bureau of Land Management (BLM) as late successional reserves. Other notable features of the subbasin are presented in Table IV- 59.

Approximately 24 miles of mainstem Redwood Creek and 161 miles of blue line tributary stream channel drain the surrounding landscape. The twenty-four miles of mainstem Redwood Creek and approximately 19 miles of tributary channels are accessible to anadromous salmonids. Anadromous fishery resources of the Middle Subbasin include Chinook and coho salmon, steelhead and coastal cutthroat trout.

Table IV- 59. Middle Subbasin summary.

Square Miles	100.14
Total Acreage	64,088
Private Acres	57,843
Federal Acres	5,838
State Acres	0
Principal Communities	Redwood Valley
Predominant Land Use	Timber production and livestock grazing
Predominant Vegetation Type	Douglas-fir forest/ hardwoods
Miles of Anadromous Stream	43.0
Low Elevation (feet)	325
High Elevation (feet)	4,091

Geology

The Middle Subbasin has more complex bedrock structure and more mass wasting than in the lower parts of the watershed. The Middle Subbasin may be the least stable in the entire Redwood Creek watershed. Eighty-one percent of the subbasin falls within the high to very high mass wasting potential categories (Table IV- 61). The high level of potential instability appears to be related to weak rocks underlying the subbasin.

Along the east side of the Grogan Fault large earth flow amphitheaters are common south of Coyote Creek in the incoherent unit of Coyote Creek (KJfc). They appear formed over many thousands of years by multiple generations of overlapping earth flow scars. These features contain active earthflow complexes and areas of disrupted ground. In the far eastern part of the Middle Subbasin the coherent unit of Lacks Creek (KJfl) underlies some of the steepest slopes in the Redwood Creek watershed and is predominantly a source of debris slides, debris flows, and small bedrock landslides, although occasional rotational landslides are also present in this unit (Plate A, Sheet 2, CGS appendix E). The first of a complex series of large cross-faults occurs immediately south of Minor Creek. The direction of movement on these faults is unknown, but they appear to be younger than the Grogan Fault because they are mapped as offsetting it. Rocks associated with the sandstone and mélange unit of Snow Camp Mountain (KJfs) first appear along the extreme west margin of the watershed in this area. For further detail, please refer to geologic maps in Appendix E.

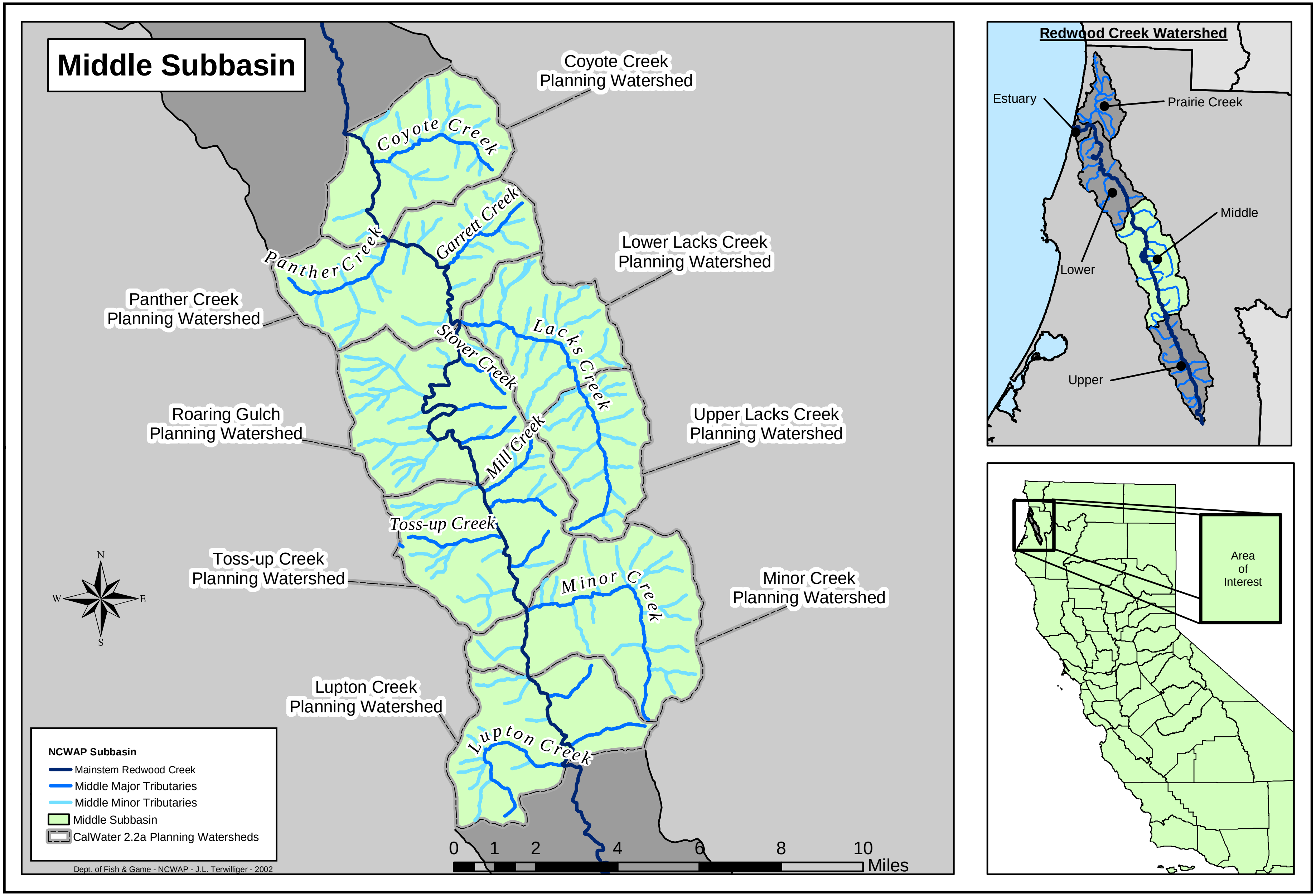

Figure IV- 33. Middle Subbasin and its tributaries, Redwood Creek.

The typical modes of mass wasting west of the Grogan Fault are large rotational landslides and debris slides. The rotational landslides are typically subdued and appear to be very old, possibly thousands of years. Some smaller active bedrock slides also are present in this area. The Redwood Creek schist (KJfr) near "the meanders" has several broad, shallow amphitheaters containing numerous, small watercourses in fan shaped arrays. These amphitheaters may be the eroding floors of fully evacuated ancient landslides. The west side of the subbasin above this section of the channel is bounded by a series of large, faceted spur-ridges. These are seen as a series of large triangular slope faces extending approximately 3000-4000 feet upslope of the channel. These slope faces may represent remnants of the original topography (ancient canyon wall) or be largely a series of ancient mass wasting features (as mapped). Corresponding facets are not present on the east side of the channel and this may be due to the weakness of the incoherent unit of Coyote Creek underlying this area.

Streamside Landslides

Table IV- 60 shows the numbers (not sizes) of small, active, streamside landslides observed in 1984 and 2000 aerial photos of the Middle Subbasin. Overall, the number of landsides increased 18%, from 376 to 442 over the 16 year period. The number of active streamside landslides increased in four of the 8 planning watersheds: Upper and Lower Lacks Creek, Panther Creek, and Roaring Gulch. Some of the highest densities of active streamside landslides in the basin occur along the channels of Lacks and Minor Creeks. The upper reaches of both watercourses follow the contact between the incoherent unit of Coyote Creek and the south facies of the coherent unit of Lacks Creek. These are probably the weakest and strongest rocks, respectively, in the watershed. The Lacks and Minor Creek planning watersheds also have the highest landslide potential of the basin, having 91-94% of their areas within the high to very high mass wasting potential categories. Lower Lacks Creek showed the most dramatic increase from 39 in 1984 to 125 small active streamside landslides in 2000. These slides probably contributed to the elevated sediment stored in the lower reach of Lacks Creek. This elevated sediment supply may adversely affect habitat for salmonids. The number of active streamside landslides decreased in three planning watersheds: Lupton, Minor and Toss-up Creeks, and stayed the same in Coyote Creek.

Table IV- 60. Middle Redwood Subbasin active streamside slides, slide index, and change in index, 1984 and 2000.

Subbasin or Planning Watershed Unit of Analysis	Analysis Unit Area (sq. km.)	1984 # of Active* Slides Along Streams	2000 # of Active* Slides Along Streams	% Change 1984-2000
Middle Redwood Subbasin	259.2	376	442	+18
Coyote Creek	31.1	74	74	0
Lower Lacks Creek	24.0	39	125	+ 221
Upper Lacks Creek	20.5	76	97	+ 21
Lupton Creek	32.6	27	12	- 56
Minor Creek	40.3	65	6	- 91
Panther Creek	39.4	31	52	+ 68
Roaring Gulch	36.0	31	46	+ 48
Toss-up Creek	35.3	33	30	-9

**Index = (# slides/analysis unit area) X 100

Table IV- 61. Middle Subbasin summary of relative landslide potential and landslide features.

Factor	Middle Subbasin		Planning Watersheds															
			Lupton Creek		Minor Creek		Toss-up Creek		Upper Lacks		Roaring Gulch		Lower Lacks		Panther Creek		Coyote Creek	
Relative Landslide Potential	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Very Low	2,689	4.2	551	6.9	231	2.3	589	6.7%	141	2.8%	791	8.9%	59	1.0%	210	2.2%	117	1.5%
Low	3,868	6.0	650	8.1	327	3.3	606	6.9%	279	5.5%	828	9.3%	288	4.9%	642	6.6%	248	3.2%
Moderate	6,002	9.4	1,140	14.2	374	3.8	906	10.4%	38	0.8%	1,248	14.0%	22	0.4%	1,680	17.3%	594	7.7%
High	20,402	31.9	2,769	34.4	3,075	30.9	2,778	31.8%	1,096	21.7%	2,709	30.4%	1,222	20.6%	3,928	40.4%	2,825	36.8%
Very High	31,023	48.5	2,930	36.4	5,929	59.7	3,847	44.1%	3,507	69.3%	3,325	37.4%	4,327	73.1%	3,274	33.6%	3,884	50.7%
High/Very High Subtotal	51,425	80.4	5,699	70.9	9,004	90.6	6,625	75.9%	4,603	91.0%	6,034	67.8%	5,549	93.8%	7,202	74.0%	6,709	87.5%
GRAND TOTAL	**63,984**	**100%**	**8,040**	**100%**	**9,936**	**100%**	**8,726**	**100%**	**5,061**	**100%**	**8,901**	**100%**	**5,918**	**100%**	**9,734**	**100%**	**7,668**	**100%**
Landslide and Selected Geomorphic Features	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Historically Active Landslide Features Total	4,166	6.5	569	7.1	831	8.4	153	1.8	168	3.3	267	3.0	1,062	17.9	302	3.1	814	10.6
Earthflow	3,187	5.0	406	5.1	774	7.8	118	1.4	89	1.8	181	2.0	572	9.7	261	2.7	785	10.2
Rock Slide	654	1.0	133	1.7	4	0.0	0	0.0	36	0.7	33	0.4	448	7.6	0	0.0	1	0.0
Debris Slide	257	0.4	29	0.4	46	0.5	16	0.2	38	0.7	45	0.5	31	0.5	33	0.3	19	0.2
Debris Flow	68	0.1	1	0	7	0.1	19	0.2	4	0.1	8	0.1	11	0.2	9	0.1	9	0.1
Dormant Landslide Features Total	15,150	23.7	2,249	28.0	2,487	25.0	2,275	26.1	198	3.9	2,843	31.9	1,365	23.1	2,205	22.7	1,528	19.9
Selected Geomorphic Features Total	13,495	21.1	2,010	25.0	2,581	26.0	961	11.0	1,247	24.6	182	2.1	706	11.9	2,934	30.1	2,874	37.5
Disrupted Ground	10,099	15.8	1,932	24.0	1,586	16.0	923	10.6	3	0.1	163	1.8	2	0.0	2,674	27.5	2,817	36.7
Debris Slide Slope	2,943	4.6	19	0.2	884	8.9	0	0.0	1,155	22.8	0	0.0	638	10.8	211	2.2	35	0.5
Inner Gorge (area)2	453	0.7	59	0.7	111	1.1	38	0.4	89	1.8	19	0.2	66	1.1	49	0.5	22	0.3
Total of All Above Features	**32,811**	**51.3%**	**4,828**	**60%**	**5,900**	**59.4%**	**3,389**	**38.8%**	**1,612**	**31.9%**	**3,292**	**37%**	**3,134**	**52.9%**	**5,441**	**55.9%**	**5,215**	**68.0%**

Vegetation

Middle Subbasin vegetation consists of 46,766 acres of conifer-dominated forestland (73% of the subbasin) and 11,861 acres (19% of the subbasin area) of hardwood forests (Table IV- 62). Although pure conifer stands are found within the subbasin, most of the forested landscape is comprised of mixed conifer-hardwood stands. Douglas-fir is by far the dominant forest type, with 44,352 acres or 69% of the subbasin area (Figure IV- 34). The Middle Subbasin has the greatest amount and proportion of tanoak stands of the Redwood Creek Basin. There are 4,771 acres of tanoak, or over 7% of the subbasin. These stands are largely the result of early conifer harvests that did not successfully re-establish conifer stands. Grassland covers 4,102 acres (6% of the subbasin). In addition small areas, scattered throughout the subbasin are covered with brush. Blueblossom (*ceanothus spp*.) along with coyote brush is found in the dryer south facing sites.

Productive timberland covers approximately 58,400 acres, or 91% of the subbasin. Productive timberland includes conifer, hardwood, and mixed forests and is defined as land capable of producing 20 cubic feet or more of commercial timber products per acre per year. Recent timber harvest units within the subbasin appear to be restocked and very productive. Since the onset of restocking requirements for timber harvests, the Department of Forestry and Fire Protection's forest practice program has indicated all harvest units within the subbasin meet the stocking standards of the Forest Practice Rules.

Table IV- 62. Generalized cover type by subbasin and planning watershed.

Subbasin or Planning Watershed	Covertype							
	Agriculture	Barren	Conifer	Hardwood	Grassland	Shrub	Developed	Water	Total
Middle Subbasin	25	277	46,766	11,861	4,102	771	11	0	63,813
Coyote Creek	0	8	4,654	1,793	1,117	80	0	0	7,652
Panther Creek	0	21	7,427	1,368	702	160	0	0	9,678
Lower Lacks Creek	0	0	2,466	2,899	573	0	0	0	5,938
Upper Lacks Creek	0	0	3,808	1,187	80	0	0	0	5,075
Roaring Gulch	25	17	7,458	1,040	269	62	11	0	8,882
Toss-up Creek	0	96	7,446	643	361	141	0	0	8,687
Minor Creek	0	3	7,198	2,081	506	130	0	0	9,918
Lupton Creek	0	132	6,309	850	494	198	0	0	7,983

Timber Harvest

Timber harvesting within the Middle Subbasin was observed on the 1948 air photo series. By the time of the 1964 flood, 50% (32,406 acres) of the subbasin area had been harvested. Even-aged silviculture has been and is still widely utilized within the subbasin. Recent operations have centered on the re-establishment of former conifer stands that, as the result of earlier harvesting, had become dominated by tanoak.

Based on aerial photo analysis and THPs, as of 2001, timber harvest had occurred on an area of 81,023 acres, equal to 126% of the total subbasin area (Table IV- 63). Multiple harvests were conducted on some portions of the subbasin (Figure IV- 35). Areas of timber harvests during 1977-2000 are shown in Figure IV- 36. As of 2001, approximately 36% (20,561 acres) of the previously harvested area (56,476 acres) within the Middle Subbasin had been harvested with a second entry. Also at this time, about 7% (3,976 acres) of the previously harvested area had received a third harvest entry. Second entries often occurred when the first entry removed the Douglas-fir component of the stand, and then a second entry was made during which the redwood trees were harvested. A second stand entry also could be made to remove the hardwoods previously occupied by a conifer stand. Removal and regeneration of a completely established "second growth" timber stand is the third reason that a second entry occur. Commercial thinning of stands also is reflected in these second and third harvest entry figures.

Table IV- 63. Timber harvest history for the Middle Subbasin planning watersheds, 1950-2000.

Subbasin or Planning Watershed	Harvest Acres by Period							
	1950 - 1964	1965 - 1974	1975 - 1983	1984 - 1992	1992 - 2000	Total Harvested	PWS Total Acres	% Harvested
Middle Subbasin	32,406	11,991	12,616	13,999	10,011	81,023	64,122	126.4
Coyote Creek	2,933	2,311	2,344	1,935	0	9,523	7,683	123.9
Lupton Creek	3,980	1,185	545	2,026	1,985	9,721	8,055	120.7
Lower Lacks Creek	1,622	981	1,396	420	163	4,582	5,939	77.2
Minor Creek	4,916	1,282	822	3,370	3,223	13,613	9,965	136.6
Panther Creek	5392	2,408	4,544	1189	1,581	15,114	9,751	154.9
Roaring Gulch	5,833	2,047	1571	890	1,375	11,716	8,911	131.4
Toss-up Creek	5,700	657	617	2535	1,475	10,984	8,739	125.7
Upper Lacks Creek	2,030	1,120	777	1634	209	5,770	5,079	113.6

Table IV- 64. Middle Subbasin multiple harvest acres.

Harvest Entry	Harvest Acres
First	56,476
Second	20,561
Third	3,976

Yarding methods employed on timber harvest plans from 1980-1999 within the Middle Subbasin are comprised of three separate systems. Ground based tractor skidding accounts for 85% of this total on an area basis. Of the approximately 28,000 acres harvested during that period, 24,095 were yarded with ground-based equipment. Cable yarding systems were used on an additional 1,660 acres (6% of the harvest area). Helicopter yarding was utilized for the 5% of the harvest area. Most of the helicopter yarding was used in clear-cut or shelterwood removal units and has occurred since 1995. Ground based yarding has been used in all types of silviculture units.

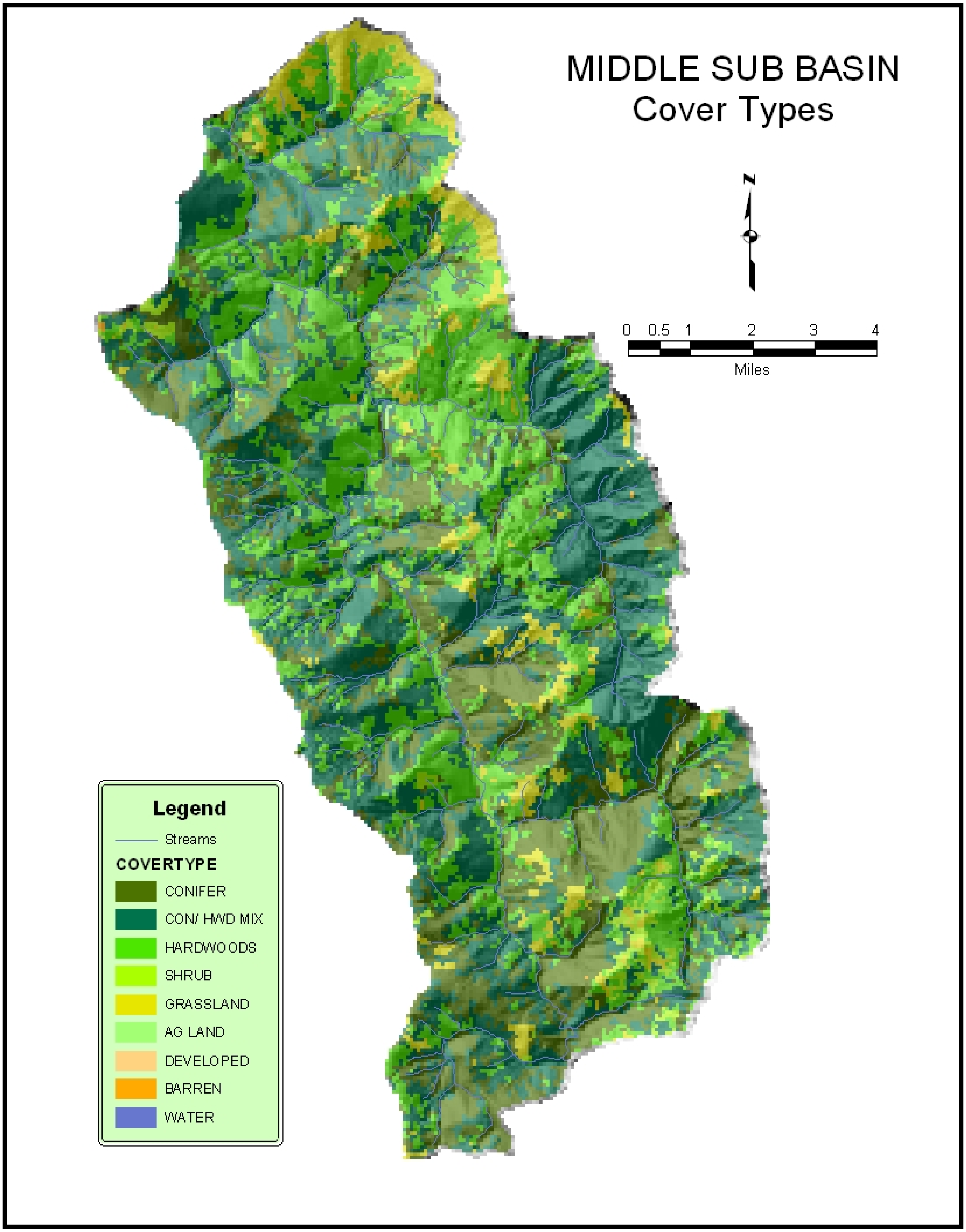

Figure IV- 34. Middle Subbasin map showing vegetation cover types.

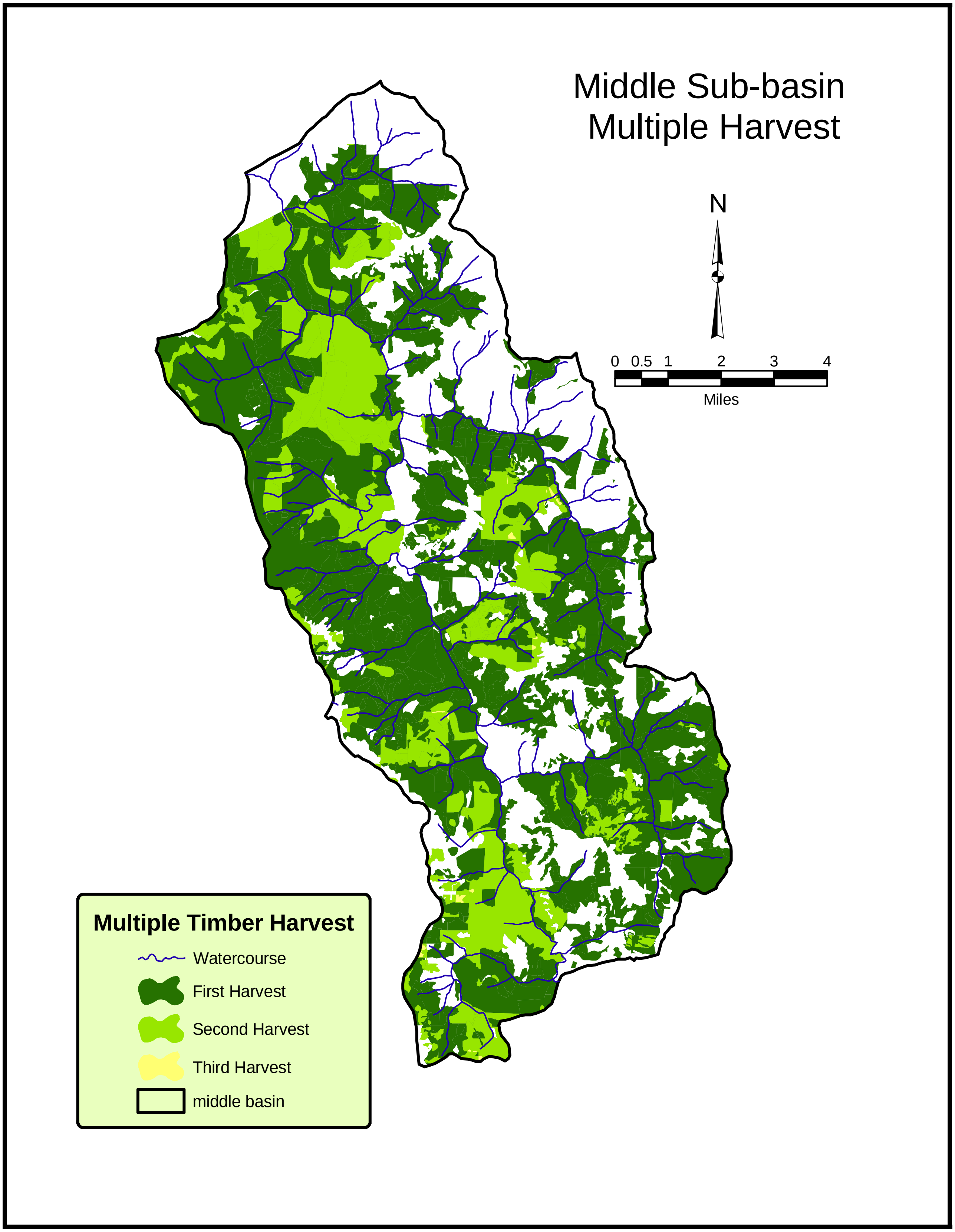

Figure IV- 35. Middle Subbasin multiple timber harvest entry map.

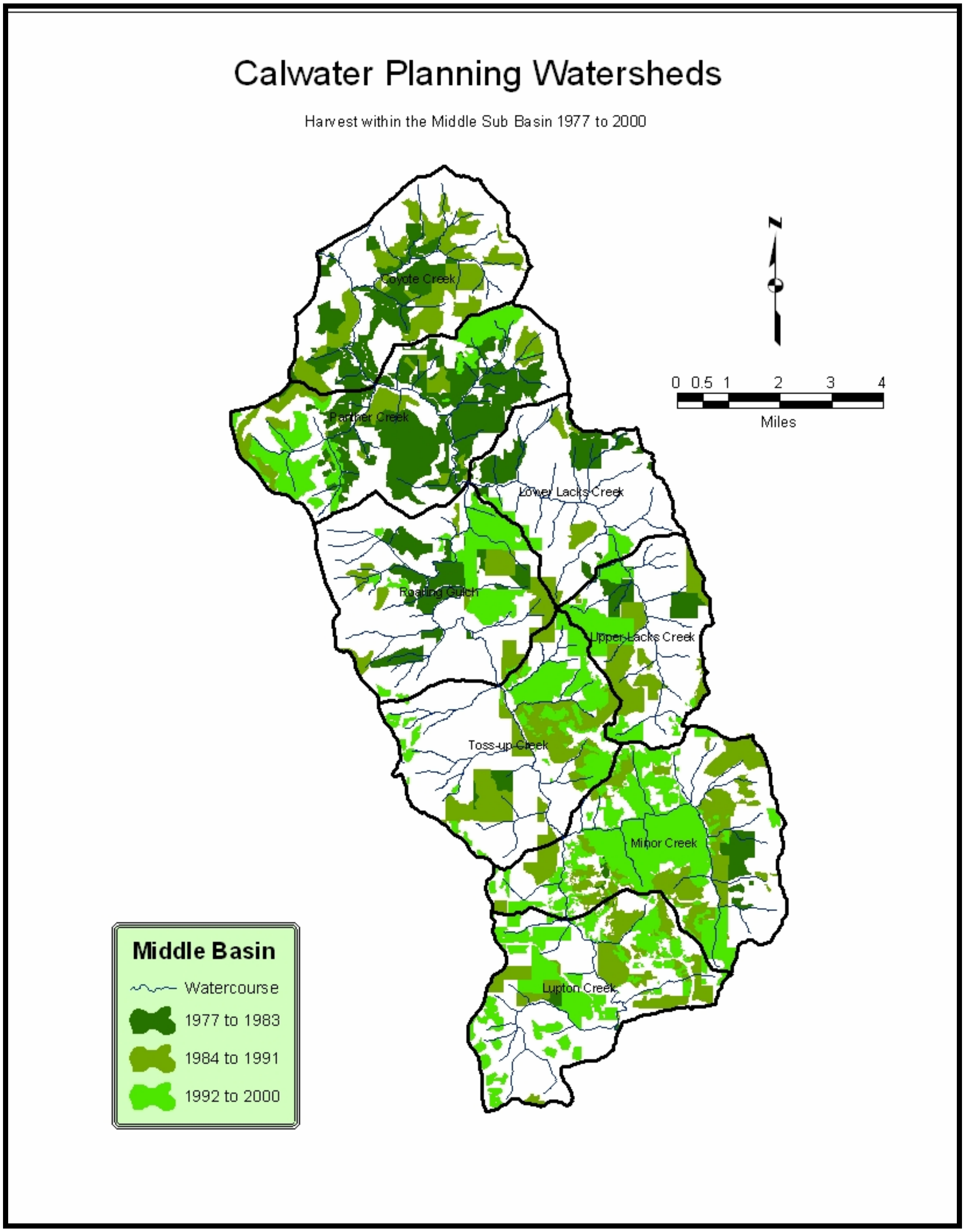

Figure IV- 36. Middle Subbasin timber harvest from 1977 to 2000.

Roads

There are 811 miles of roads and road density of 8.1 miles of road per square mile of land base within the Middle Subbasin (Figure IV- 37). Approximately 51% of the total road miles were constructed prior to 1958 (Figure IV- 38). Pre-1958 road construction standards were very different from standard practices of today. Roads built in that era generally were built with undersized culverts, did not have compacted road fills, were built over-width, and lacked sufficient cross drains and ditches. Approximately 47% of the road miles are classified as abandoned. Abandoned roads are constructed features that are no longer in use and do not normally receive any maintenance. Most of the abandoned road miles are located in the lower portions of the canyons and/or within close proximity to watercourses. Roads built close to streams and to older standards generally have a higher likelihood to deliver significant quantities of sediment to streams than do roads located further from streams and built to current standards. Erosion-proofed abandoned roads generally contribute much less fine sediment than roads used and/or maintained through out the year. Twenty-three percent of the total road miles within the subbasin receive maintenance. Only 34 miles (4%) of the roads within the Middle Subbasin were built to the standards of the Forest Practice Rules.

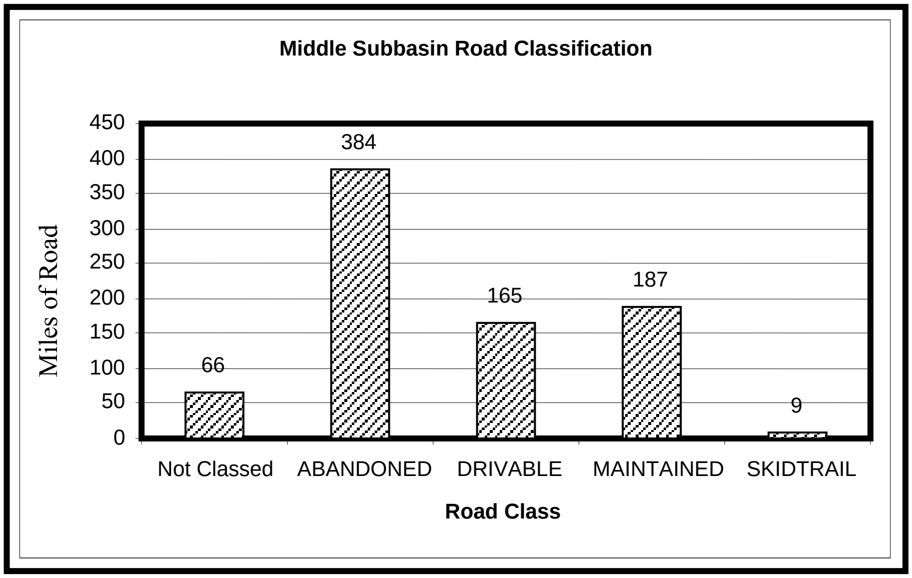

Figure IV- 37. Middle Subbasin classification of roads.

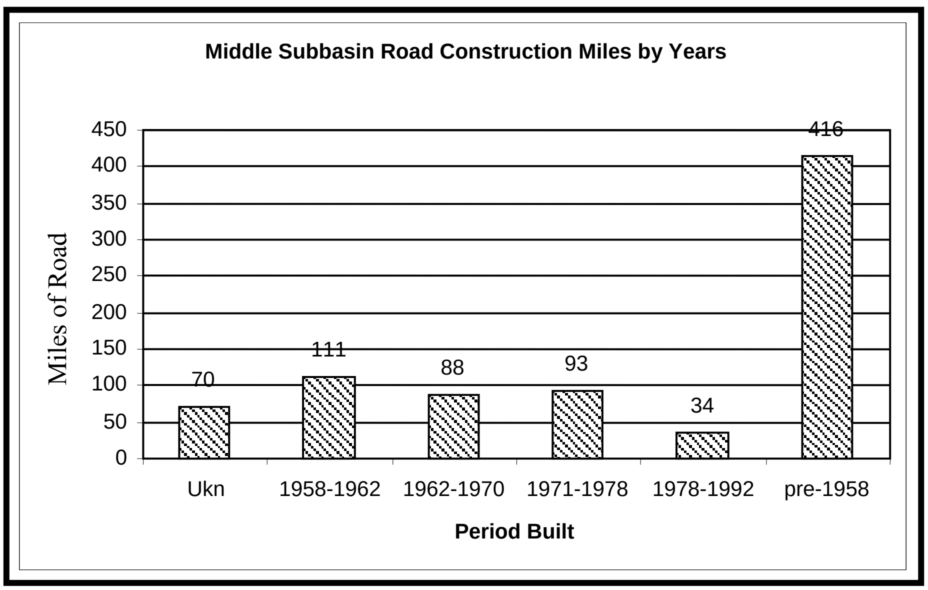

Figure IV- 38. Middle Subbasin miles of roads constructed by years.

Fire and Fuels

The Middle Subbasin is almost evenly split between moderate and high fuel rank areas, with small discontinuous zones of very high rank scattered throughout (Table IV- 65 and Figure IV- 39). On a percentage basis, the Roaring Gulch planning watershed appears to have the lowest fuel rankings and Upper Lacks Creek planning watershed the highest.

Table IV- 65. Fuel ranks summary for the Middle Subbasin and its planning watersheds.

Area of Analysis	Fuel Rank								Total Acres
	Moderate		High		Very High		Not Mapped		
	Acres	%	Acres	%	Acres	%	Acres	%	
Middle Subbasin	29,675	46	31,121	49	3,220	5	110	<1	64,126
Coyote Creek Planning Watershed	4,422	58	2,906	38	350	5	6	<1	7,683
Panther Creek Planning Watershed	5,745	59	3,597	37	395	4	15	<1	9,751
Lower Lacks Creek Planning Watershed	2,444	41	3,202	54	286	5	7	<1	5,939
Upper Lacks Creek Planning Watershed	1,195	24	3,459	68	415	8	10	<1	5,080
Roaring Gulch Planning Watershed	5,729	64	2,841	32	313	4	29	<1	8,912
Toss-Up Creek Planning Watershed	3,631	42	4,626	53	460	5	22	<1	8,740
Minor Creek Planning Watershed	3,231	32	5,983	60	740	7	11	<1	9,966
Lupton Creek Planning Watershed	3,278	41	4,507	56	261	3	10	<1	8,056

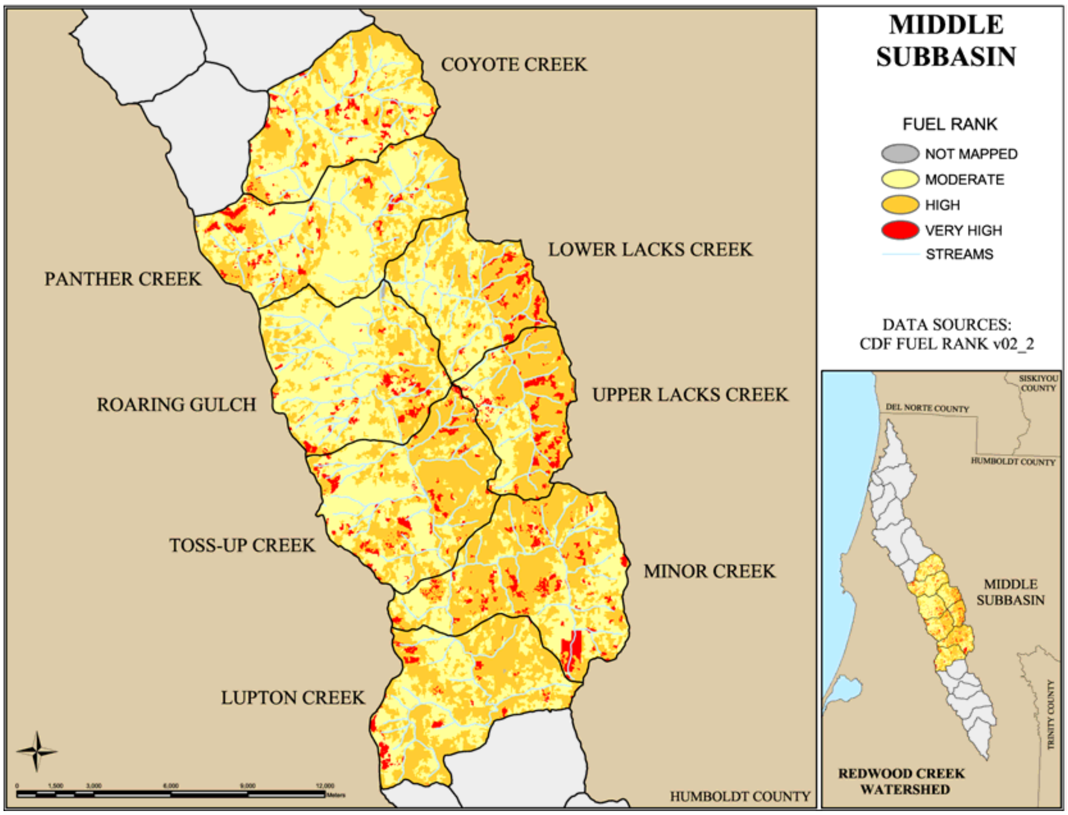

Figure IV- 39. Middle Subbasin fuel ranking map.

Fluvial Geomorphology

The middle reach of Redwood Creek closely follows the Grogan fault zone from Highway 299 Bridge to the confluence with Beaver Creek. Then the valley containing the mainstem channel widens significantly below the mouth of Minor Creek to form Redwood Valley. Here stream bars and terraces, which are characteristic of a depositional stream reach, are more abundant and voluminous than in upstream reaches. Sediment storage predominates and the multiple terraces show that has been the case for thousands of years. Streamside landslides in Redwood Valley appear to be less frequent compared to upstream and downstream reaches within the subbasin.

Down stream from Beaver Creek, the mainstem narrows and meanders tightly to the west of the Grogan fault zone and flows through the Redwood Creek schist. The tight meanders beginning near Roaring Gulch are not typical of this coastal mountain stream, and appear to be remnants of earlier, gentler (antecedent) valley topography west of the fault. Madej (1995) suggested that there were Pleistocene-aged river terraces in this area. Inner gorge debris slides are rare along this section of channel indicating that the underlying bedrock is relatively stable and resistant. Downstream, beyond the meanders, streamside landslides are once again abundant near the mouths of Panther and Coyote Creeks. Here again, the main stem veers westward into the Redwood Creek schist and away from the zone of the Grogan fault.

In the upper, wider portion of the Middle Subbasin, mainstem bankfull widths are 75-416 feet and floodplain widths are up to 660 ft (Madej and Ozaki 1996). In the lower reaches, bankfull widths are 80-115 ft and the floodplain generally is less than 165 ft wide. Channel gradient at both ends of the middle basin is a low (0.4%).

After the 1964 flood, channel-stored sediment increased by 32% (Madej and Ozaki 1996); 62% of these flood deposits were transported downstream within 16 years (Madej 1984a, b). Further decreases in stored sediment were observed between 1980 and 2000 at Redwood Creek channel cross section number 34, near the middle of the subbasin, and cross section number 40, at the upstream end of the subbasin. At both of these stations, between 1980 and 2000, there was still a cumulative loss of bed elevation in the range of -1.3 to -1.6 ft (-0.4 to -0.5 m) (see appendix E).

The abundance of steep tributary source reaches in the Middle Subbasin provides a ready supply of sediment to overload the mainstem channel and its downstream reaches during large storms (Table IV- 66). The situation can be exacerbated by land management practices on the steep slopes. Source reaches concentrated in the upper parts of the tributaries comprise more than 53% of the stream reaches in the Middle Subbasin. Consequently, the lower gradient, potential fish habitat reaches along the mainstem and lower parts of tributaries in the can be overwhelmed with sediment from surrounding steep areas, filling pools, widening banks and aggrading channels. Transport reaches are 32% and response reaches, mostly in the mainstem, are 15% of the reaches in the Middle Subbasin.

Table IV- 66. Middle Subbasin stream miles by planning watersheds.

Planning Watershed	**Planning Watershed Area (acres)**	**Miles of tributary blue-line streams**			**Miles of Redwood Creek mainstem**		**Number of blue-line tributary segments (number of these that drain directly into Redwood Creek)**		
Coyote Creek	7,683	17.3			3.7		17 (4)		
Panther Creek	9,751	22.7			3.3		25 (7)		
Roaring Gulch	8,911	23			7		24 (11)		
Lower Lacks	5,939	21			0		19 (1)		
Upper Lacks	5,079	16			0		15 (0)		
Toss-up Creek	8,739	21.7			3.3		20 (7)		
Minor Creek	9,965	23.3			1.7		15 (2)		
Lupton Creek	8,055	15.7			2.8		13 (7)		
% Stream by Gradient	**Middle Redwood Subbasin**	**Lupton Creek**	**Minor Creek**	**Toss-up Creek**	**Upper Lacks**	**Roaring Gulch**	**Lower Lacks**	**Panther Creek**	**Coyote Creek**
< 1% (Response Reach)	11.6%	18.3%	7.7%	14.2%	0.0%	22.1%	2.1%	14.1%	14.6%
1-4% (Response Reach)	5.1%	5.3%	9.2%	2.6%	5.8%	3.9%	10.4%	2.7%	4.4%
4-20% (Transport Reach)	31.1%	47.3%	18.2%	27.2%	33.4%	17.7%	25.8%	38.4%	27.6%
>20% (Source Reach)	52.3%	29.2%	65.6%	56.0%	60.7%	56.4%	61.6%	44.7%	53.4%
Historically Active and Dormant Landslide and Selected Geomorphic Features4	% stream length	% stream length	% stream length	% stream length	% stream length	% stream length	% stream length	% stream length	% stream length
Within 180' of Blue Line Stream	20.5%	26.0%	36.4%	12.3%	45.8%	5.1%	25.2%	15.1%	10.7%

Observations of a sequence of aerial photographs showed changes in Redwood Creek at the mouth of Lacks Creek after the storm of 1964. In 1948, the mainstem channel contained point bars; in 1965 the channel was widened with sediment from the 1964 storm and lacked discrete stream bars. In 2000, discrete stream bars reappeared in Redwood Creek, however, the channel remained wider than it was in 1948.

Observations from photo year 2000 showed that the channel of Lower Lacks Creek contained large quantities of stored sediment. Lacks Creek, near the confluence with Redwood Creek, is a very low-gradient response reach (<1%). The planning watersheds of Roaring Gulch, Panther, and Devils Creek appeared not to contain excessive amounts of stored sediment. The mainstem of Redwood Creek contained the most stored sediment near Toss Up and Lacks Creeks and the least amounts stored sediment near Panther and Coyote Creeks.

Stream Disturbance

Between years 1984 and 2000, streams of the Middle Subbasin showed an overall decrease of 76% (52.7 mi. to 12.8 mi.) in length of stream disturbance features (Table IV- 67). The large change suggests that the sediment delivery has decreased and excess sediment has moved downstream. This could be due to the lack of major storms (except a 12 year event in 1997) and the 16-year period of gradual transport of elevated sediment downstream.

However, A few reaches showed increases, for example the mainstem Redwood Creek within the Toss Up and Roaring Gulch planning watersheds show an increase in lateral bars. New disturbance in Toss up and Pilchuck Creeks suggest new, post-1984 sediment sources. Air photo analysis indicates that the number of streamside landslides and length of negative stream features increased in Lacks Creek while decreasing in Minor Creek between years 1984 and 2000. Lupton and Minor Creeks appear to have improved, because they showed a decrease in streamside landslides and a decrease in length of disturbance features between 1984 and 2000.

Table IV- 67. Length of observed stream disturbance features and percent change in planning watershed streams 1984 to 2000.

Planning Watershed	Creek Name	Stream Disturbance features (ft)		% Change in Stream Disturbance features between 1984 and 2004
		1984	2000	
Coyote Creek	Unnamed east side trib	794.8	0.0	- 100
	Coyote Creek	18495.5	2700.8	- 85
	Joplin Creek	0.0	0.0	0.0
	Unnamed west side no blue line	548.9	0.0	- 100
	Redwood Creek	11625.0	539.2	- 95
	Total	31464.3	3240.0	- 90
Panther Creek	Panther Creek	0.0	0.0	0.0
	Johnson Prairie Creek	1106.4	0.0	- 100
	Garrett Creek	471.7	0.0	- 100
	Monroe Flat Creek	2444.0	0.0	- 100
	George Creek	0.0	0.0	- 100
	Redwood Creek	6380.2	1318.1	- 79
	Total	10402.3	1318.1	- 87
Roaring Gulch	Stover Creek	0.0	0.0	0.0
	Dolly Varden	0.0	0.0	0.0
	Lee Creek	0.0	0.0	0.0
	Roaring Gulch	0.0	0.0	0.0
	Garcia Creek	0.0	0.0	0.0
	Cashmere Creek	0.0	0.0	0.0
	Beaver Creek	10635.2	0.0	- 100
	Redwood Creek	8247.4	9020.5	+ 9
	Total	18882.6	9020.5	- 52
Lower Lacks Creek	Lower Lacks Creek	18553.1	7439.8	- 60
	Total	18553.1	7439.8	- 60
Upper Lacks Creek	Upper Lacks Creek	9199.0	3403.1	- 63
	Total	9199.0	3403.1	- 63
Toss-Up Creek	Pilchuck Creek	0.0	1728.0	NA
	Mill Creek	4676.0	0.0	- 100
	Molasses Creek	6254.7	0.0	- 100
	Unnamed east side trib - no blue line	2553.0	0.0	- 100
	Toss-up Creek	0.0	927.6	NA
	June Creek	2086.6	0.0	- 100
	Moon Creek	5291.5	0.0	- 100
	Unnamed east side trib - no blue line	3697.0	0.0	- 100

Planning Watershed	Creek Name	Stream Disturbance features (ft)		% Change in Stream Disturbance features between 1984 and 2004
		1984	2000	
	Wiregrass Creek	723.0	0.0	- 100
	Redwood Creek	8789.0	11276.3	+ 28
	Total	89574.8	35617.7	- 60
Minor Creek	Minor Creek	59083.2	0.0	- 100
	Lion Creek	0.0	0.0	0.0
	Redwood Creek	4471.7	2319.2	- 48
	Total	63555.0	2319.2	- 96
Lupton Creek	Santa Fe Creek	0.0	0.0	0.0
	Greenpoint Creek	0.0	0.0	0.0
	Sweathouse Creek	14210.1	0.0	- 100
	Captain Creek	9689.6	0.0	- 100
	Lupton Creek	6537.8	1610.0	- 75
	Redwood Creek	6001.6	3773.1	- 37
	Total	36439.0	5383.1	- 85

Water Quality

Temperature

Continuous temperature data have been collected in the Middle Subbasin streams since 1996. The mainstem is monitored at one site, upstream from the confluence with Lacks Creek. Water temperature is monitored on the following 10 tributaries: Lupton, Sweathouse, Minor, Moon, Molasses, Mill, Beaver, Lacks, Panther, and Coyote Creeks.

The summer MWAT in the mainstem of Redwood Creek typically increases only slightly from 71 to 72ºF as it flows downstream through the subbasin from the O'Kane station to just above the confluence with Lacks Creek (Table IV- 68). The measured MWATs of Redwood Creek peak at the Lacks Creek site. This suggests that most of the heat input to Redwood Creek is derived from the Upper Subbasin and it is maintained throughout the Middle Subbasin. The MWAT measured in the mainstem is well above a desirable water temperature range for salmonids of less than 64ºF MWAT.

Upper reaches of the tributaries are generally cool and are within the desirable range over summer rearing of juvenile salmonids. The lower reaches of the tributary streams were usually warmer than the upper reaches, reaching MWAT levels above 65ºF (Table IV- 68). Contributing flows from tributaries do not decrease mainstem Redwood Creek temperatures through the middle portion of the basin. However, tributary flows likely help to moderate water temperature from reaching higher levels and may provide localized cooler areas in the mainstem at their confluences. The mainstem would likely benefit if the tributaries maintained and contributed the cooler temperatures observed from their upper reaches. Many factors contribute to the warm water in the mainstem including: warm water flowing from the Upper Subbasin, high air temperatures, lack of shade canopy cover, and the basin's NW/SE aspect.

Maximum daily temperatures recorded during the summers of 1994 to 2001 for the sites in the Middle Subbasin ranged from 57 to 77ºF in the tributaries and 80ºF on the mainstem (Table IV- 68). These data indicate that at least one day during the hottest part of the year, temperatures in the middle mainstem and the larger tributaries approach or exceed the lethal limit of 75ºF for salmonids. The temperature may remain hot for several hours, thus causing stress and damage or death to salmonids.

Table IV- 68. Middle Subbasin maximum MWATs and seasonal maximum temperatures.

Site ID	Site	Period of Record	Max MWAT year	Max MWAT (F)
824	Coyote Creek5	1994	1994	61
50	Panther3	1974	1974	66
984	Panther mouth5	1998	1998	58
2019	Upper Panther Creek5	1994-95	1995	57
3004, Lac	Lacks Creek5, 1	1997-2001	1997	67
1144	Upper Lacks Creek5	1998	1998	61
3011	*RedCrk upstm Lacks Creek5	1997-98	1998	72
1118	Beaver Creek5	1997-98	1998	62

Site ID	Site	Period of Record	Max MWAT year	Max MWAT (F)
1119, Mill	Mill Creek5, 1	1997-98, 2001	1998	61
1120	Molasses Creek5	1997-98	1998	63
1121	Moon Creek5	1998	1998	68
3006, 1145, Min	Minor Creek5, 1	1997-99, 2001	1999	65
1123	Minor Creek Trib5	1998	1998	59
1124	Upper Minor Creek5	1997-98	1998	61
1125	Sweathouse Creek5	1998	1998	62
957	Lupton Creek5	1997-98	1998	59

From 1974-2001.Data sources: 1RNSP (2001), Woods (1975), Lewis T. et al. (2000), Simpson (2000) (*) indicates locations on mainstem Redwood Creek.

Table IV- 69. Middle Subbasin annual maximum temperatures from 1994-2001.

Site	Stream Location	1994	1995	1996	1997	1998	1999	2000	2001
824	Coyote Cr.	63							
984	Panther Cr. mouth					61			
2019	Upper Panther Cr.	56	59						
3004	Lacks Cr.				73	72	72	72	73
1144	Upper Lacks Cr.					65			
3011	Redwood Cr upstm Lacks				80	80			
1118	Beaver Cr.				65	66			
1119	Mill Cr.				63	64			62
1120	Molasses Cr.				67	70			
1121	Moon Cr.					79			
3006	Minor Cr.				74	73	77		70
1123	Minor Cr. Trib					63			
1124	Upper Minor Cr.				64	63			
1125	Sweathouse Cr.					65			
957	Lupton Cr.				62	62			

Data sources: RNSP (2001), Lewis T. et al. (2000), Simpson (2000).

Water Column Chemistry

USGS monitored water quality at four sites in the Middle Subbasin from 1973 to 1977. Three sites were on mainstem Redwood Creek and two were tributary sites on Highslope and Lacks creeks. Data for dissolved oxygen ranged from 8-12mg/L (water quality objective >8mg/L), pH ranged from 6.5-8.5 (water quality objective 6.5-8.5), and conductivity ranged from 40-260umhos (water quality objective <220umhos), slightly outside the objective goal. These data collected from the Middle Subbasin are quite old, but were in compliance with Basin Plan water quality objectives. See Appendix C for chemistry data from the Middle Subbasin.

In-Channel Sediment

In-channel sediment was sampled for median particle size and percent of fine materials at five sites in the Middle Subbasin between 1979 and 1994. Pebble counts to determine D50 particle size were collected on the mainstem upstream from Panther Creek seven times between 1979 and 1994. McNeil core samples were collected upstream from Panther Creek in 1983 and 1987 and Panther, Lacks and Molasses creeks, were sampled at various times between 1974 and 1994.

The RNSP and USGS sampled mainstem Redwood Creek for D50 particle size at a cross section through a gravel bar located upstream from Panther Creek. Of the seven samples taken between 1979 and 1994, three met the TMDL minimum D50 target of >37mm (see Appendix C for the D50 data). These samples were taken in 1989, 1991 and 1994. According to the CGS fluvial geomorphology assessment of the Middle Subbasin, this mainstem site received a large amount of sediment from numerous streamside landslides to the mainstem seen in 1984 air photos. The D_{50} data show an increase in particle size from 17mm in 1979 to 34mm in 1982. A decrease to 26mm occurred in 1985 followed by a large increase to 48mm in 1989 then to 60mm in 1991. The D_{50} particle size in 1994 dropped again to 42mm. The large increase in the median particle size from 1985 to 1989 may reflect a decrease in stored sediment noted by CGS. As a gravel bar erodes away, the D_{50} particle size is expected to increase as finer particles are washed downstream leaving larger ones behind which will raise the median. The D_{50} particle size sample from 1994 shows a decrease from the 1991 sample, which may reflect the beginning of the destruction of the gravel bar. The gravel bar did not show in the 2000 photos examined by CGS. Unfortunately, because this site was not sampled after 1994 we cannot determine trends in sediment composition of the gravel bar. The CGS assessment of 1997 and 2000 photos noted no active streamside slides at this site or upstream. Another point to note is that there was a large concrete bridge across the channel at this site. It was destroyed in 1997 and a road now crosses through the channel during summer low flows where the bridge once was. Pebble count surveys conducted anytime after 1997 will show changes to in-channel sediment resulting from the bridge removal and will contribute to a more accurate and current assessment of this site. It will be important to know if the D_{50} particle size is meeting the minimum TMDL target today, since a downward trend was noted in 1994 when the last sample was taken.

Panther Creek was sampled for fine sediment using core samplers by the RNSP, USGS, and Woods (1975). The percentage of fine sediment presented in data from the RNSP and USGS are not comparable to TMDL targets due to different methods of analysis. A slight increase can be noted from the RNSP and USGS samples between the two years sampled at each site, however only two years of data were examined so a trend can not be defined (See Appendix C for data from these sampling events). Subsurface sediment data from Woods (1975) are directly comparable to TMDL targets because the samples were analyzed volumetrically. In 1974, the percent of fine sediment at Panther Creek was 30%. This sample exceeded the TMDL target of <14% for the <0.85mm size class.

Salmonid Habitat

Streams of the Middle Subbasin provide spawning and rearing habitat for populations of Chinook, coho, steelhead, summer steelhead, coastal cutthroat trout, and other valuable fishery resources (Table IV- 70). Approximately 25 miles of mainstem Redwood Creek and 19 miles of tributary channel are accessible to anadromous salmonids within the subbasin. The 25 mile reach of mainstem Redwood Creek in the Middle Subbasin contains important spawning habitat for Chinook salmon and provides a migratory route to approximately 20 miles of tributary spawning and rearing habitat for salmonids. The tributaries that provide the most anadromous salmonid habitat are Lacks, Minor, Coyote, and Panther creeks. Coho have been observed during past CDFG surveys of Panther, Coyote, Dolly Varden (Karen), Pilchuck, Minor and Redwood creeks. Coho were not observed in Middle Subbasin tributaries during 2001 surveys. Summer steelhead may be the most threatened of all salmonid stocks of the Redwood Basin. They rely on deep, cool, and sheltered pools in the mainstem and lower reaches of a few tributaries for holding habitat over summer and fall seasons. These cool and complex pools are now rarely found in the basin.

Table IV- 70. Middle Subbasin streams, species present, and number of stream miles accessible to anadromous salmonids.

Stream	Species Observed		Stream Length Access (miles)	References
Lacks Creek	Chinook coho coastal cutthroat steelhead	Pacific lamprey rainbow trout Pacific giant salamanders	4.54	CDFG 2001 & 1966 stream surveys, Ridenhour and Hofstra 1994, Brown 1988, RNSP/USFS-RSL revisit of 1981 thesis sites field notes
Minor Creek	Chinook coho steelhead		2.92	CDFG 2001 & 1966 stream surveys, Ridenhour and Hofstra 1994, and Brown 1988, PCFWWRA 1995.
Coyote Creek	coho coastal cutthroat steelhead brook trout	Pacific lamprey yellow legged frog Pacific giant salamander	2.44	CDFG 2001 & 1966 stream surveys, Brown 1988, and USFS/RNP barrier study notes
Panther Creek	coho coastal cutthroat steelhead	rainbow trout Pacific giant salamander	1.74	CDFG 1975 & 2001 stream surveys, Brown 1988, and RNP/USFS-RSL revisit of 1981 thesis sites field notes
Wiregrass Creek	steelhead		1.12	CDFG 2001 stream surveys and Brown 1988
Dolly Varden Creek	steelhead	coho	0.94	CDFG 2001 stream surveys, Brown 1988
Toss Up Creek	steelhead pacific giant salamander	yellow-legged frog	0.75	CDFG 2001 stream surveys, carcass surveys 1998 and 1999, RNP/USFS-RSL revisit of 1981 thesis sites field notes, and Brown 1988
Garrett Creek	steelhead		0.56	CDFG 2001 stream surveys and Brown 1988
Lupton Creek	steelhead		0.56	Brown 1988
Sweathouse Creek	steelhead		0.37	CDFG 2001 stream surveys and Brown 1988

Stream	Species Observed		Stream Length Access (miles)	References
Pilchuck Creek	steelhead	coho	0.31	CDFG 2001 stream surveys, Ridenhour and Hofstra 1994, Brown 1988
Mill Creek	steelhead	Pacific giant salamanders	0.25	CDFG 2001 stream surveys, carcass surveys 1998,99, RNP/USFS-RSL revisit of 1981 thesis sites field notes, and Brown 1988
Molasses Creek	steelhead		0.25-0.5	CDFG 2001 stream surveys and Brown 1988
Captain Creek	steelhead rainbow trout	Pacific giant salamander	0.25	CDFG 2001 stream surveys and Brown 1988
Garcia Creek	Steelhead		0.25	Brown 1988
Beaver Creek	steelhead	Pacific giant salamanders	0.19	CDFG 2001 stream surveys and Brown 1988
Cashmere Creek	steelhead		0.25	Brown 1988
Roaring Gulch	steelhead		0.12	Brown 1988
Loin Creek	steelhead		0.12	Brown 1988
Santa Fe Creek	steelhead		0.06	Brown 1988
Redwood Creek	Chinook salmon coho salmon coastal cutthroat steelhead summer steelhead	speckled dace lamprey spp three-spine stickleback sculpin spp Sacramento sucker	24.7	Weseloh, T., personal communications. CDFG 2001 stream surveys, Gerstrung 2001, RNSP 2001 and 1989, Anderson 2000, and Brown 1988; Sparkman 2001

Stream Surveys 1966–1995

Fish habitat conditions in the Middle Subbasin were by the CDFG and others between 1965 and 1995. The tributary surveys conducted in the mid 1960s to late 1970s indicated various degrees of channel disturbance from logging activities, but often noted the presence of abundant numbers of juvenile salmonids. Coyote, Panther, Garrett, Mill, and Molasses creeks were surveyed by CDFG from 1975-1977. These assessments used standard survey rating forms along with written summaries to describe both key aquatic habitat components and the status of fishery resources. A summary table of past surveys is presented in Appendix D.

In 1966, Redwood Creek, Minor Creek, and Lacks Creek were surveyed by CDFG to determine the extent of damage associated with past logging impacts (Fisk et al 1966). The 1966 survey documents the affects of the December 1964 flood on Redwood Creek. In 1966, Redwood Creek was considered “severely damaged” as pools were almost non-existent, there were large deposits of silt, sand and gravel, and a near total loss of shelter for fish, making the river channel largely unsuitable as a nursery for young salmon and steelhead (Fisk et al 1966). The lower reach of Minor Creek was considered “moderately damaged” by accumulations of “logging debris and flood damage” (Fisk et al. 1966). Minor Creek had considerable accumulations of silt, a loss of pools, and loss of streamside canopy, and instream shelter was lacking (Fisk et al. 1966). Lacks Creek was considered “lightly damaged,” showing partial decline of habitat quality due to loss of shelter, increased siltation, loss of pools and canopy. However, fingerling salmonids were observed in high abundance in Minor Creek and in moderate to high abundance in Lacks Creek.

The middle reach of Redwood Creek experienced drastic changes in size, frequency, and distribution of pool, riffle, and run habitats after the flood of December 1964 (peak discharge estimated at 50,500 cfs at Orick, a 50-year flood). The flood occurred during the era when much of the Redwood Creek basin had recently experienced and was undergoing unregulated timber harvests. Those timber harvest activities contribute to destabilization of the land and faster runoff rates causing severe erosion and severe damage to Redwood Creek including channel widening and filling of most pools with sediments (Taft 1933, Fisk et al. 1966, Janda et al. 1975, and Wahrhaftig 1976). An earlier 50-year flood occurred in 1955, but much less stream damage was noted by CDFG personnel than was noted in 1965 (Van Kirk 1994) and there was much less land disturbance at that time.

The years of 1972 and 1975 each had floods with peak discharge of approximately 50,000 cfs. Following the 1975 flood and associated landsliding, the channel bed of Redwood Creek was almost flat and featureless in many reaches, as a pulse of new sediment entered the system. From 1976 to 1996, stream flows never exceeded a five-year reoccurrence interval in Redwood Creek, sediment inputs declined, and the channel began to organize into discrete bedforms (Madej 1999; 2001). Channel cross-section monitoring studies conducted by RNSP scientists between 1977 and 1996 showed an increase in depth and frequency of pools and a general decrease in bed elevations, as sediments were transported downstream (Madej and Ozaki 1996, Madej 1999). However in 1997, a winter storm brought heavy precipitation, a peak discharge of over 40,000 cfs (a 12-year flood). The rains initiated landsliding which delivered large inputs of sediment to the streams. This was the first aggradation, decrease in water depth, and loss of bed variability measured in Redwood Creek since channel cross section monitoring began in 1977 (Madej 2001).

A CDFG stream survey of the lower reach of Panther Creek in 1975 found good habitat conditions with a high abundance of fingerlings, including many coho salmon (CDFG 1975). Stream habitat was composed of many small pools up to six feet in depth, abundant shelter provided by fallen logs and boulders, good spawning gravels, and good streamside canopy. Surveys found that Stover Creek ran through a culvert under Redwood Creek Road 10 feet upstream from its confluence with Redwood Creek. The stream drops 20 feet from the culvert, forming an impassable barrier to anadromous fish (CDFG 1975). This culvert is still creates a barrier to fish passage. The culvert has not been addressed because of the high repair costs compared to the amount of useable stream habitat available upstream (S. Downie CDFG personal communication).

In 1995, stream surveys of Lacks, Minor, Mill, Molasses, Toss Up, Roaring Gulch, Stover and Redwood creeks were conducted by Pacific Coast Fish, Wildlife and Wetlands Restoration Association (PCFWWRA) using CDFG stream current survey protocols described in Flosi (1998). These surveys provide data that is comparable to surveys conducted in 2001 (for this assessment) and can help determine short term trends in key habitat conditions. Results from the 1995 surveys show development of some favorable fish habitat in terms of pool riffle and run relationships in tributary streams.

Comparisons of primary habitat components in Lacks Creek between the 1995 and 2001 surveys are provided below (Figure IV- 40, Figure IV- 41). A general reduction of deep pool habitat occurred along survey reaches as shown in a comparison of 1995 and 2001 for the Middle Subbasin tributaries (Figure IV- 42). Sediment inputs and associated erosion that occurred in the flood of 1997 are responsible for these changes (Madej 2001). Further discussion and graphic presentations of the 1995 and 2001 stream survey data and summaries of all past stream survey reports are presented in Appendix D.

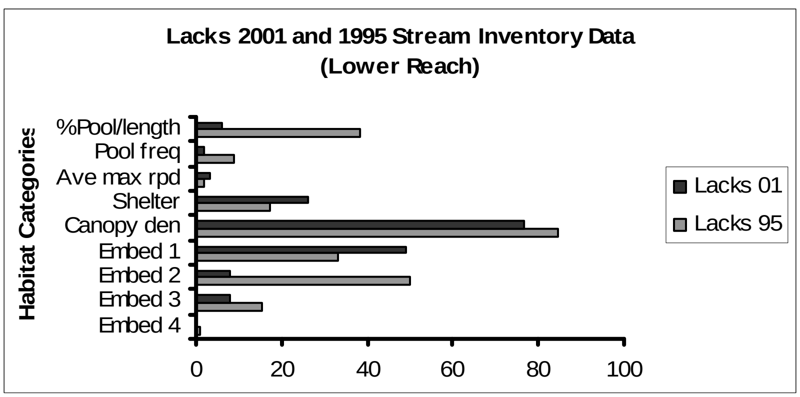

Figure IV- 40. Comparison of habitat conditions in lower Lacks Creek 1995 and 2001.

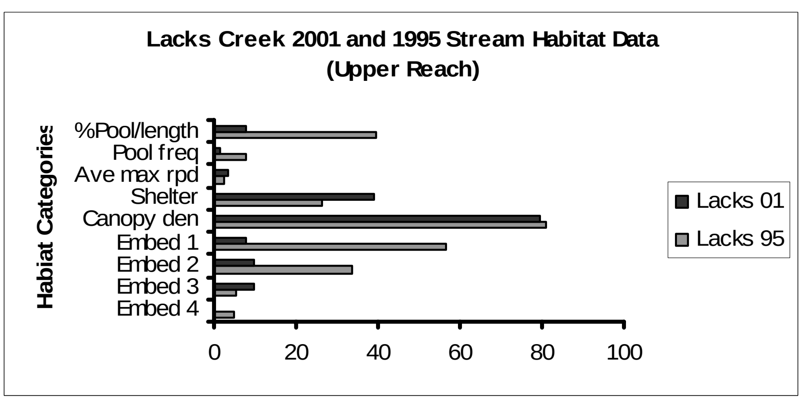

Figure IV- 41. Comparison of habitat conditions in upper Lacks Creek 1995 and 2001.

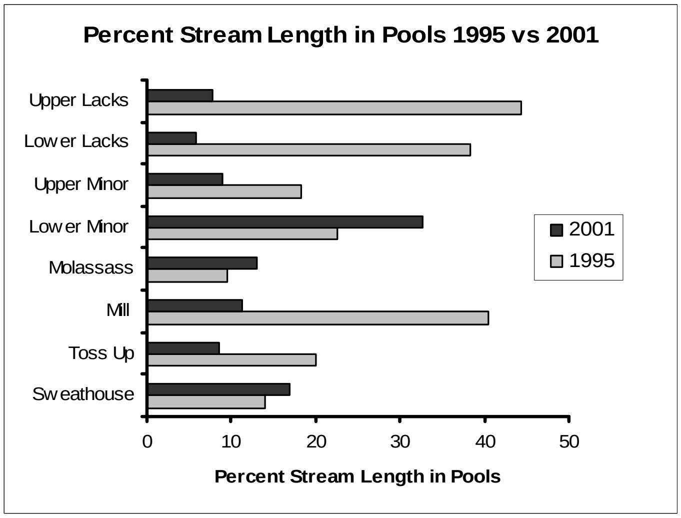

Figure IV- 42. Comparison of amount of pool habitat for survey years 1995 and 2001 in tributary streams.

Stream Surveys 2001

In 2001, CDFG crews surveyed approximately 25 miles of mainstem Redwood Creek and 19 miles of tributary habitat in the Middle Subbasin (Figure IV- 43). The 2001 survey data were collected using protocols presented in Flosi et al (1998). For analysis purposes, Redwood Creek was divided into 5 reaches, each approximately 5 miles in length. Abbreviated report summaries generated from stream surveys are provided in Appendix D.

Results from stream surveys are summarized below. This section begins with a comparison of general channel features between the 1995 and 2001 survey results.

Pool:Riffle:Run

Significance: Productive anadromous streams are generally composed of a balance of pool:riffle:run habitat, each plays an important role as salmonid habitat. These channel features are influenced by slope, channel bed and bank materials, sinuosity, discharge, flow obstructions such as LWD and boulders, and disturbance from episodic events such as major floods and large sediment inputs (Leopold 1994 and Madej 1999).

In 1995, Lacks, Mill and Toss Up creeks were comprised of approximately 40% pools by occurrence and length (Table IV- 71). Only 811 feet of Stover Creek was surveyed because a culvert forms a barrier to anadromy limits upstream passage of salmonids.

Table IV- 71. Middle Subbasin percent by occurrence and length of pool, run, riffle, and dry habitats in anadromous fish reaches summer 1995.

Stream	Survey Length (ft.)	Pool:Riffle:Flatwater % Occurrence (1)	Pool:Riffle:Flatwater % Total Length (1)	Dry % Total Length	Culvert % Total Length
Lacks Creek 95	15,147	43 : 15 : 41	41 : 9 : 49		
Mill Creek 95	2,468	45 : 20 : 35	40 : 14 : 46		
Minor Creek 95	14,046	25 : 31 : 45	21 : 26 53		
Molasses Creek 95	2,806	18 : 36 : 46	10 : 36 : 54		
Stover Creek 95	811	38 : 22 : 28	32 : 17 : 34	8	9 *
Toss Up Creek 95	2,922	39 : 34 : 27	39 : 34 : 27		

[1] Includes side channel and secondary channel habitats
*Culvert barrier to fish passage

A comparison of tributary stream surveys from 1995 and 2001 shows a general reduction of pool percent occurrence, percent pool length, and an increase riffle habitat in Lacks, Mill and Toss Up creeks in 2001(Table IV- 71 and Table IV- 72). It appears that 1997 winter storm and associated upslope erosion and sediment inputs reduced the amount of pool habitat in these streams. The number of pools declined, but the percent length of stream in pool habitat shows a greater decline.

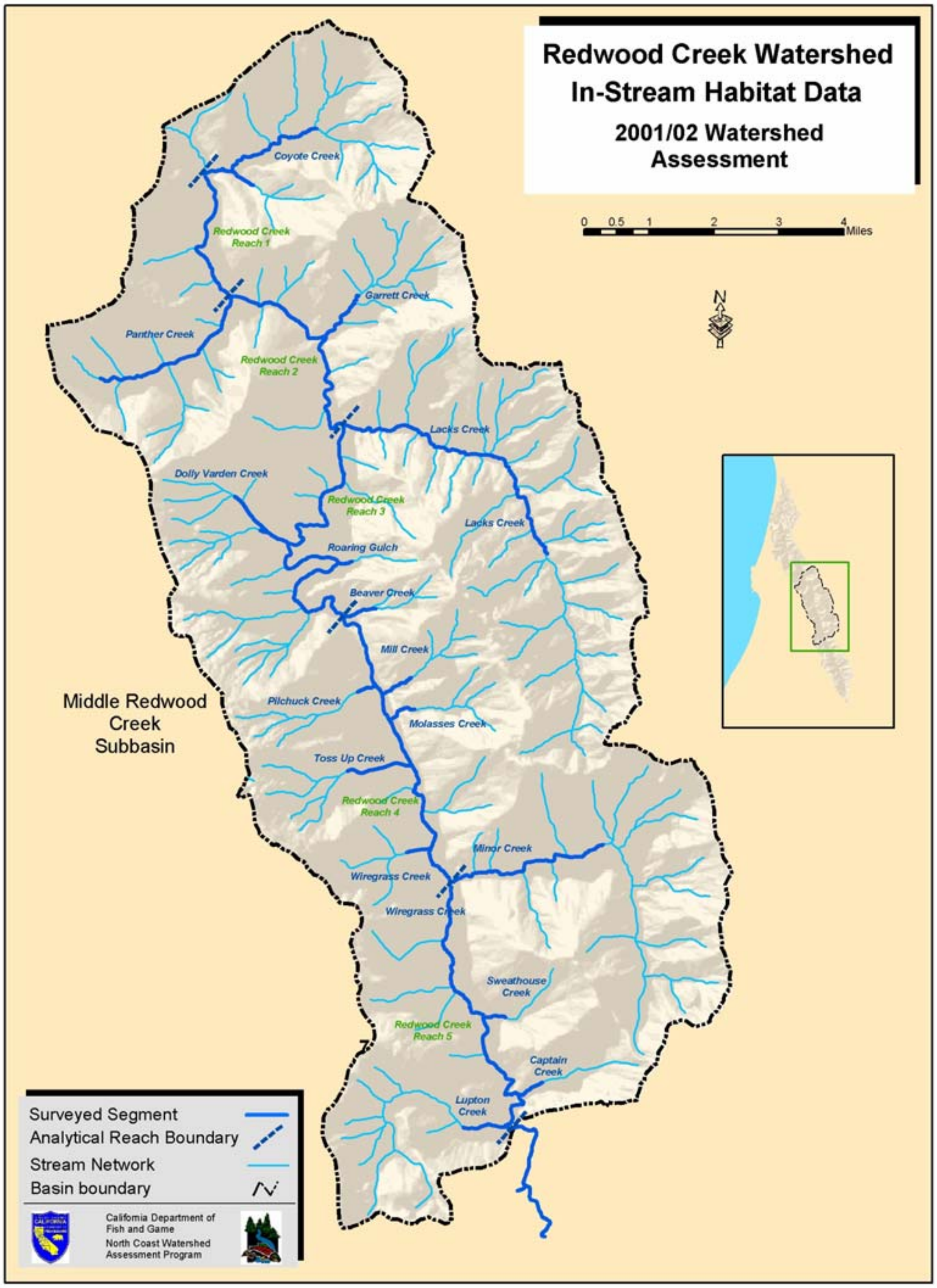

Figure IV- 43. 2001 Middle Subbasin habitat survey reaches are shown in dark blue.
The five mainstem reach boundaries are delineated by dotted lines.

In 2001, Panther and Garrett creeks and an unnamed tributary to Coyote Creek had at least 30% of the survey reach length of pools. In general, the other tributary streams lack pool habitat. A general pattern observed is the pool percent occurrence is generally higher than pool percent of total reach length, indicating that under present conditions, pools on average are shorter in length than runs and riffle habitats. In 2001, the middle mainstem of Redwood Creek averaged 52% by length in pool habitat, with the five reaches ranging from 27 to 66% pools by reach length.

Table IV- 72. Middle Subbasin percent by occurrence and length of pool, run, riffle, and dry habitats in anadromous fish reaches summer 2001.

Stream	Survey Length (ft.)	Pool:Riffle:Flatwater % Occurrence (1)	Pool:Riffle:Flatwater % Total Length (1)	Dry % Total Length	Culvert % Total Length
Beaver Creek	2,731	32 : 38 : 28	11 : 44 : 43		2*
Captain Creek	2,360	25 : 40 : 35	10 : 60 : 31		
Coyote Creek	11,282	37 : 33 : 28	26 : 33 : 37	5	
Coyote Ck. Trib 1	2106	48 : 35 : 17	36 : 44 : 20		
Dolly Varden Creek	5,968	44 : 27 :28	27 : 24 : 46	1	
Garrett Creek	4,779	46 : 22 : 30	31 : 21 : 46	1	
Lacks Creek	24,262	15 : 52 : 33	8 : 63 : 29		
Lupton Creek	3,832	42 : 38 : 16	42 : 25 : 18	2	13*
Mill Creek	2,788	34 : 30 : 36	11 : 34 : 54		
Minor Creek	14,418	28 : 39 : 33	17 : 44 : 38		
Molasses Creek	2,556	31 : 33 : 36	13 : 24 : 62		
Panther Creek	14,504	46 : 35 : 17	33 : 37 : 28	1	**
Pilchuck Creek	1,617	29 : 49 : 22	18 : 52 : 30		
Sweathouse Creek	1611	25 : 41 : 31	14 : 8 : 56	22	
Toss up Creek	5,462	30 : 43 : 27	23 : 48 : 29		
Wiregrass Creek	2,000	43 : 17 : 40	13 : 15 : 71		
Redwood Creek 1 (1)	12,202	37 : 26 : 37	27 : 16: 57		
Redwood Creek 2 (1)	20,886	46 : 21 : 34	38 : 15 : 48		
Redwood Creek 3 (1)	35,904	63 : 10 : 27	56 : 6 : 38		
Redwood Creek 4 (1)	34,110	55 : 17 : 29	47 : 12 : 41		
Redwood Creek 5 (1)	41,377	68 : 15 : 17	66 : 15 : 19		
Redwood Creek Total	130,874	59 : 16 : 25	52 : 12 : 36		

[1] Includes side channel and secondary channel habitats
* Culverts impede or are fish passage barriers
** Culvert replaced with bridge Sept. 2001

Pool Characteristics

***Significance*:** Pool depth, pool area, pool frequency, and pool shelter complexity are fundamental attributes of channel morphology and are largely dependent on stream gradient, discharge, the presence of instream large woody debris (LWD) or boulders, channel width, and channel type. Moderately deep pools that provide shelter are often preferred rearing habitat for juvenile salmonids and are necessary holding and resting habitat for adult salmonids during spawning migrations. Streams of the Middle Subbasin have a high degree of variation in pool characteristics, but overall, pool quantity and quality (depth and shelter complexity) could improve with addition of LWD and pool enhancement structures to meet desirable conditions for anadromous salmonid production.

Pool Depth

***Significance*:** Deep pools are important as year round rearing habitat for coho salmon and coastal cutthroat trout and holding habitat for all adult salmonids during spawning migrations. Flosi et al. (1998) suggest that pool enhancement projects should be considered when pools with maximum depths of 2 feet (for 1st and 2nd order streams) or 3 feet (for 3rd order streams) comprise less than 40% of the length of total stream habitat. A shortage of deep pools may indicate a disruption to channel forming processes which may be caused by a lack of LWD and/or elevated levels of stored sediments.

Results from stream surveys conducted in 2001 show that most tributary streams lack adequate deep pool habitat. The pools of tributary streams were generally shallow except for a few pools in reaches of Coyote Creek, Lacks Creek, and Minor Creek (Figure IV- 44). Lupton Creek has a few long and deep pools in the lower reach which account for 10% of the total survey length. Lacks Creek has few pools, but these pools are relatively deep compared to other tributary streams of the subbasin (Figure IV- 45). Redwood Creek shows mixed results for pool depths. Reaches 2 and 3 contained deep pools while reaches 1 and 5 provided few deep pools. Overall, in the middle reach of Redwood Creek, the mean maximum residual pool depth was 4.0 feet with 55% of pools having maximum residual pools depths of four feet or less shows the distribution of residual pool depths in the middle reach of Redwood Creek.

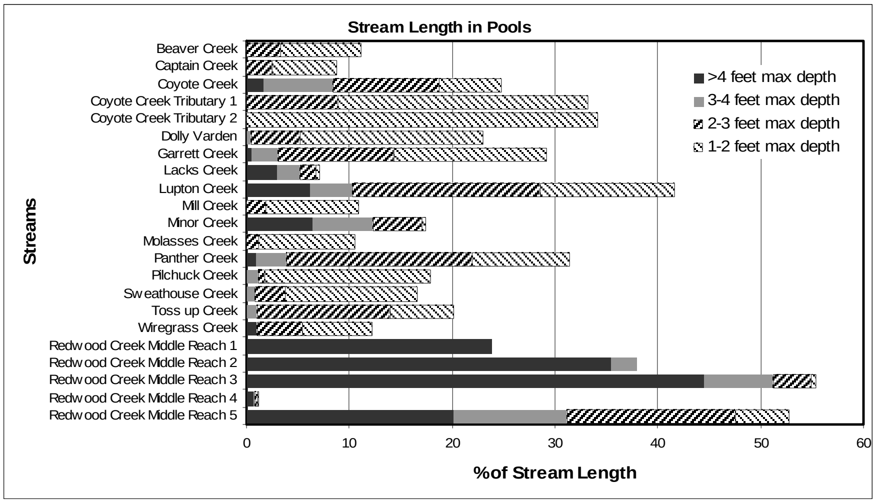

Figure IV- 44. Middle Subbasin percent stream lengths at various pool depths surveyed, 2001.

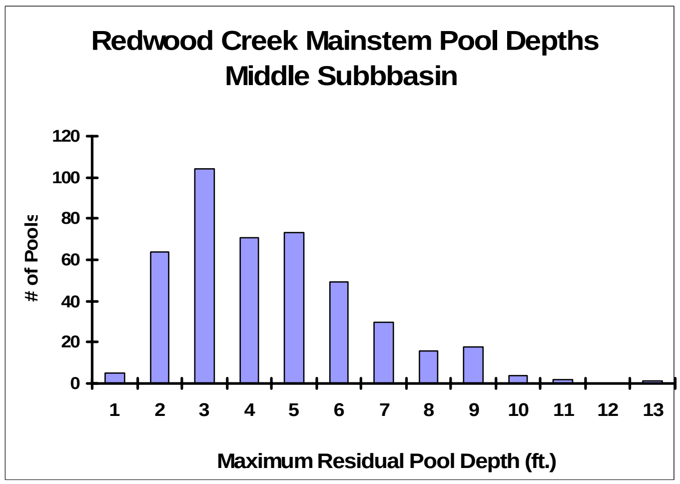

Figure IV- 45. 2001 Middle Subbasin mainstem Redwood Creek maximum residual pool depths.

Pool Frequency

Significance: Pool frequency is measured as a ratio of the number of bank full widths (BFW) per pool in a stream reach. Using this metric, pool to pool spacing in many redwood forest streams ranges from approximately 2 to 7 BFWs and is often controlled by LWD (Keller and MacDonald 1981). In straight and meandering streams, pools are often spaced more or less regularly at a repeating distance of 5 to 7 BFWs (Leopold 1994). This pool frequency metric may be confounded by BFWs that have increased from excessive bank erosion or by inaccurate BFW measurements. Bank full width measurements were only measured at pool-tail-crests during CDFG stream surveys which may underestimate the actual average bank full channel width.

Most tributary streams in the Middle Subbasin fit the general pool frequency range of one pool for every two to seven BFWs (Table IV- 73). Six stream reaches were well outside the desirable frequency range indicating a low number of pools, most notably Lacks, Beaver, Mill and Molasses creeks. Pool frequency was not estimated for Redwood Creek, because there were not sufficient BFW measurements collected to develop the ratio.

Table IV- 73. Stream order, pool frequency, and mean residual pool depths in Middle Subbasin tributaries.

Stream	Stream Order	Reach Length (ft.)	Estimated Bank Full Width (ft.)	Pool Count	BFW: Pool ratio	Mean Residual Max Pool Depth (ft.)
Coyote trib	1	2106	21	26	4 : 1	1.5
Panther Creek	1	5413	18.8	77	4 : 1	1.4
Mill Creek	1	2788	17	34	5 : 1	1.2
Pilchuck Creek	1	1617	26	13	5 : 1	1.4
Molasses Creek	1	2556	18.2	11	13 : 1	1
Toss Up Creek	1	3555	21.6	32	5 : 1	1.7
Wiregrass Creek	1	2000	24.9	19	4 : 1	1.4
Sweathouse Creek	1	1859	28	8	8 : 1	1.9
Captain Creek	1	2360	30.8	10	8 : 1	1.6
Lupton Creek	1	3832	32.2	19	6 : 1	1.6
Coyote Creek	2	2013	44.5	18	3 : 1	2.4
Garret Creek	2	4779	37.3	58	2 : 1	1.8
Panther Creek	2	9176	28.3	52	6 : 1	2
Lacks Creek	2	12982	38	20	17 : 1	3
Dolly Varden Creek	2	5833	23	77	3 : 1	1.3
Beaver Creek	2	2608	11.8	19	12 : 1	1.3
Toss Up Creek	2	1907	29.2	38	2 : 1	1.6
Minor Creek	2	14418	42.3	34	10 : 1	2.8
Coyote Creek	3	9269	40.5	58	4 : 1	2
Lacks Creek	3	11280	47.4	20	12 : 1	3.1
Redwood Creek	4	126720	na	437	na	3.7

Data collected during CDFG stream surveys, 2001.

Pool Shelter Complexity

***Significance*:** The pool shelter rating is a relative measure of the quantity and composition of LWD, root wads, boulders, undercut banks, bubble curtain, and submersed or overhanging vegetation. These elements serve as instream habitat, create areas of diverse velocity, provide protection from predation, and separation of territorial units to reduce density related competition. The rating does not consider factors related to changes in discharge, such as water depth. A pool shelter rating of approximately 100 is desirable (Flosi et al. 1998).

Pool shelter ratings were generally below desirable targets for all tributaries and Redwood Creek (Figure IV-46). The low pool shelter ratings indicate the lack of LWD, undercut banks, and other shelter elements in fish bearing streams of the Middle Subbasin.

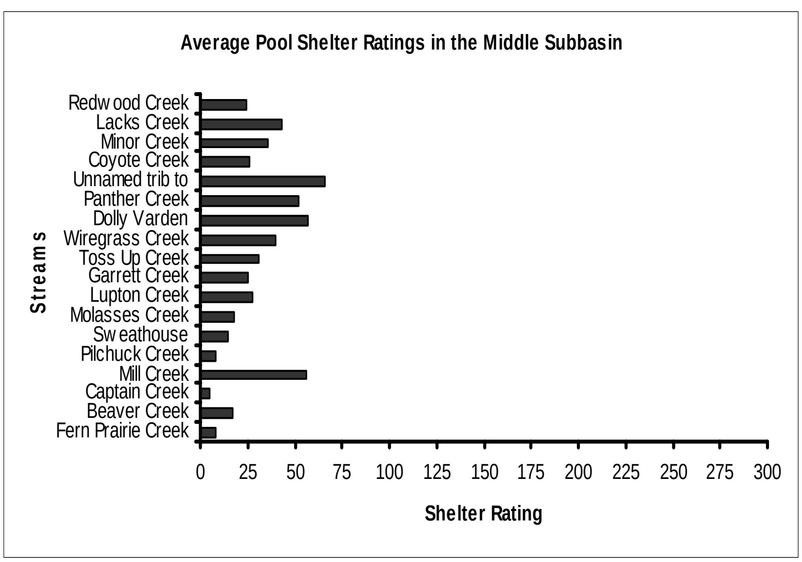

Figure IV- 46. Middle Subbasin average pool shelter ratings from 2001 CDFG Stream Surveys.

Average pool shelter ratings of 100 are considered desirable.

Pool Shelter Composition

Boulders are the dominant shelter elements in the tributaries and mainstem of Redwood Creek and woody debris is the subdominant element (Table IV- 74). Boulders ranked highest in 14 of the 17 tributaries and highest in all of the mainstem reaches. Woody debris was consistently the next most common shelter type, ranking either second or first in all but two tributaries and one mainstem reach. However, few pools formed by the presence of wood were noted in the 2001 stream surveys. In forested streams of the North Coast, it would be expected that large woody debris would contribute to forming many pools and be a more dominant cover element than boulders. Taken together, the lack of pools formed by wood, the dominance by boulders and the general unsuitability of shelter ratings indicate a lack of large woody debris within many Middle Subbasin stream channels.

Table IV- 74. Middle Subbasin summary of shelter composition.

Streams	Undercut Banks	Woody Debris	Terrestrial Vegetation	Aquatic Vegetation	White-water	Boulders	Bedrock Ledges
Beaver Ck	2					1	
Captain Ck		2				1	
Coyote Ck		2				1	
Trib. to Coyote Ck		1				2	
Dolly Varden Ck		1				2	
Fern Prairie Ck		2				1	
Garrett Ck		2				1	
Lacks Ck		2				1	
Lupton Ck		2				1	
Mill Ck		2				1	
Minor Ck		2				1	
Molasses Ck		2				1	
Panther Ck		2				1	
Pilchuck Ck		1				2	
Sweathouse Ck	2					1	
Toss Up Ck		2				1	
Wiregrass Ck		2				1	
Mainstem Redwood Ck							
Reach 1		2				1	
Reach 2		2				1	
Reach 3	2					1	
Reach 4		2				1	
Reach 5						1	2

Dominant (1) and Subdominant (2) shelter types in pool and flatwater units in the Middle Subbasin. See figures located in Appendix D for details.

Spawning Cobble Embeddedness

***Significance*:** Measures of percent cobble embeddedness helps determine suitability of substrate for spawning, egg incubation, and fry emergence. Cobble embeddedness of 25% or less is considered high quality spawning habitat (Flosi et al. 1998). An excessive accumulation of fine sediments causes high cobble embeddedness which also reduces water flow (permeability) through gravels in redds which may suffocate eggs or developing embryos. Excessive levels of fine sediment accumulations over gravel and cobble substrate also may alter insect species composition and food availability for growing fish. High embeddedness ratings may indicate elevated levels of erosion occurring somewhere in the watershed.

Embeddedness ratings showed mixed results for both tributaries and mainstem Redwood Creek. The most high quality spawning substrate was observed in reaches of Molasses, Minor, upper Lacks, and Coyote creeks (Figure IV- 47). The highest level of embeddedness was observed in Toss up, Panther, Lupton, Sweathouse Creeks, and mainstem Redwood Creek. Lacks, Pilchuck, and Captain Creek and others had pool tails rated as unspawnable because the dominate substrate was predominantly composed of boulders or sometimes silt. In some cases the spawning substrate at pool tails was in good condition, but these sites were few in number due to the lack of pools in the survey reach.

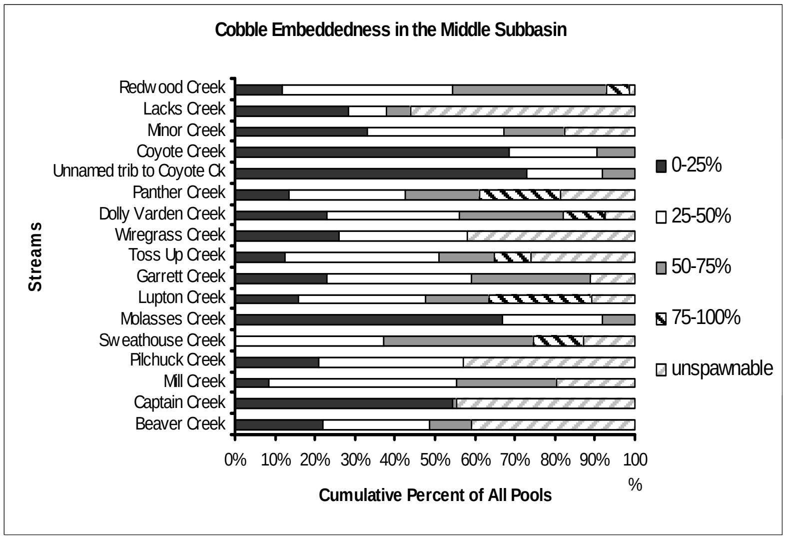

Figure IV- 47. Percent cobble embeddedness in Middle Subbasin streams.

Cobble embeddedness of 0-25% is considered high quality salmonid spawning substrate. The unspawnable category includes pool tails composed of bedrock or silt or contain boulders or logs that prohibit spawning.

Streamside Canopy Density

Significance: Streamside canopy density is a measure of the percentage of wetted stream that is influenced by nearstream forest canopy. Tree canopy provides shade to reduce direct sun light from warming water, provides a source of nutrients in the form of terrestrial insects, organic debris, and leaf litter, and contributes to LWD recruitment. The roots of riparian vegetation also help maintain soil and stream bank stability. The riparian trees providing streamside canopy in the subbasin are typically composed of mixed hardwood and coniferous tree species. Generally, riparian management projects are considered when canopy density is less than 80% (Flosi et al. 1998).

The average canopy density over the mainstem Redwood Creek of the Middle Subbasin was approximately 40% (Figure IV- 48). The wide channel of the mainstem and historical harvest of streamside conifers (Urner and Madej 1998) impair riparian and nearstream forest canopy from providing shade on large areas of mainstem Redwood Creek. Lack of shade over the water contributes to high water temperature.

The average canopy densities along most tributary streams provide sufficient shade to moderate the heating effects from direct sunlight on stream water. Portions of Lacks, Captain and Coyote creeks show the lowest amount of canopy cover. A closer review of the data shows that the great majority of the shade canopy was formed by deciduous trees (Figure IV- 48). The small fraction of conifer tress providing shade is considerably less than desirable considering these are coniferous forest streams. The lack of large sized conifers impairs processes such as LWD loading potential and moderating air temperature along most Middle Subbasin tributary streams and along the mainstem of Redwood Creek.

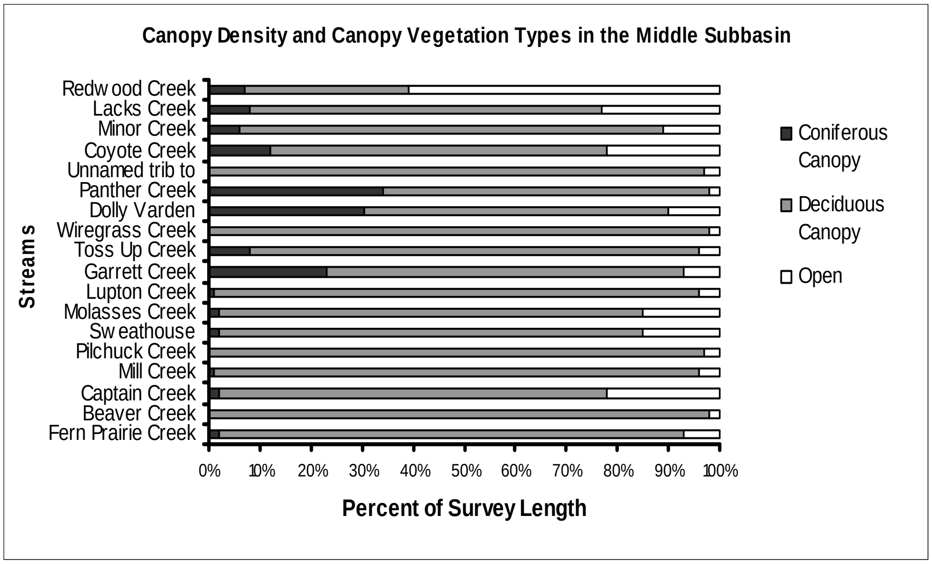

Figure IV- 48. Middle Subbasin percent canopy density and percent vegetation type contributing to stream shade cover.

Barriers to Fish Passage

Culverts that impede fish passage were noted on Beaver, Lupton, Stover, and Panther creeks. Large debris accumulations (LDA) and a sediment delta that impede fish passage were found on Panther Creek. The culvert on Panther Creek was replaced with a bridge in September, 2001 and the LDAs were modified to accommodate fish passage in 2003-04. However, fish passage through the mouth and lowermost reach of Panther Creek is impaired by an accumulation of small boulders or a perched delta (Figure IV- 49). The stream flow is spread across the channel and through spaces between the boulders making adult fish passage near impossible during low to moderate stream flows. The delta is perched to a height several feet above the mainstem channel and is accessible to spawners only during the highest mainstem and tributary stream flows which generally occur after the peak of coho and Chinook spawning runs. For this reason Chinook and coho are only likely to gain access to Panther Creek for spawning in years with early rains of sufficient intensity to raise mainstem Redwood Creek and create sufficient surface flow in Panther Creek to provide upstream passage. Redwood Creek is unusually wide at this location so it is difficult for the water surface elevation to rise significantly. These features are typically not noted using present CDFG stream survey protocols. The perched deltas and associated passage problems may be found on other streams of the Middle Subbasin.

Figure IV- 49. Example of perched delta at mouth of Panther Creek, summer 2004.
Stream is flowing under boulder accumulations. The delta accumulations impede fish passage into Panther Creek during upstream spawning migrations at all but the highest flows. Juvenile coho salmon were noted as numerous in 1975 in Panther Creek. Coho were not detected here in 2001. The perched deltas and associated passage problems may be found on other streams of the Middle Subbasin.

Salmonid Fishery Resources

Coho Salmon

A review of past and present spawner and redd counts and surveys for juvenile salmonids concludes that coho salmon have declined in abundance and distribution in the Middle Subbasin. Coho populations of the Middle Subbasin have been adversely impacted by multiple factors. Droughts of 1976-78 and 1988-1993, barriers, aggraded channels, and associated loss of habitat diversity and complexity have all contributed to a decline in coho numbers and distribution.

In the 1970s and 1980s, juvenile coho were observed during surveys of Coyote, Panther, Dolly Varden (Karen), Pilchuck, Lacks, Minor and Redwood creeks in (CDFG 1975, Brown 1988;). Spawning surveys conducted in 1986-87 reported several adult coho in Redwood Creek in the Redwood Valley area (Personal communications, Mitch Farro 2002). In the mid 1990’s juvenile coho salmon were observed during snorkel surveys in cool water patches found in Redwood Creek at the confluences with Minor and Lacks creeks and in the impoundment behind the Chezem dam (Weseloh 1994; 1995; 1996;). Juvenile Coho were also observed in 1995 stream surveys in Minor Creek (PCFWWRA 1995). However, juvenile coho were not observed from any Middle Subbasin streams during 2001 electrofishing surveys designed to detect coho presence. Two adult coho were observed in Redwood Creek just above the confluence with Toss Up Creek during a spawning survey in 2000 (PCFWWRA 2001). However, juvenile coho were not observed during the four years of downstream trapping (1999-2003) studies on mainstem Redwood Creek (near Toss Up Creek) (Sparkman 2003).

Chinook Salmon

Chinook salmon typically use the middle reach of Redwood Creek, and the lower reaches of Lacks and Minor creeks for spawning. These are some of the best spawning areas for Chinook salmon in the Redwood Creek Basin (USFWS 1960 and M. Farro, PCFWWRA, written communications, 2002).

The peak migration period out of the Middle Subbasin for Chinook juveniles is generally from Mid April to early May (Sparkman 2000; 2001; 2002; 2003, 2004). Juvenile Chinook arrive in the estuary soon after leaving the Middle Subbasin at size of (50-60 mm FL). Water temperatures in the middle reach of Redwood Creek are generally too warm to support salmonids over the summer months. However, juvenile Chinook were observed rearing in lower Lacks Creek (August 2002) (B. Reisberger, IFWM, personal communications) where temperatures are cooler than the mainstem.

Spawner surveys conducted in the 2001-2002 season along an approximately 10 mile reach of Redwood Creek mainstem (between Lacks and Toss Up creeks) yielded 113 Chinook redds or 11.3 redds per mile. A total of 265 live Chinook, 83 Chinook carcasses, were also observed in this reach (M. Farro 2002 written communications). More information on spawner surveys is presented in the general discussion of Chinook salmon in the Fishery Resources of section III of this report.

Beginning in 2000 a rotary screw trap was operated on mainstem Redwood Creek just upstream of Toss Up Creek. The trapping efforts provided a basis for estimating numbers of juvenile Chinook produced in the approximately the upper third of the Redwood Creek Basin, which includes the upper half of the Middle Subbasin. Population estimates ranged from 987 in 2003 to over 500,000 in 2002. The trapping results show inter-annual variation in Chinook spawning success in Redwood Creek (Sparkman 2000; 2001; 2002; 2003). Details of the trapping counts are presented in the general discussion of Chinook salmon in the Fishery Resources of section III of this report.

Steelhead

Steelhead is the most commonly observed salmonid species found in the anadromous reaches of the Middle Subbasin streams. They are found in the mainstem Redwood Creek and in 22 tributary streams of the Middle Subbasin. During electrofishing surveys in Middle Subbasin tributaries Coyote, Panther, Lacks, Minor and Toss Up creeks produced the highest numbers of steelhead YOY per unit effort (#fish / seconds e-fished) (Appendix D). The presence and abundance of YOY indicates successful spawning and hatching. Beaver Sweathouse and Wiregrass creeks produced the least number of YOY steelhead per unit of effort. Panther and Coyote creeks produced the highest numbers of age 1 and older steelhead. Beaver, Sweathouse, Pilchuck, and Dolly Varden creeks produced the lowest numbers of yearling and older steelhead. The presence and abundance of steelhead age 1 and older in a stream provide some insight into stream habitat suitability for different age classes. Thus streams supporting abundant numbers and all age classes may be viewed as good steelhead streams. Conversely, the presence of large numbers of sub-yearling steelhead, but very few age 1 and older fish may indicate a bottleneck or habitat factor that is limiting the advancement to older age classes.

Summer Steelhead

The summer steelhead is a unique stock of steelhead that migrates from the ocean into Redwood Creek from March through June, but do not spawn until the following rainy season. Summer steelhead depend upon deep, complex and cool pools of the Middle Subbasin for over summer habitat as they wait for the fall rains to complete the spawning run.

Counts of adult summer steelhead collected by RNSP 1981-2000 from dive surveys of Redwood Creek ranged from 3 fish in 2000 to 37 fish in 1997. The low counts of summer steelhead indicate that they are likely the most threatened by extirpation of all the anadromous stocks in the Redwood Creek Basin. In addition, it has been noted that the current numbers of adult spawners may be less than the minimum size needed to sustain a viable summer steelhead population (Meffe 1986 and Nehlsen 1991).

Primary reasons for the decline in summer steelhead numbers include the reduction of deep, complex pools, and cool water temperature needed for summer holding habitat, and perhaps competition for suitable juvenile rearing habitat. Most of the pool habitat loss occurred after the flood of December 1964 (Fisk et al 1966) and this condition persisted for many years. The summer steelhead population likely declined abruptly without the deep, sheltered, and cool pool habitat needed to sustain adults over the summer season.

Coastal Cutthroat

The full range of coastal cutthroat of the Middle Subbasin is not known. Coastal cutthroat have been observed in Redwood Creek during past surveys as well as Lacks, Coyote, and Panther creeks. However, Panther Creek produced the only positively identified coastal cutthroat from Middle Subbasin streams during 2001 electrofishing surveys in anadromous reaches. Young coastal cutthroat are very difficult to distinguish from young steelhead and resident rainbow trout. Their numbers may be underestimated, but older age classes become easier to separate from the steelhead or rainbow trout. Like coho, coastal cutthroat prefer cool water and a high amount of shelter complexity including LWD. The high water temperatures and lack of habitat complexity may preclude coastal cutthroat from residing in the middle reach of Redwood Creek.

Resident populations of coastal cutthroat are found above the anadromous reach of Panther Creek (B. Michaels personal communication 2002) and likely occur in other streams. Only 17 coastal cutthroats were captured during the three years of rotary screw trapping efforts on the mainstem Redwood Creek (Sparkman 2002). No large coastal cutthroats have been reported during recent summer steelhead dive surveys (Weseloh 1994, 1995, 1996).

Middle Subbasin General Issues

Salmonid populations have declined from historic levels, prompting listings under the state and federal ESAs:

- There is a decline in abundance and distribution of coho salmon and coastal cutthroat trout in the Middle Subbasin;
- Coho salmon were not observed in 2001 fish surveys;
- The summer steelhead population has declined to critically low levels of abundance;
- Chinook salmon show variable spawning success among years.

Impairments to freshwater habitat needed to complete salmonid freshwater life cycles have been identified as a leading factors in the decline of Redwood Creek's anadromous salmonids:

- Mixed conditions for salmonid spawning and rearing success exist in the subbasin;
- There is a lack of shade canopy along mainstem Redwood Creek;
- High summer water temperature along the mainstem Redwood Creek and lower reaches of Lacks and Minor creek impairs juvenile rearing habitat and adult holding habitat for summer steelhead;
- There is a lack of deep and complex pools in tributary streams and mainstem Redwood Creek;
- A lack of instream LWD impairs fish habitat;
- Stream habitat conditions in the Middle Subbasin can be improved.

The Middle Subbasin terrain is highly susceptible to erosion:

- High potential exists for large sediment inputs from disturbed and unstable hillslopes;
- High levels of sediment are stored in mainstem and some tributary channels;
- Historically active landslide features cover 4,200 acres (6.5%) of the subbasin. These features are critical sources of sediment inputs to stream channels.

Land management can influence watershed processes:

- Land use has made the Middle Subbasin's terrain more susceptible to erosion;

- High road density of both abandoned and useable roads adds to sediment delivery potential;
- Debris slides and debris flows are often initiated by management activities (such as road construction) that take place on existing earthflows or rockslides.

Riparian and near stream forests have been altered by timber harvests and bank erosion:

- Timber harvests have caused significant levels of disturbance to riparian and near stream forest areas causing a reduction in both overstory shade canopy and LWD input potential;
- In response to aggraded channels, stream banks erode, channels widen, and riparian vegetation becomes less affective to provide shade over the water;

The Chezem summer dam alters aquatic habitat during dam construction and decommissioning;

- Dam construction increases suspended sediment levels to downstream reaches;
- Mutes changes in diurnal water temperatures to downstream reaches;
- Inundates approximately one mile of stream habitat.

Integrated Analysis

Integrated Analysis and Cumulative Effects

The Middle Subbasin is located inland from the coastal fog belt so it has a warmer summer climate and cooler winter climate than the Prairie Creek and Lower subbasins. The warm and dry summer climate influences the distribution of both terrestrial and aquatic biota. Conifer forests are dominated by Douglas fir instead of redwoods and hardwood forests also become more expansive than within the coastal areas. The warmer climate also affects water temperatures. In mainstem Redwood Creek average water temperatures are above desirable levels for anadromous salmonids throughout the mainstem reach. Cool water is found in thermally stratified pools or near patches of cool water, which may be located at the confluence of tributaries. Cool water habitat, needed by salmonids during summer months is found in most tributaries.

Subbasin-wide, 6.5% or 4,166 acres of the area is comprised of historically active landslide features with earthflows as the predominant landslide feature type (Table IV- 75). Lower Lacks Creek Planning Watershed has the highest percentage of area (18%) in historically active landslide features followed by Coyote Creek (10.6%) and Minor Creek (8.3%) planning watersheds. These three planning watersheds are located on the east side of the Grogan Fault and their underlying bedrock is largely composed of the incoherent unit of Coyote Creek. This bedrock is highly erodible, contains active earthflows, and is very susceptible to land sliding. Ground disturbance adds to the tendency for landsliding on this unstable geology. Toss Up, Roaring Gulch, and Panther Creek planning watersheds have the lowest percentages of area (1.7, 3.0, and 3.1% respectively) in historically active landslide features in the Middle Subbasin. These planning watersheds are located mostly on the west side of the Grogan Fault. There, the underlying bedrock is composed of Redwood Creek schist. The schist is generally more stable than the bedrock of the eastern portion of the subbasin and most erosion in the form of debris slides on steep slopes.

Subbasin-wide, woodland and grassland underlain by historically active landslides accounts for 2.8% of the area or 1,802 acres. Lower Lacks Creek Planning Watershed has the highest percentage (12.5%) of its area in woodland and grassland on historically active landslides; Toss Up Creek has the lowest at 0.3%. Debris slides and debris flows cover 325 acres (0.5%) of the subbasin. These features are critical sources of sediment inputs to stream channels. Debris slides and debris flows are often initiated by management activities (such as road construction) on earthflows or rockslides. These features may be prevented by recognizing their potential for erosion and planning management activities to minimize or avoid decreasing slope stability.

Streamside landslides are often included in the debris slide or debris flow categories but also may be considered rock slides in Table IV- 75. The number of active stream side landslides recently increased by 18% (from 376 in 1984 to 442 in 2001) within the Middle Subbasin. The largest increase was observed in Lower Lacks Creek (+221%) and Panther Creek (+68%) planning watersheds. The winter storm of 1997 contributed to the increase in landslides. The largest decline in numbers of active stream side landslides was in Minor Creek (-91%) and Lupton Creek (-56%) planning watersheds.

Recent THPs on historically active landslide features comprise 1.3% of the subbasin, or 852 acres. The Panther Creek planning watershed had the lowest percentage (essentially zero) of its area in recent THPs on historically active landslide features. Minor Creek has the highest percentage (5.0%) of its area in recent THPs on historically active landslide features. Considering past timber activities, over half (44,400 acres) of the timber harvest in the Middle Subbasin occurred between 1950 and 1974, before modern harvest management rules were implemented. Another 26,600 acres were harvested between 1974 and 1991. Table IV-77 does not consider the relationships from these past harvest activities and these slides. The pre 1974 harvests generated more ground disturbance from road construction and skid trails than most re-entry harvests of recent years. Much of the recent harvest involved second and third entry silvicultural prescriptions (including hardwood removal) and used the existing road system. Second and third entry harvests do not usually have the same level of impacts as the initial entries.

Table IV- 75 broadens the view of potential slope instability and land use interactions by addressing relative landslide potential. Eighty percent of the subbasin falls into high and very high relative landslide potential classes. The bulk of this area is comprised of timberlands with no recent harvest (54%), followed by recent THPs (13.6%) and woodland or grassland (13%). Looking across the planning watersheds, Lower Lacks Creek has the greatest percentage (93.5%) of area in the highest two classes, followed by Upper Lacks Creek (90.7%), Minor Creek (90.4%), and Coyote Creek (87.4%). The planning watersheds with the smallest percentages of their area in the highest two relative landslide potential classes are Roaring Gulch (67.8%) and Lupton Creek (70.8%).

Table IV- 75. Acres and percent area of historically active landslide features associated with recent land use and vegetation type

Subbasin or Planning Watershed	**Historically Active Landslide Feature[1]**	**Entire Subbasin or Planning Watershed**		**Woodland and Grassland[2]**		**THPs 1991 - 2000[5]**		**Timberland, No Recent Harvest[3]**		**Roads[4]**	
		Area (acres)	**% Area**	**Area (acres)**	**% Area**	**Area (acres)**	**% Area**	**Area (acres)**	**% Area**	**Length (miles)**	**% Total Length**
Middle Redwood Creek Subbasin (64,082 acres) (716.1 road miles)	Earthflow	3,187	5.0	1,392	2.2	818	1.3	1,184	1.8	31.9	4.5
	Rock Slide	654	1.0	376	0.6	0	0.0	277	0.4	7.0	1.0
	Debris Slide	257	0.4	23	0.0	28	0.0	205	0.3	2.6	0.4
	Debris Flow	68	0.1	11	0.0	6	0.0	51	0.1	0.8	0.1
	All Features	**4,166**	**6.5**	**1,802**	**2.8**	**852**	**1.3**	**1,717**	**2.7**	**42.3**	**5.9**
Coyote Creek (7,678 acres) (79.6 road miles)	Earthflow	785	10.2	445	5.8		0.0	334	4.3	8.6	10.8
	Rock Slide	1	0.0	0	0.0		0.0	0	0.0	0.0	0.0
	Debris Slide	19	0.2	2	0.0		0.0	17	0.2	0.3	0.4
	Debris Flow	9	0.1	2	0.0		0.0	7	0.1	0.1	0.1
	All Features	**814**	**10.6**	**449**	**5.8**	**0**	**0.0**	**358**	**4.7**	**9.0**	**11.3**
Lower Lacks Creek (5,935 acres) (47.3 road miles)	Earthflow	572	9.6	359	6.0	40	0.7	173	2.9	3.8	8.0
	Rock Slide	448	7.5	376	6.3		0.0	72	1.2	4.2	8.8
	Debris Slide	31	0.5	7	0.1	2	0.0	23	0.4	0.1	0.2
	Debris Flow	11	0.2	1	0.0	2	0.0	8	0.1	0.1	0.1
	All Features	**1,062**	**17.9**	**742**	**12.5**	**43**	**0.7**	**276**	**4.7**	**8.1**	**17.2**
Lupton Creek (8,050 acres) (116.4 road miles)	Earthflow	406	5.0	112	1.4	154	1.9	139	1.7	3.5	3.0
	Rock Slide	133	1.7		0.0	0	0.0	132	1.6	1.8	1.5
	Debris Slide	29	0.4	0	0.0	4	0.0	24	0.3	0.5	0.4
	Debris Flow	1	0.0		0.0	0	0.0	1	0.0	0.0	0.0
	All Features	**569**	**7.1**	**112**	**1.4**	**158**	**2.0**	**297**	**3.7**	**5.8**	**4.9**
Minor Creek (9,959 acres) (122.2 road miles)	Earthflow	774	7.8	281	2.8	477	4.8	185	1.9	9.4	7.7
	Rock Slide	4	0.0		0.0		0.0	4	0.0		0.0
	Debris Slide	46	0.5	2	0.0	14	0.1	31	0.3	0.6	0.5
	Debris Flow	7	0.1		0.0	2	0.0	5	0.0	0.1	0.1
	All Features	**831**	**8.3**	**283**	**2.8**	**493**	**5.0**	**224**	**2.2**	**10.1**	**8.3**
Panther Creek (9,745 acres) (94.1 road miles)	Earthflow	261	2.7	83	0.9		0.0	177	1.8	2.4	2.5
	Rock Slide		0.0		0.0		0.0		0.0		0.0
	Debris Slide	33	0.3	6	0.1	0	0.0	24	0.2	0.2	0.2

Subbasin or Planning Watershed	Historically Active Landslide Feature[1]	Entire Subbasin or Planning Watershed		Woodland and Grassland[2]		THPs 1991 - 2000[5]		Timberland, No Recent Harvest[3]		Roads[4]	
		Area (acres)	% Area	Area (acres)	% Area	Area (acres)	% Area	Area (acres)	% Area	Length (miles)	% Total Length
	Debris Flow	9	0.1	1	0.0	1	0.0	8	0.1	0.1	0.1
	All Features	**302**	**3.1**	**90**	**0.9**	**1**	**0.0**	**208**	**2.1**	**2.7**	**2.8**
Roaring Gulch (8,906 acres) (108.0 road miles)	Earthflow	181	2.0	48	0.5	105	1.2	74	0.8	1.5	1.4
	Rock Slide	33	0.4		0.0		0.0	32	0.4	0.4	0.3
	Debris Slide	45	0.5	3	0.0	5	0.1	37	0.4	0.5	0.4
	Debris Flow	8	0.1	1	0.0		0.0	7	0.1	0.1	0.1
	All Features	**267**	**3.0**	**53**	**0.6**	**110**	**1.2**	**151**	**1.7**	**2.4**	**2.2**
Toss-up Creek (8,734acres) (94 road miles)	Earthflow	118	1.4	20	0.2	37	0.4	62	0.7	1.6	1.7
	Rock Slide		0.0		0.0		0.0		0.0		0.0
	Debris Slide	16	0.2	1	0.0	1	0.0	14	0.2	0.2	0.2
	Debris Flow	19	0.2	6	0.1		0.0	12	0.1	0.2	0.2
	All Features	**153**	**1.7**	**27**	**0.3**	**38**	**0.4**	**88**	**1.0**	**2.0**	**2.1**
Upper Lacks Creek (5,076 acres) (54.4 road miles)	Earthflow	89	1.8	45	0.9	5	0.1	40	0.8	1.3	2.3
	Rock Slide	36	0.7		0.0		0.0	36	0.7	0.7	1.3
	Debris Slide	38	0.7	0	0.0	2	0.0	36	0.7	0.3	0.5
	Debris Flow	4	0.1	0	0.0	1	0.0	3	0.1	0.1	0.1
	All Features	**168**	**3.3**	**45**	**0.9**	**8**	**0.2**	**114**	**2.3**	**2.3**	**4.2**

[1] Refer to Plate 1 and California Geological Survey appendix. Areas of disrupted ground are not included as active landslide features in this analysis. These areas are likely underlain by earthflow or rockslide complexes. If so, this would substantially increase the miles of roads and area of land type and land use on active landslide features.
[2] Woodland and grassland includes areas mapped in 1998 as grassland and non-productive hardwood.
[3] Area of timberlands that were not contained in a THP during the 1991 to 2000 period.
[4] Roads layer is from the Information Center for the Environment (ICE) at UC Davis.
[5] THPs are complete or active between the 1991 and 2000 timeframe.
Empty cells denote zero.
Percent of area is based on the unit of analysis: subbasin or planning watershed.

Recent THPs (1991-2000) on the higher relative landslide potential classes comprise 13.6% of the Middle Subbasin area (Table IV- 76). On a planning watershed basis, the Coyote Creek Planning Watershed had no THPs on these lands. The Minor Creek planning watershed had 30.5% of its area in THPs on the high and very high relative landslide potential classes during the 1991-2000 decade. This relatively high rate of harvest on areas of high relative landslide potential is a cause for concern and further investigation, though keeping in mind the mitigation measures built into the THP process for addressing such concerns and the type of harvest. The discussion above regarding THPs on historically active landslide feature raised a similar concern. Lupton Creek planning watershed also had a relatively high level (18.2%) of timber harvest on areas of high and very high relative landslide potential. Lower Lacks Creek (5.6%) and Panther Creek (8.5%) had relatively low levels of recent harvests on the highest two classes of relative landslide potential, but yielded the highest increase in recent landslide activity.

Roads on areas of higher relative landslide potential also merit exploration as potential risk factors for slope instability and sediment generation. At the subbasin level, 74.4% (524 miles) of the road length is on areas of high or very high relative landslide potential (Table IV- 76). This appears to indicate a fairly high potential for road failure due to slope instability. Looking across the planning watersheds, the highest percentage of road length on the highest two classes of relative landslide potential are on Lower Lacks Creek (89.0% or 42.1 miles), Minor Creek (88.2% or 108.0 miles), and Upper Lacks Creek (86.0% or 46.8 miles). Roaring Gulch Creek planning watershed has the lowest percentage of roads on the highest two classes of relative landslide potential (60.9% or 65.8 miles). The roads located on the high landslide potential area may be priority candidates for road improvement projects.

Table IV- 77 presents an integrated information summary for the Middle Subbasin. It provides the reader the opportunity to compare a large number of factors across the watershed and subbasins and, for some of the subbasins, to look at potential interactions between disturbance factors and watershed condition.

Table IV- 76. Middle Subbasin acres and percent of area by relative landslide potential and land use or type classes.

Subbasin or Planning Watershed	Relative Landslide Potential[1]	Entire Subbasin or Planning Watershed		Woodland or Grassland[2]		THPs 1991 – 2000[4]		Timberland, No Recent Harvest[3]		Roads	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Middle Redwood Creek Subbasin (64,082 acres) (716.1 road miles)	Very Low	2,689	4.2%	375	0.6%	334	0.5%	1,840	2.9%	44.5	6.2%
	Low	3,868	6.0%	454	0.7%	571	0.9%	2,803	4.4%	57.4	8.0%
	Moderate	6,002	9.4%	209	0.3%	849	1.3%	4,851	7.6%	81.4	11.4%
	High	20,402	31.8%	3,040	4.7%	2,836	4.4%	14,409	22.5%	241.3	33.7%
	Very High	31,023	48.4%	5,133	8.0%	5,859	9.1%	20,192	31.5%	291.6	40.7%
	High/Very High Subtotal	51,425	80.2%	8,173	12.8%	8,695	13.6%	34,601	54.0%	532.9	74.4%
	TOTAL	**63,984**	**100%**	**9,211**	**14%**	**10,448**	**16%**	**44,095**	**69%**	**716.2**	**100%**
Coyote Creek (7,678 acres) (79.6 road miles)	Very Low	117	1.5%	58	0.8%	0	0.0%	55	0.7%	2.4	3.0%
	Low	248	3.2%	50	0.7%	0	0.0%	195	2.5%	3.4	4.3%
	Moderate	594	7.7%	5	0.1%		0.0%	587	7.6%	5.9	7.4%
	High	2,825	36.8%	938	12.2%	0	0.0%	1,878	24.5%	30.5	38.3%
	Very High	3,884	50.6%	998	13.0%	0	0.0%	2,780	36.2%	37.3	46.9%
	High/Very High Subtotal	6,709	87.4%	1,936	25.2%	0	0.0%	4,658	60.7%	67.8	85.2%
	TOTAL	**7,668**	**100%**	**2,049**	**27%**	**0**	**0%**	**5,495**	**72%**	**79.5**	**100%**
Lower Lacks Creek (5,935 acres) (47.3 road miles)	Very Low	59	1.0%	16	0.3%	4	0.1%	34	0.6%	1.1	2.3%
	Low	288	4.9%	124	2.1%	28	0.5%	134	2.3%	3.9	8.2%
	Moderate	22	0.4%	6	0.1%		0.0%	16	0.3%	0.2	0.4%
	High	1,222	20.6%	530	8.9%	73	1.2%	642	10.8%	11.7	24.7%
	Very High	4,327	72.9%	1,468	24.7%	257	4.3%	2,639	44.5%	30.4	64.3%
	High/Very High Subtotal	5,549	93.5%	1,998	33.7%	330	5.6%	3,281	55.3%	42.1	89.0%
	TOTAL	**5,918**	**100%**	**2,144**	**36%**	**362**	**6%**	**3,465**	**58%**	**47.3**	**100%**
Lupton Creek (8,050 acres) (116.4 road miles)	Very Low	551	6.8%	47	0.6%	64	0.8%	435	5.4%	10.1	8.7%
	Low	650	8.1%	57	0.7%	179	2.2%	404	5.0%	13.0	11.2%
	Moderate	1,140	14.2%	56	0.7%	413	5.1%	647	8.0%	19.5	16.8%
	High	2,769	34.4%	270	3.4%	738	9.2%	1,765	21.9%	40.2	34.5%
	Very High	2,930	36.4%	350	4.3%	731	9.1%	1,860	23.1%	33.7	29.0%
	High/Very High Subtotal	5,699	70.8%	620	7.7%	1,469	18.2%	3,625	45.0%	73.9	63.5%
	TOTAL	**8,040**	**100%**	**780**	**10%**	**2,124**	**26%**	**5,111**	**63%**	**116.5**	**100%**
Minor Creek (9,959 acres) (122.2 road miles)	Very Low	231	2.3%	37	0.4%	78	0.8%	109	1.1%	4.8	3.9%
	Low	327	3.3%	51	0.5%	97	1.0%	179	1.8%	4.0	3.3%
	Moderate	374	3.8%	21	0.2%	44	0.4%	310	3.1%	5.6	4.6%
	High	3,075	30.9%	336	3.4%	873	8.8%	1,772	17.8%	41.9	34.2%
	Very High	5,929	59.5%	747	7.5%	2,160	21.7%	3,018	30.3%	66.1	54.0%
	High/Very High Subtotal	9,004	90.4%	1,083	10.9%	3,034	30.5%	4,790	48.1%	108.0	88.2%
	TOTAL	**9,936**	**100%**	**1,192**	**12%**	**3,252**	**33%**	**5,388**	**54%**	**122.4**	**100%**
Panther Creek (9,745 acres) (94.1 road miles)	Very Low	210	2.2%	26	0.3%	26	0.3%	135	1.4%	4.2	4.5%
	Low	642	6.6%	63	0.6%	70	0.7%	498	5.1%	7.3	7.8%
	Moderate	1,680	17.2%	17	0.2%	239	2.4%	1,397	14.3%	20.3	21.6%
	High	3,928	40.3%	549	5.6%	503	5.2%	2,850	29.2%	38.0	40.4%
	Very High	3,274	33.6%	487	5.0%	328	3.4%	2,447	25.1%	24.3	25.8%
	High/Very High Subtotal	7,202	73.9%	1,036	10.6%	831	8.5%	5,297	54.4%	62.3	66.2%
	TOTAL	**9,734**	**100%**	**1,142**	**12%**	**1,166**	**12%**	**7,327**	**75%**	**94.1**	**100%**
Roaring Gulch (8,906 acres) (108 road miles)	Very Low	791	8.9%	68	0.8%	15	0.2%	677	7.6%	11.2	10.4%
	Low	828	9.3%	20	0.2%	23	0.3%	768	8.6%	11.9	11.0%
	Moderate	1,248	14.0%	52	0.6%	69	0.8%	1,099	12.3%	19.0	17.6%
	High	2,709	30.4%	127	1.4%	215	2.4%	2,390	26.8%	34.5	31.9%
	Very High	3,325	37.3%	396	4.4%	840	9.4%	2,246	25.2%	31.3	29.0%
	High/Very High Subtotal	6,034	67.8%	523	5.9%	1,055	11.8%	4,636	52.1%	65.8	60.9%
	TOTAL	**8,901**	**100%**	**663**	**7%**	**1,162**	**13%**	**7,180**	**81%**	**107.9**	**100%**
Toss-Up Creek (8,734 acres) (94 road miles)	Very Low	589	6.7%	113	1.3%	81	0.9%	331	3.8%	8.0	8.5%
	Low	606	6.9%	56	0.6%	84	1.0%	457	5.2%	9.4	10.0%
	Moderate	906	10.4%	42	0.5%	81	0.9%	771	8.8%	10.4	11.1%
	High	2,778	31.8%	125	1.4%	232	2.7%	2,366	27.1%	30.3	32.2%
	Very High	3,847	44.0%	325	3.7%	1,023	11.7%	2,491	28.5%	35.9	38.2%
	High/Very High Subtotal	6,625	75.9%	450	5.2%	1,255	14.4%	4,857	55.6%	66.2	70.4%
	TOTAL	**8,726**	**100%**	**661**	**8%**	**1,501**	**17%**	**6,416**	**73%**	**94.0**	**100%**
Upper Lacks Creek (5,076 acres) (54.4 road miles)	Very Low	141	2.8%	10	0.2%	66	1.3%	64	1.3%	2.7	5.0%
	Low	279	5.5%	33	0.7%	90	1.8%	168	3.3%	4.5	8.3%
	Moderate	38	0.7%	10	0.2%	3	0.1%	24	0.5%	0.5	0.9%
	High	1,096	21.6%	165	3.3%	202	4.0%	746	14.7%	14.2	26.1%
	Very High	3,507	69.1%	362	7.1%	520	10.2%	2,711	53.4%	32.6	59.9%
	High/Very High Subtotal	4,603	90.7%	527	10.4%	722	14.2%	3,457	68.1%	46.8	86.0%
	TOTAL	**5,061**	**100%**	**580**	**11%**	**881**	**17%**	**3,713**	**73%**	**54.5**	**100%**

[1] Refer to Plate 1 and California Geological Survey appendix. Empty cells denote zero.
[2] Woodland and grassland include areas mapped in 1998 as grassland and non-productive hardwood.
[3] Area of timberlands that were not contained in a THP during the 1991 to 2000 period.
[4] THPs are complete or active between the 1991 and 2000 timeframe. Percent of area is based on the unit of analysis: subbasin or planning watershed.

Table IV- 77. Middle Subbasin integrated information summary.

Factor	Middle Redwood Subbasin		Planning Watersheds																	
			Lupton Creek		Minor Creek		Toss-up Creek		Upper Lacks		Roaring Gulch		Lower Lacks		Panther Creek		Coyote Creek	
Relative Landslide Potential1	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Very Low	2,689	4.2%	551	6.9%	231	2.3%	589	6.7%	141	2.8%	791	8.9%	59	1.0%	210	2.2%	117	1.5%
Low	3,868	6.0%	650	8.1%	327	3.3%	606	6.9%	279	5.5%	828	9.3%	288	4.9%	642	6.6%	248	3.2%
Moderate	6,002	9.4%	1,140	14.2%	374	3.8%	906	10.4%	38	0.8%	1,248	14.0%	22	0.4%	1,680	17.3%	594	7.7%
High	20,402	31.9%	2,769	34.4%	3,075	30.9%	2,778	31.8%	1,096	21.7%	2,709	30.4%	1,222	20.6%	3,928	40.4%	2,825	36.8%
Very High	31,023	48.5%	2,930	36.4%	5,929	59.7%	3,847	44.1%	3,507	69.3%	3,325	37.4%	4,327	73.1%	3,274	33.6%	3,884	50.7%
High/Very High Subtotal	51,425	80.4%	5,699	70.9%	9,004	90.6%	6,625	75.9%	4,603	91.0%	6,034	67.8%	5,549	93.8%	7,202	74.0%	6,709	87.5%
GRAND TOTAL	**63,984**	**100%**	**8,040**	**100%**	**9,936**	**100%**	**8,726**	**100%**	**5,061**	**100%**	**8,901**	**100%**	**5,918**	**100%**	**9,734**	**100.0%**	**7,668**	**100.0%**
Landslide and Selected Geomorphic Features	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% area**	**acres**	**% Area**	**acres**	**% Area**
Historically Active Landslide Features Total	4,166	6.5%	569	7.1%	831	8.4%	153	1.8%	168	3.3%	267	3.0%	1,062	17.9%	302	3.1%	814	10.6%
Earthflow	68	0.1%	1	0.0%	7	0.1%	19	0.2%	4	0.1%	8	0.1%	11	0.2%	9	0.1%	9	0.1%
Rock Slide	257	0.4%	29	0.4%	46	0.5%	16	0.2%	38	0.7%	45	0.5%	31	0.5%	33	0.3%	19	0.2%
Debris Slide	3,187	5.0%	406	5.1%	774	7.8%	118	1.4%	89	1.8%	181	2.0%	572	9.7%	261	2.7%	785	10.2%
Debris Flow	654	1.0%	133	1.7%	4	0.0%	0	0.0%	36	0.7%	33	0.4%	448	7.6%	0	0.0%	1	0.0%
Dormant Landslide Features Total	15,150	23.7%	2,249	28.0%	2,487	25.0%	2,275	26.1%	198	3.9%	2,843	31.9%	1,365	23.1%	2,205	22.7%	1,528	19.9%
Selected Geomorphic Features Total	13,495	21.1%	2,010	25.0%	2,581	26.0%	961	11.0%	1,247	24.6%	182	2.1%	706	11.9%	2,934	30.1%	2,874	37.5%
Disrupted Ground	10,099	15.8%	1,932	24.0%	1,586	16.0%	923	10.6%	3	0.1%	163	1.8%	2	0.0%	2,674	27.5%	2,817	36.7%
Debris Slide Slope	2,943	4.6%	19	0.2%	884	8.9%	0	0.0%	1,155	22.8%	0	0.0%	638	10.8%	211	2.2%	35	0.5%
Inner Gorge (area)2	453	0.7%	59	0.7%	111	1.1%	38	0.4%	89	1.8%	19	0.2%	66	1.1%	49	0.5%	22	0.3%
Total of All Above Features	**32,811**	**51.3%**	**4,828**	**60.0%**	**5,900**	**59.4%**	**3,389**	**38.8%**	**1,612**	**31.9%**	**3,292**	**37.0%**	**3,134**	**52.9%**	**5,441**	**55.9%**	**5,215**	**68.0%**
Timber Harvest 1991 -2000[3]	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Silviculture Category 1																		
Tractor	3,375	5.3%	881	11.0%	1,082	10.9%	780	8.9%	82	1.6%	337	3.8%	1	0.0%	213	2.2%	0	0.0%
Cable	896	1.4%	141	1.7%	325	3.3%	177	2.0%	45	0.9%	80	0.9%	13	0.2%	115	1.2%		
Helicopter	112	0.2%	10	0.1%	97	1.0%									5	0.0%		
TOTAL	**4,383**	**6.9%**	**1,031**	**12.8%**	**1,504**	**15.1%**	**957**	**11.0%**	**126**	**2.5%**	**417**	**4.7%**	**14**	**0.2%**	**333**	**3.4%**	**0**	**0.0%**
Silviculture Category 2																		
Tractor	1,761	2.8%	156	1.9%	204	2.1%	424	4.9%	132	2.6%	583	6.5%	243	4.1%	19	0.2%		
Helicopter	79	0.1%	6	0.1%	30	0.3%	6	0.1%	11	0.2%	26	0.3%				0.0%		
Cable	203	0.3%			172	1.7%									31	0.3%		
TOTAL	**2,043**	**3.2%**	**162**	**2.0%**	**406**	**4.1%**	**430**	**4.9%**	**143**	**2.8%**	**609**	**6.8%**	**243**	**4.1%**	**50**	**0.5%**	**0**	**0.0%**
Silviculture Category 3																		
Tractor	3,129	4.9%	849	10.6%	530	5.3%	245	2.8%	581	11.5%	144	1.6%	13	0.2%	766	7.9%		
Helicopter	582	0.9%	38	0.5%	313	3.2%			30	0.6%			92	1.5%	109	1.1%		
Cable	689	1.1%	102	1.3%	583	5.9%	4	0.0%										

TOTAL	4,400	6.9%	989	12.3%	1,426	14.4%	250	2.9%	611	12.1%	144	1.6%	105	1.8%	876	9.0%	0	0.0%
GRAND TOTAL	10,826	16.9%	2,182	27.1%	3,336	33.6%	1,636	18.8%	880	17.4%	1,170	13.1%	362	6.1%	1,258	12.9%	0	0.0%
Other Land Uses	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Grazing	1,301	2.0%	237	3.0%	126	1.3%	144	1.7%			159	1.8%	44	0.7%	491	5.0%	99	1.3%
Agriculture	24	0.0%									24	0.3%						
Development	11	0.0%									11	0.1%						
Timberland, No Recent Harvest	44,095	68.9%	5,111	63.6%	5,388	54.2%	6,416	73.5%	3,713	73.4%	7,180	80.7%	3,465	58.6%	7,327	75.3%	5,495	71.7%
TOTAL	**45,430**	**71.0%**	**5,348**	**66.5%**	**5,514**	**55.5%**	**6,560**	**75.2%**	**3,713**	**73.4%**	**7,373**	**82.8%**	**3,509**	**59.3%**	**7,818**	**80.3%**	**5,594**	**73.0%**
Factor	**Middle Redwood Subbasin**		**Planning Watersheds**															
			Lupton Creek		**Minor Creek**		**Toss-up Creek**		**Upper Lacks**		**Roaring Gulch**		**Lower Lacks**		**Panther Creek**		**Coyote Creek**	
Roads																		
Road Density (miles/sq. mile)	7.2		9.3		7.9		6.9		6.9		7.8		5.2		6.2		6.8	
Density of Road Crossings (#/stream mile)	1.1		1.2		1.2		1.1		2.0		1.4		1.4		0.9		0.9	
Roads within 200' of Stream (miles/stream mile)	0.2		0.3		0.3		0.2		0.2		0.2		0.2		0.2		0.2	

[1] Refer to California Geological Survey appendix for landslide map (Plate 1), relative landslide potential map (Plate 2) and description.

[2] Area based on inner gorges captured as polygons plus inner gorges captured as linear features, which are treated as having an average width of 100 feet.

[3] Category 1 includes clearcut, rehab, seed tree step, and shelterwood seed step prescriptions; Category 2 includes shelterwood prep step, shelterwood removal step, and alternative prescriptions; Category 3 includes selection, commercial thin, sanitation salvage, transition, and seed tree removal step prescriptions.

[4] Landslide features and selected geomorphic features include earth flow, rock slide, debris slide, debris flow, debris slide slopes, disrupted ground, eroding banks and inner gorges.

EMDS Potential Sediment Production Results

Table IV- 78 to Table IV- 81 look at the results of the EMDS potential sediment production model for the Middle Subbasin. While we believe that this model has utility based on the model structure, we caution that it be interpreted only as being indicative of relative conditions and not as a definitive assessment of absolute conditions. We encourage readers to see the EMDS Appendix to review the sediment production model structure, hierarchy, and weighting system. Table IV- 78 presents the top three levels of the EMDS sediment model. This analysis shows potential sediment production is related to both natural processes and land management sources. A review of the following tables helps explain the results for natural processes and management related potential sediment sources.

Table IV- 78. EMDS Ratings for potential sediment production and delivery to streams; top three levels of model.

Subbasin or Planning Watershed	All Sources	Natural Processes				Management-Related Sources			
		All	Surface Erosion	Streamside Erosion	Mass Wasting	All	Surface Erosion	Streamside Erosion	Mass Wasting
Middle Redwood Subbasin	-	-	U	+	-	-	-	-	-
Coyote Creek	-	--	U	--	---	-	-	-	-
Lower Lack's Creek	-	--	U	-	---	+	++	-	+
Lupton Creek	-	-	U	-	-	-	-	-	-
Minor Creek	--	-	U	-	--	--	--	-	--
Panther Creek	-	-	U	+	-	+	+	-	+
Roaring Gulch	-	+	U	++	+	-	-	-	--
Toss-Up Creek	+	+	U	++	+	-	-	-	-
Upper Lacks Creek	-	-	U	++	--	-	+	-	-

The sediment production potential rating is assigned with respect to suitability for anadromous salmonid production. The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---"score represents the most potential sediment delivery to streams. A 'U' represents a lack of data to categorize.

Table IV- 79 takes a closer look at potential sediment production from management related surface erosion. These relative ratings vary widely across the individual factors and planning watersheds, though the general direction among these is for relatively higher sediment production potentials. Road related sources generally are rated as having higher relative sediment production levels than are land use related sources. Lower Lacks Creek and Upper Lacks Creek stand out as having relatively low sediment production potential related to land use because the timber harvest used cable yarding systems and did not use tractor logging techniques. Cable yarding is not considered to promote erosion by the EMDS model while tractor logging is considered to initiate surface erosion. Minor Creek stands out as having the highest relative sediment production potential of all the planning watersheds; timber management appears to be an important contributing factor.

Table IV- 79. Potential stream sediment production from management-related surface erosion sources.

Subbasin or Planning Watershed	All Mgmt.-Related Surface Sources	Road Related			Land Use Related	
		All Road Related	Density of Roads by Hillslope Position	Density of Roads Proximate to Streams	All Land Use Related	Timber Land Use
Middle Redwood Subbasin	-	-	--	-	-	+
Coyote Creek	-	-	-	-	+	+
Lower Lack's Creek	++	+	+	+	++	++
Lupton Creek	-	-	---	--	+	+
Minor Creek	--	-	--	--	---	--
Panther Creek	+	-	-	-	+	-
Roaring Gulch	-	-	--	-	--	+
Toss-Up Creek	-	-	-	-	+	++
Upper Lacks Creek	+	-	-	-	++	++

The "+++" score represents the least amount of sediment delivery to streams on a relative scale; the "---"score represents the most sediment delivery to streams. Upper and Lower Lacks creeks Planning Watersheds received positive scores because timber harvest used high line cable systems. The model considered only tractor logging harvest methods to generate and deliver surface erosion sediments to stream channels.

Table IV- 80 examines potential sediment production from management related streamside erosion processes. These relative ratings show a somewhat high potential for sediment production from road related sources across the subbasin and planning watersheds. The density of stream crossings on Upper Lacks Creek planning watershed appears to be a particularly high potential sediment source.

Table IV- 80. Potential stream sediment production from management-related streamside erosion sources.

Subbasin or Planning Watershed	All Management-Related Streamside Sources	Road Related	
		Density of Roads Proximate to Streams	Density of Road Crossings
Middle Redwood Subbasin	-	-	-
Coyote Creek	-	-	-
Lower Lack's Creek	-	+	--
Lupton Creek	-	--	-
Minor Creek	-	--	-
Panther Creek	-	-	+
Roaring Gulch	-	-	--
Toss-Up Creek	-	-	-
Upper Lacks Creek	-	-	---

The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---"score represents the most potential sediment delivery to streams.

The results from the management related sources and mass wasting show a somewhat high relative rating for sediment production potential across the subbasin and planning watersheds (Table IV- 81). Model results show the high road density and high number of stream crossings as the major sources of potential sediment delivery to streams. Land use related sources have a somewhat low relative sediment production potential. This result is partially due to areas of timber harvests using cable yarding systems that were not considered to generate sediment by the model.

Table IV- 81. Potential stream sediment production from management related mass wasting sources.

Subbasin or Planning Watershed	All Mgmt.-Related Mass Wasting Sources	Road Related				Land Use Related	
		All Road Related	Density of Roads Crossings	Density of Roads by Hillslope Position	Density of Roads on Unstable Slopes	All Land Use Related	Timber Land Use
Middle Redwood Subbasin	-	-	-	--	--	-	+
Coyote Creek	-	-	-	-	--	+	+
Lower Lack's Creek	+	-	--	+	-	++	++
Lupton Creek	-	-	-	---	+	+	+
Minor Creek	--	--	-	--	---	---	--
Panther Creek	+	-	+	-	-	+	-
Roaring Gulch	--	--	--	--	-	--	+
Toss-Up Creek	-	-	-	-	--	+	++
Upper Lacks Creek	-	--	---	-	--	++	++

The "+++" score represents the least amount of potential sediment delivery to streams on a relative scale; the "---"score represents the most potential sediment delivery to streams. Upper and Lower Lacks creeks Planning Watersheds received positive scores because timber harvest used high line cable systems. The model considered only tractor logging harvest methods to generate and deliver mass wasting sources of sediments to stream channels.

EMDS Stream Reach Condition Results and Limiting Factors Analysis

The overall reach condition of the streams located in the Middle Subbasin were all rated "somewhat unsuitable" for salmonid production by EMDS. The maps displays (Table IV- 82) results at the stream reach scale while Table IV-84 shows the average condition for each stream. These stream habitat elements that receive a negative (-) EMDS evaluation score should be considered as potential limiting factors to salmonid production in the Middle Subbasin.

The somewhat unsuitable condition rating is largely due to the lack of deep pools and a lack of pool shelter complexity in the tributary streams and the lack of shelter in pools and shade canopy over the mainstem Redwood Creek. A deficiency in the EMDS model likely contributed to negative evaluations of the pool depth attribute throughout the basin. However, shallow pool conditions are often found in low gradient reaches within small watersheds that lack sufficient discharge to deeply scour the channel.

In some instances, the EMDS results alone do not provide the most accurate description of the stream condition. For example, the mainstem Redwood Creek Reach 5 had over 50% of it s length in pools, 20% of the reach length was in pools ≥ 4 feet in maximum residual pool depth. The 20% of reach length in deep pools is at the lower limit of the EMDS suitability curve for a fourth order streams, thus the reach received the lowest EMDS rating of fully unsuitable. A closer examination of the pool depths provided in the Fish Habitat Relationships section above provides a better description of pool status than the indicated by the EMDS results and that overall, pools depths are not as poorly suited for anadromous salmonids as the EMDS scores indicate.

Table IV- 82. Summary of the results from the Middle Subbasin EMDS Stream Reach Evaluation.

Subbasin and Reach	Reach Length	Reach Condition	Canopy Density	Pool Quality	Pool Depth	Pool Shelter	Embeddedness
Redwood Middle Basin		-					
Beaver Creek	2608	-	+++	- - -	- - -	- - -	+
Captain Creek	2360	-	+ +	- - -	- - -	- - -	+ +
Coyote Creek	13379	-	+ +	- -	- -	- -	+ +
Dolly Varden Creek	5833	-	+++	-	0	-	-
Fern Prairie Creek	852	-	+ + +	- - -	- - -	- - -	0
Garrett Creek	4779	-	+ + +	- - -	- - -	- - -	-
Lacks Creek	24262	-	+	- -	- - -	- -	+ +
Lupton Creek	3832	-	+ + +	- -	-	- - -	-
Mill Creek	2788	-	+ + +	- -	- - -	- -	-
Minor Creek	14418	-	+ +	- -	- -	- -	+
Molasses Creek	2556	-	+ + +	- - -	- - -	- - -	+ +
Panther Creek	14589	-	+ + +	- -	- - -	-	-
Pilchuck Creek	1617	-	- - -	- - -	- - -	- - -	0
Sweathouse Creek	1859	-	+ + +	- - -	- - -	- - -	- -
Toss up Creek	5462	-	+ + +	- -	- - -	- -	-
Wiregrass Creek	2000	-	+ + +	- -	- - -	- -	+ +
Mid Basin Tribs Wt. Avg.	103194	-	+ +	- -	- -	- -	+
Redwood Creek Mid 1	12002	-	- -	- -	-	- - -	+
Redwood Creek Mid 2	19919	-	- - -	-	+	- - -	-
Redwood Creek Mid 3	32044	-	- - -	0	+ + +	- - -	- -
Redwood Creek Mid 4	28724	-	- - -	- - -	- - -	- - -	- -
Redwood Creek Mid 5	29406	-	- - -	- - -	- - -	- - -	-
Redwood Creek Mid Wt. Ave	130520	-	- -	- -	-	- - -	-

\+ Somewhat Suitable ++ Moderately Suitable +++ Fully Suitable
\- Somewhat Unsuitable -- Moderately Unsuitable --- Fully Unsuitable 0 Uncertain
These scores provide a general overview of current stream conditions and may be used to identify limiting habitat factors to anadromous salmonid production and to focus on areas for habitat improvements.

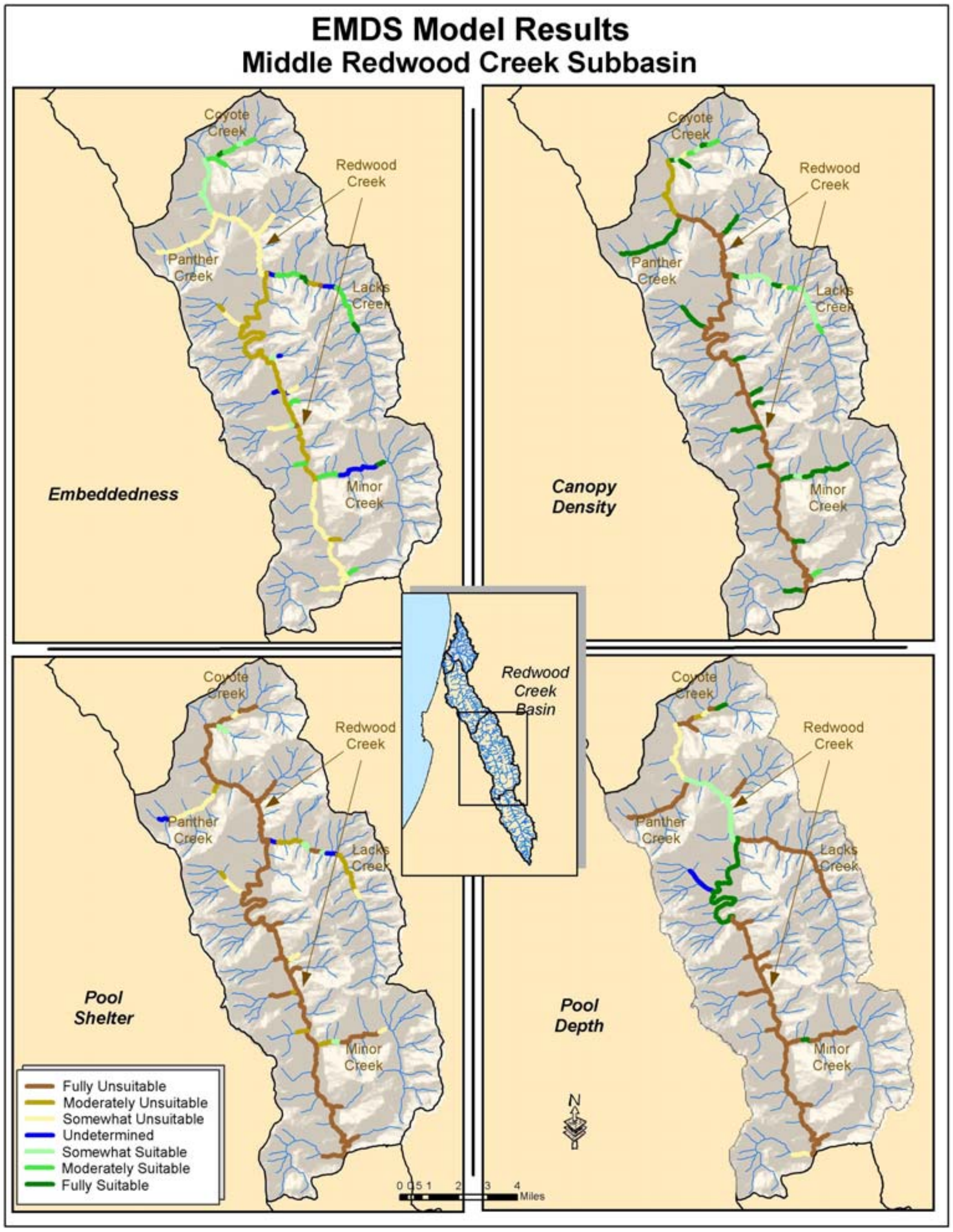

Figure IV- 50. Middle Subbasin EMDS map results for selected stream reach factors.

Stream Habitat Improvement Recommendations

Stream habitat improvement recommendations were developed based on results from stream surveys conducted along anadromous salmonid bearing stream reaches in 2001. Therefore the recommendations do not directly consider stream conditions above the limits of anadromy. Because the majority of tributary streams provide less than one-half mile anadromous salmonid habitat, there is a considerable amount of area that was not surveyed in the Middle Subbasin. A full list of recommendations for each stream in the Middle Subbasin can be found in Appendix D.

The most frequently listed recommendation category across the subbasin is to improve instream habitat factors pool frequency, depth, and shelter complexity followed by erosion/sediment and riparian/temperature treatments (Table IV- 83 and Table IV- 84). In Mainstem Redwood Creek, work should be focused on reducing water temperature and increasing pool depths and shelter complexity. In Lupton, Panther, and Dolly Varden creeks large debris accumulations may need to be modified to facilitate fish passage and reduce stored sediments that fill pool habitat. In addition accumulations of small boulders or (perched deltas) within the lowermost reach of streams like Panther Creek impair fish passage into tributaries during spawning migrations.

Table IV- 83. Top three ranking recommendation categories by number of tributaries and mainstem reaches in the Redwood Creek basin.

Basin Target Issue	Related Table Categories	Count
Erosion / Sediment	Bank / Roads	11
Riparian / Water Temp	Canopy / Temp	9
Instream Habitat	Pool / Cover	41
Gravel / Substrate	Spawning Gravel / LDA	7
Other	Livestock / Barrier	3

Lacks and Minor Creeks have suitable water temperatures for salmonids in their upper reaches, but their lower reaches have temperatures above desirable targets (MWATs of 65°F or more). A reduction in temperature will likely occur as the result of increasing pool frequency and depth, controlling erosion and increasing the coniferous component of the riparian zone.

In general, the recommendations that involve erosion and sediment reduction by treating roads and failing stream bank and near stream vegetation improvements, and temperature reduction precede the instream recommendations for pool development and spawning gravel projects. The various project treatment recommendations can be made concurrently if watershed and stream conditions warrant. Fish passage problems, especially in situations where favorable stream habitat reaches are being separated by a man-caused feature (e.g., culvert), deltas, or debris jams are usually a treatment priority. Specific treatment strategies are presented in Flosi et al. (1998).

Table IV- 84. Prioritization of steps to address limiting factors.

Survey Streams	Survey Length (Ft)	Temperature	Pool	Cover	Bank	Roads	Canopy	Spawning Gravel	LDA	Live Stock	Access
Lacks Creek	24,262	4	2	1	3	5	6	7			
Minor Creek	14,418	5	3	1	2	6	4	7			
Coyote Creek	11,282		5	1	2	3	4				
Panther Creek	14,504		4	3		5		6	1		2
Wiregrass Creek	2,000		2	1		3	4				
Dolly Varden Creek	5.968		1	3		4	5		2		
Toss Up Creek	5,462		3	1	2	4	5	6			
Garrett Creek	4,779		4	1	2	3		5			
Lupton Creek	3,832		4	1	5	2	6	7	8		3
Sweathouse Creek	1,611		2	1	6	3	5	4			
Pilchuck Creek	1,617		2	1	5	4		3			
Mill Creek	2,788		1	2		4	3	5			
Molasses Creek	2,556		1	2	5	4	3				
Captain Creek	2,360	1	4	3		5	4	7	6		2
Beaver Creek	2,731		2	3	6	4	5	7			1
Middle Subbasin Tributaries (total)	103,194	3	14	15	6	1	2	4	2		2
Redwood Creek	130,520	1	4	2	5	6	3	7			

Key to fields: Temp = summer water temperatures seem to be above optimum for salmon and steelhead; Pool = pools are below target values in quantity and/or quality; Cover = escape cover is below target values; Bank = streambanks are failing and yielding fine sediment into the stream; Roads = fine sediment is entering the stream from the road system; Canopy = shade canopy is below target values; Spawning Gravel = spawning gravel is deficient in quality and/or quantity; LDA = log debris accumulations are retaining large amounts of gravel and could need modification; Livestock = there is evidence that stock is impacting the stream or riparian area and exclusion should be considered; Access = there are human made barriers to fish migration in the stream.

Refugia Areas

Most of the streams of the Middle Subbasin are classified as potential refugia based on the status of watershed conditions, stream habitat conditions, salmonid populations, and risk from land use (Table IV- 85). Although, the majority of streams support populations of anadromous salmonids, 2001 fish numbers appear low compared to past assessments. The instream conditions were also considered in need of improvement to increase salmonid populations. Addressing limiting habitat factors with the treatments identified in Table IV- 85 should improve the refugia designations for Middle Subbasin streams.

Table IV- 85. Middle Subbasin anadromous salmonid refugia designations for streams.

Stream	Refugia Categories:				Other Categories:		
	High Quality	High Potential	Potential	Low Quality	Passage Barrier Limited	Critical Contributing Area/Function	Data Limited
Lacks Creek			X				
Minor Creek			X				
Coyote Creek		X					
Panther Creek			X				
Dolly Varden Creek (Karen)		X			X	X	
Wiregrass Creek			X				
Garcia Creek							X
Toss Up Creek				X			
Garrett Creek							
Lupton Creek					X	X	
Sweathouse Creek			X				
Mill Creek			X				
Molasses Creek			X				
Captain Creek			X				
Beaver Creek			X		X		
Pilchuck Creek				X			
Cashmere Creek							X
Roaring Gulch							X
Loin Creek							X
Santa Fe Creek							X
Redwood Creek			X				

Responses to Assessment Questions

<u>What are the history and trends of the size, distribution, and relative health and diversity of salmonid populations?</u>

- The Middle Subbasin supports populations of Chinook salmon, steelhead, summer steelhead, and coastal cutthroat trout;
- Recent trapping studies show that Chinook salmon are successfully spawning in the middle reach of mainstem Redwood Creek, although spawning success varies considerably among years;
- Coho were once noted as present or abundant in Coyote, Panther, Dolly Varden (Karen), Pilchuck, Minor and Redwood creeks. Surveys conducted in 2001and 2002 failed to detect coho presence in any Middle Subbasin streams; indicating a decline in coho distribution and abundance within the Redwood Creek Basin;
- A comparison of 1966, 1975 -77 to 2001 fish surveys found that the Middle Subbasin tributaries contained higher species diversity and higher numbers of salmonids in the past than were observed in 2001 surveys. Most of the past surveys, particularly from the 1966 and 1975 survey years, gave indications of abundant salmonids (mostly juvenile steelhead and coho);
- Juvenile steelhead are the most widely distributed and abundant salmonid found throughout the middle subbasin;
- Summer steelhead populations are greatly reduced from historic abundance. Anecdotal information from the 1920s indicated the presence of deep pools containing numerous, large summer steelhead;
- As few as 3 summer steelhead were observed in recent annual snorkel surveys of mainstem Redwood Creek above Lacks Creek;
- Coastal cutthroat were identified only in Panther Creek and Redwood Creek during 2001 surveys;
- Consistent, long term data are not available to quantify the population size of adult anadromous salmonids.

What are the current salmonid habitat conditions? How do these conditions compare to desired conditions?

- The Middle Subbasin provides critical habitat for anadromous salmonids;
- Many pools in mainstem Redwood Creek and its tributaries are relatively shallow and lack shelter complexity;
- Tributary reaches have less than the desirable amount of pool habitat;
- Anecdotal information and past studies indicate that water temperatures in the mainstem were cooler prior to the flood of 1964;
- Stream temperatures along the middle reach of Redwood Creek exceed the suitable range for salmonids. MWATs reach >72°F and daily maximums reach 80°F;
- A few discrete cool water patches within Redwood Creek create thermal refuge for salmonids during periods of heat stress;
- There is a lack of streamside tree canopy providing shade over the water along most of mainstem Redwood Creek;
- Most tributary streams that were monitored for temperature were within desirable ranges. Temperatures measured by MWATs were below 64°F;
- Lower reaches of Lacks and Minor creeks had MWATs of 65 and 67°F respectively and maximum daily temperatures approached lethal limits;
- In most tributaries, the amount of shade over the water is within desired conditions;
- LWD is in low supply in most stream channels across the subbasin;
- The near term recruitment potential for coniferous LWD is low in the mainstem of the Middle Subbasin;
- The size of most near stream conifers is too small to provide full benefits of overstory shade and LWD loading;
- Only approximately 25% of the pool tails sampled in the Middle Subbasin are considered high quality spawning substrate;
- The majority of pool tail spawning substrate in Panther, Dolly Varden, Toss Up, Garrett, Lupton, Sweathouse, and Mill creeks is highly embedded with fine sediment. The majority of pool tail spawning substrate in Redwood Creek were also highly embedded with fine sediment;
- Turbidity levels are high and prolonged. Anecdotal information suggests that prior to 1964, Redwood Creek ran much cleaner and high turbidity episodes were of short duration;
- Construction and operation of the Chezem Dam on Redwood Creek may have adverse impacts to fishery resources and their habitat.

What are the past and present relationships of geologic, vegetative, and fluvial processes to stream habitat conditions?

- The Middle Subbasin terrain is naturally unstable. Approximately 80% of the Upper Subbasin is classified in either high or very high relative landslide potential;
- Upon receiving heavy winter rains the subbasin becomes prone to erosion and is a source of sediment inputs to stream channels;
- Excessive amounts of sediment in mainstem Redwood Creek have adversely impacted salmonid habitat in the Middle Subbasin for decades;
- Excessive sediment input to streams initiates a sequential series of adverse changes to stream habitat. These include aggraded stream channels, filling of pools, channel widening, stream bank erosion, raising

water table, stream side landslides, loss of shade canopy, increase of width to depth ratio, elevated water temperature, intermittent surface water flows, and loss of connectivity between surface flows and ground water;

- The middle reach of Redwood Creek experienced drastic changes in distribution of pool, riffle, and run habitats after the flood of December 1964 (a 50-year flood). In 1955 a similar 50-year flood occurred, but much less stream damage was noted by CDFG personnel than was noted in 1965 because of less ground disturbance in the basin;
- The overall result of the 1964 flood was a severe alteration of stream habitat conditions associated with excessive sediment inputs;
- Following the 1975 flood, the channel bed of Redwood Creek was left almost flat and featureless in many reaches, as a pulse of new sediment entered the system;
- Relatively minor actions, such as undercutting the toes of slopes, increasing the duration of ground saturation, or reducing soil shear strength by a relatively small amount, can trigger extensive landslides in this subbasin;
- The number of active stream side landslides recently increased by 18% (from 376 in 1984 to 442 in 2001) within the Middle Subbasin. The largest increase was observed in Lower Lacks Creek (+221%) and Panther Creek (+68%) planning watersheds;
- A trend of decreasing stored in channel sediments and an increase in channel diversity occurred through the middle reach of Redwood Creek during low to moderate rain years (1977 to 1996). During a recent high rain year (1997), erosion within the basin's uplands resulted in elevated erosion and sediment delivery, channel aggradation, and loss diversity in the mainstem channel. Since 1997, the decreasing trend in stored in channel sediment has resumed during moderate years of rains and stream flows;
- Large portions of the mainstem reach, such as in Redwood Valley, have unconfined channels and low channel gradients, which are prone to sediment accumulations;
- There were more active streamside landslides observed from aerial photos in Upper and Lower Lacks Creek, Roaring Gulch and Panther Creek planning watersheds in 2000 compared to 1984. No change was detected in Coyote Creek and a decrease in the number of active streamside landslides was observed in the remaining planning watersheds in the Middle Subbasin;
- Tributary flows may help to moderate mainstem temperature from reaching higher levels and provide localized patches of cool water, but do not significantly decrease mainstem Redwood Creek temperatures in the Middle Subbasin;
- The measured MWATs of Redwood Creek change from 71 to 72 in the Middle Subbasin and peak near the confluence with Lacks Creek. This suggests that most of the heat input to Redwood Creek occurs in the Upper Subbasin;
- The middle reach of Redwood Creek is subjected to direct solar hearting due to a lack of shade canopy;
- Large conifer trees that once lined the stream banks were removed during timber harvests. Much of the beneficial characteristics attributed to large trees in the near stream conifer forest (including shade, microclimate, and LWD recruitment potential) are not provided by existing vegetation;
- Although stream buffers are re-growing under current land management practices and Forest Practice rules, dense buffers of conifers large enough to function as LWD in channel formation processes have not yet been reestablished.

How has land use affected these natural processes?

- Much of the erosion of the Middle Subbasin that occurred during recent winter storms is attributed to land use;
- Past logging activities, particularly the construction of roads and skid trails and the removal of vegetative ground cover, have been a major factor contributing to erosion and sediment delivery to streams;

- Between 1950 and 1964, approximately 40% (32,000 acres) of the Middle Subbasin was logged for timber without rules to protect watersheds. There were at least 625 miles of poorly constructed roads and numerous miles of tractor skid trails across the unstable geology of the subbasin. As a result of this large amount of ground disturbance concentrated over a short period of time, the subbasin was highly susceptible to erosional processes exacerbated by the rain on snow storm event and ensuing flood of December 1964 and other recent storm events;
- Cumulative affects from winter storms in 1964, 1972, 1975 and continued land use have caused excessive erosion and excessive amounts of sediment to be delivered to stream channels. These impacts impaired salmonid habitat in the Middle Subbasin for decades;
- Excessive sediment inputs exacerbated by land use has aggraded channel beds, covered salmonid spawning habitat with fine sediment, filled pools with sediments, widened channels, eroded banks;
- The removal of large conifers during timber harvests has reduced near stream forest shade canopy density, reduced root strength to hold soils, reduced LWD loading potential and accelerated storm runoff rates in the Middle Subbasin;
- There are 524 miles of roads located on areas of high or very high relative landslide potential within the Middle Subbasin. High road density on unstable slopes and poor road maintenance practices has caused slope failures, stream diversion, gully erosion, and increased sediment input to streams;
- The density of stream crossings on Upper Lacks Creek planning watershed appears to be a particularly high potential sediment source;
- Historic livestock overgrazing in upper Redwood Valley may have lead to loss of native grasses, loss of top soils, and increased erosion and creation of gullies;
- The construction and operation of Chezem dam affects water flow and mutes temperature regimes in downstream reaches of mainstem Redwood Creek. The reservoir also inundates over a mile of stream channel.

Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?

- High water temperatures (MWAT of 72°F and daily maximum of 80°F) severely limit salmonid production in Redwood Creek and high water temperature (MWAT 67°F and daily maximum of 77°F) likely limits production in the lower reaches of Lacks and Minor creeks;
- Anadromous salmonid production is also likely limited by low abundance of deep pools with complex shelter in Redwood Creek, Lacks Creek, Minor Creek, Mill Creek, Molasses Creek, and Beaver Creek;
- The sparse amount of instream LWD in Redwood Creek and most anadromous fish bearing tributary reaches limits pool development, nutrient inputs, and channel diversity and complexity needed to increase carrying capacity and increase production of anadromous salmonids;
- The low recruitment potential for LWD in Redwood Creek and many of the tributary streams will impede future pool formation, sediment routing and likely act to constrain channel diversity and complexity for decades;
- Spawning success may be impaired by excessive amounts of fine sediments in some streams;
- The naturally steep channel gradient of the tributary streams limits anadromous salmonid distribution to the lower reaches of many tributaries in the Middle Subbasin;
- The decline in abundance of spawning salmon has likely caused a corresponding decrease in nutrients and organic matter available to streams. The nutrients contributed to streams by eggs and decaying carcasses may be needed to maintain historic salmonid production levels in the middle subbasin.

<u>What watershed and habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?</u>

Barriers to fish passage

- Investigate improving fish passage through 500 foot long culvert under HWY 299 on Lupton Creek;
- Modify sediment deltas or boulder accumulations that impede upstream migration into tributaries. A sediment delta formed by boulder accumulations is located within the lowermost reach of Panther Creek and possibly other tributaries;
- Modify large debris accumulations that may impede fish passage on Panther Creek and other tributaries (completed by Green Diamond and the California Conservation Corps in 2004).

Flow and Water Quality Improvement Activities:

- Reducing water temperature is essential to improve anadromous salmonid habitat in the Middle Subbasin. A long term goal should be to reduce water temperature in the middle reach of Redwood Creek and the lower reaches of tributary streams including Panther, Coyote, Minor and Lacks creeks;
- A reduction in temperature will likely occur as the result of increasing pool frequency and depth, controlling erosion, increasing the coniferous component of the riparian zone and allowing near stream conifers to obtain large size for development of microclimate benefits;
- Functional nearstream conifer forests need to be developed and/or maintained along Redwood Creek in the Middle Subbasin. Large near stream conifers are needed to help increase shade canopy, moderate air temperatures, and to promote LWD loading. This may require more than the minimum protection provided by present Forest Practice Rules;
- Increase shelter complexity in existing cool water refuge sites;
- Managers should explore methods to develop cool water refuge sites on Redwood Creek and the lower reaches of Panther, Lacks, and Minor and other creeks. Methods should include using pool scour elements, and increasing connectivity to cool ground water sources.

Erosion and Sediment Delivery Reduction Activities:

- In streams where the majority of pool tail spawning substrate is highly embedded with fine sediment, sediment sources should be located, rated according to their potential sediment yields, and treated;
- Upgrade or decommission roads in accordance with existing or future road assessment surveys. This work should be done especially on older roads built below current standards on unstable slopes and roads near streams in Upper and Lower Lacks, Minor, Lupton, Panther, and Coyote and Roaring Gulch planning watersheds;
- For timber management in Lacks, Minor, Coyote and other planning watersheds, with active landslides or on steep and/or potentially unstable slopes (slopes ≥ 35%) we recommend the use of lower impact silvicultural prescriptions to maintain vegetative cover, root strength, and the use of cable systems or helicopter yarding to reduce the potential for mass wasting and sediment production;
- Land management activities adjacent to all streams, particularly in the inner gorge, head walls, and on slopes 35% (19 degrees) or greater, must be carefully evaluated and designed to avoid generation and delivery of sediment to stream systems;
- Timberland managers should decrease the use of tractor or ground lead yarding on all slopes steeper than 35% (19 degrees); and use fully suspended (skyline) cable or helicopter yarding on steep and unstable slopes;
- RNSP and private landowners should continue efforts such as road improvements (e.g., upgrading crossings, rocking native surface roads, outsloping, ensuring surface drainage does not flow directly into watercourses, etc.) and decommissioning (e.g., removing unstable fills, removing drainage structures and

fills, restoring natural contours, blocking vehicle access, etc.) throughout the Redwood Creek basin to reduce sediment delivery to Redwood Creek and its tributaries;

- A qualified, licensed geologist or engineer should be consulted before initiating any project that involves road construction, timber harvest, or building. The NCWAP Landslide Potential maps should be reviewed before modifying hillslopes to avoid creating, or contributing to, hillslope instability and excessive, human-induced erosion through mass wasting or creation of gullies.

Riparian and Stream Habitat Improvement Activities:

- To increase overstory shade and to promote input of large woody debris, encourage near stream conifers to grow to large sizes and retain them along Redwood Creek and all tributary streams in the subbasin;
- Where there is adequate shade canopy along Lacks, Minor, Molasses, and Coyote Creeks, land managers should consider thinning hardwoods from below in riparian areas to hasten the development of large near stream conifers;
- Trees large enough to function as LWD need to be allowed to grow and recruit to stream channels from riparian and near stream forest areas;
- Consider adding pool forming structures to increase the number of pools in Redwood, Lacks, Minor, Lupton, Molasses, Panther, Mill, and Beaver creeks;
- Deepen and increase the size of existing pools in Dolly Varden, Toss Up, Garret, Lupton creeks and in lower reach of Coyote Creek;
- Add wood into pools and flatwater units to increase shelter complexity especially where the average size of near stream conifers is less than 2 feet DBH in Redwood, Lacks, Minor, Lupton, Panther, Coyote and Molasses creeks;
- Consider adding shelter complexity to existing temperature refuge sites on Redwood Creek;
- Consider the use of conservation easements along Redwood Creek to protect valuable riparian and near stream forest from development or timber harvests.

Education, Research, and Monitoring Activities:

- Water temperature monitoring should continue at the current locations to observe changes in temperature as effects from aggradation, degradation, channel widening, and riparian condition adjust over time;
- Identify potential perched sediment deltas and/or debris accumulations that may impede passage for spawning into Panther Creek and other Middle Subbasin tributaries;
- A long term, concerted monitoring effort between land owners, interested parties and responsible agencies is needed to determine the status, abundance and trends of anadromous fish populations of the Middle Subbasin streams;
- Investigate impacts from fine sediments on salmonid spawning success and aquatic insect community structure;
- Formal stream reach surveys were not done for LWD; however observations of crews and findings regarding pool complexity indicate that there is limited instream LWD. Formal survey for LWD loadings could be done to verify these observations;
- Monitoring in-channel sediment routing and storage(e.g., sediment size distribution, turbidity, V*, photo points, etc.) should be increased and tracking of streambed levels (i.e., stream channel cross sections) should be continued;
- Summer steelhead dive counts should be conducted on an annual basis on the middle reach of mainstem Redwood Creek and in the lower reach of Lacks and Minor creeks;

- Continue monitoring juvenile fish population trends such as downstream migrant trapping operations on mainstem Redwood Creek;
- Investigate possible improvements to cool water refugia and potential to increase such areas;
- Further study of the effects of Chezem summer dam on fish and fish habitat is warranted;
- Ensure that CEQA-compliant environmental assessment is conducted prior to issuance of the Fish and Game Code 1603 streambed alteration permits and Corps of Engineers or NOOA Fisheries permitting requirements are complete for any summer dams on Redwood Creek.

Subbasin Conclusions

Middle Subbasin streams provide important spawning and rearing habitat for anadromous salmonids. Steelhead and coastal cutthroat predominate in the tributary streams year round while Chinook depend mostly on the mainstem for spawning habitat and temporary juvenile rearing. Coho once noted as present in some tributaries were not observed during 2001 surveys. Summer steelhead are likely the most threatened salmonid stock inhabiting the Redwood Creek Basin.

The mainstem Redwood Creek has slowly adjusted from destructive impacts related to intensive land use and the 1964, 1972, 1975 floods. These storms occurred during an era when much of the Redwood Creek basin was undergoing unregulated timber harvests. Timber harvest activities contributed to destabilization of the land and increased runoff rates causing severe erosion, and severe damage to Redwood Creek including aggradation, widened channel, streambank erosion, and filling of pools with sediments. Presently, sediments are moving from the active channel of tributaries and upper and middle reaches of Redwood Creek, but they tend to accumulate in lowest gradient and unconfined reaches. An increase in channel structure has recently been observed, however this has not occurred without setbacks related to landslides induced by moderate storm events. Because of the combination of natural instability across the Middle Subbasin, legacy land disturbances effects, and land use that results in new ground disturbance, winter storms still pose risks for excessive erosion and sediment inputs to anadromous salmonids streams. This was shown during the winter of 1997 when an increase in landslides and associated sediment inputs were measured at RNSP cross sections.

High water temperature is likely the most limiting factor to salmonid production in mainstem Redwood Creek. The high water temperature is related to the lack of shade over the water along middle and upper mainstem reaches. Other significant factors affecting salmonids production in the mainstem are related to excessive sediment inputs and include lack of pools and lack of instream shelter complexity. Trees large enough to function as LWD, need to be allowed to grow and recruit to stream channels from riparian and near stream forest areas. Tributary streams generally provide good water temperature, except in lower reaches of Lacks and Minor creeks. Tributaries also showed a lack of deep pool habitat and instream shelter complexity.

The Middle Subbasin offers opportunities for implementing watershed habitat improvement activities. Watershed management strategies aimed at reducing erosion and developing functional near stream forests will help address landscape issues. This will help to reduce water temperature, increase bank stability, provide a source of LWD, and reduce sediment inputs to stream channels. Stream habitat improvement activities should focus on increasing depth and complexity to existing pool habitats, and adding shelter complexity to cool water refuge sites.

Upper Subbasin

The Upper Subbasin drains approximately 68 square miles of the CalWater 2.2 Lake Prairie Hydrologic Area and includes the land and waterways from the confluence of Lupton Creek upstream to the headwaters of Redwood Creek (Table IV- 86 and Figure IV- 51). This subbasin has the highest relief and greatest proportion of natural prairies of all Redwood Creek subbasins. The predominant land use is timber production and rural developments. The Upper Subbasin has the most area of all the Redwood Creek Basin in small land ownerships. The Upper Subbasin includes the following Planning Watersheds:

Windy Creek	Noisy Creek	Cloney Gulch
High Prairie Creek	Bradford Creek	Twin Lakes Creek

Approximately 19 miles of mainstem, and 21 miles of blue line perennial tributary streams drain the subbasin. The Upper Subbasin supports populations of Chinook salmon, steelhead, and coastal cutthroat. It is unclear if coho salmon have ever spawned or reared in the Upper Subbasin.

Table IV- 86. Upper Subbasin summary.

Square Miles	67.72	
Total Acreage	43,344	
Private Acres	40,640	
Federal Acres	2,240	
State Acres	0	
Principal Communities	None	
Predominant Land Use	Timber Production	
Predominant Vegetation Type	Hardwoods / Douglas-fir forest	
Miles of Anadromous Stream	23.0	
Low Elevation (feet)	866	
High Elevation (feet)	5,322	
Fish Species	steelhead coastal cutthroat trout	Chinook salmon coho salmon? Pacific lamprey

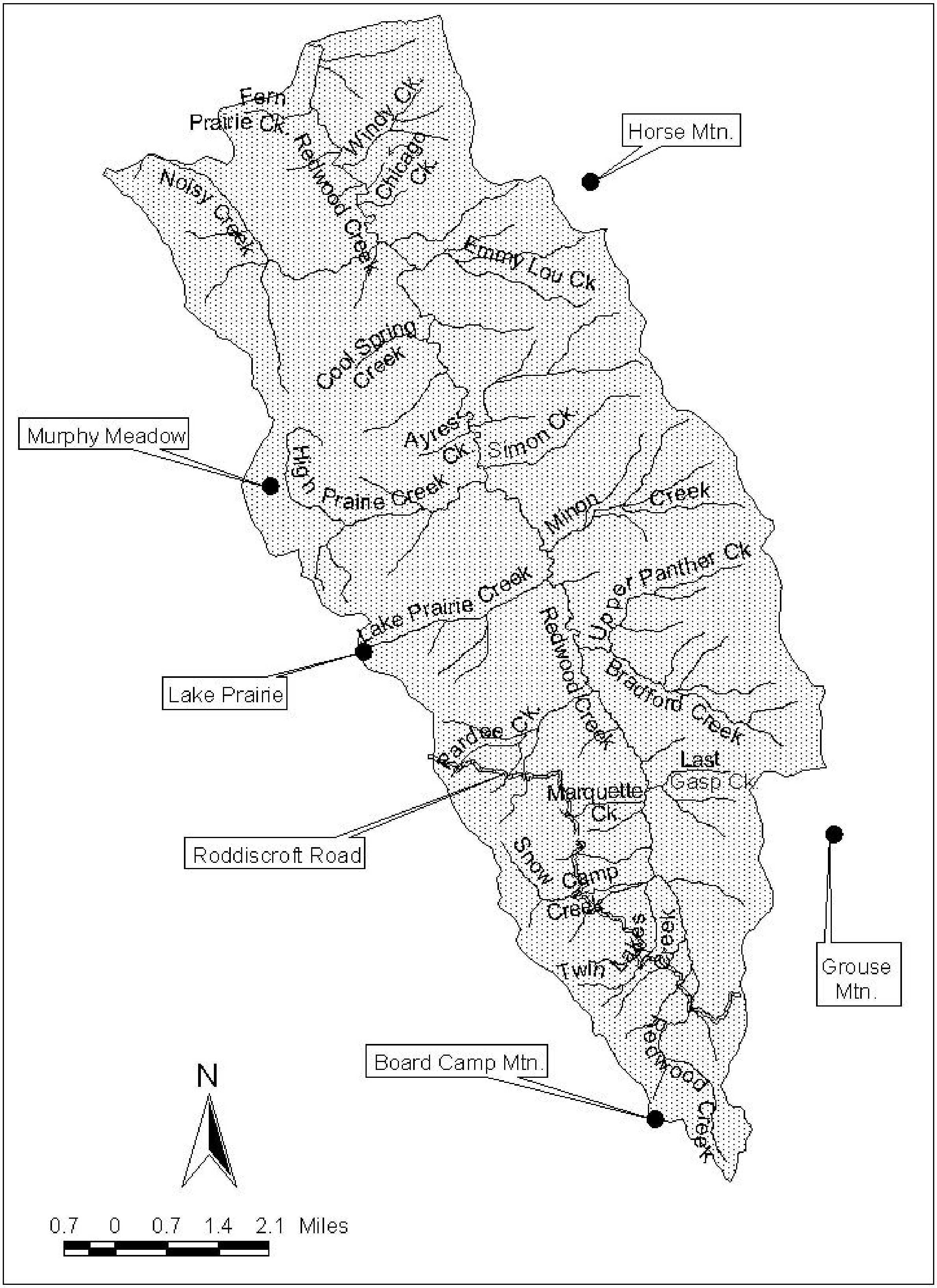

Figure IV- 51. Upper Subbasin and its tributaries.

Geology

The lower portion of the Upper Subbasin starts near Fern Prairie Creek to the west and Captains Creek to the east. The channel of Captains Creek closely follows a mapped cross-fault. The Coherent Unit of Lacks Creek (KJfl) and Incoherent Unit of Coyote Creek (KJfc) rocks are offset along this fault. The cross fault continues into the Schist of Redwood Creek, but does not appear to offset its western contact with the Sandstone and Mélange of Snow Camp Mountain (KJfsc).

The upper mainstem of Redwood Creek lies within a narrow channel that follows the trace of the Grogan Fault zone. Abundant streamside landslides flank the narrow main stem channel, or inner gorge. These slides appear to have delivered sediment directly into the creek (Madej 1984).

The Grogan Fault Zone widens to nearly 0.75 miles at the Captains Creek cross fault. From this point south 4.5 miles, the Redwood Creek channel exhibits a striking series of sharp zigzag bends that appear to be structurally controlled. The dominant orientations appear to be southwest and northwest and nearly orthogonal to one another. These channel sections may follow major fracture sets in the underlying Grogan Fault Zone rocks.

Murphy Meadow is a large, gently east-sloping ridge-top basin straddling the western boundary of the drainage. A fault separating the Sandstone and Mélange Unit of Snow Camp Mountain (KJfs) from the Schist of Redwood Creek (KJfr) bounds the basin on the northwest and the Snow Camp Mountain Lineaments (a parallel pair of prominent aerial photograph lineaments) bound the southwest and northeast sides of the basin.

Given the type offset on a majority of the faults along this part of North America, this feature could be a fault-bounded pull-apart basin (see Appendix E for an illustration). Prior field reconnaissance by CDMG personnel identified numerous ridge-top depressions (perhaps Sackungen; see Appendix E) and marshy areas along this part of Snow Camp Ridge. Local ranchers have modified many of these features for use as stock ponds.

The cross-faulting and aerial photograph lineaments appear to continue south to the head of Redwood Creek where they culminate in the Snow Camp Creek fault zone (separates the Schist of Redwood Creek (KJfr) from the Sandstone and Mélange Unit of Snow Camp Mountain (KJfs) to the south). The Grogan Fault Zone does not appear to be offset by the Snow Camp fault zone and is mapped as continuing southeastward, partially obscured by a 0.25 mile wide, 2-mile long earth flow complex. The source of this earth flow is not clear, but it appears to have issued from what is now a deeply eroded, broad amphitheater. The major modes of mass wasting are typically rotational slides, earth flows and debris slides. Well developed gully networks are common within the more active earthflow areas and these are considered a significant sediment sources because they are directly connected to the drainage system.

The Upper Subbasin has approximately 73% of its area considered as high and very high landslide potential (Table IV- 87). Proportionally, the Windy Creek Planning Watershed has 2 to 3 times more area involved in historically active landslides than the other planning watersheds in the subbasin. The incoherent unit of Coyote Creek underlies most of this area.

Streamside Landslides

Active streamside landslides were mapped from the 1984 and 2000 air photos and their density was coarsely analyzed per acre, total stream length, and drainage density (Table IV- 88 and Figure IV- 52, Figure IV- 53, and Figure IV- 54). The size of these slides was not considered in this preliminary analysis, though volume of landslides is important.

Table IV- 87. Upper Subbasin summary of relative landslide potential and landslide features.

Factor	Upper Subbasin		Planning Watersheds											
			Twin Lakes		Bradford		High Prairie		Cloney Gulch		Noisy Creek		Windy Creek	
Relative Landslide Potential	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Very Low	3,302	7.6	363	4.0	427	6.1	1,076	10.4	375	7.3	807	11.9	254	5.3
Low	4,318	10.0	889	9.7	535	7.6	1,227	11.8	426	8.3	969	14.3	272	5.6
Moderate	4,243	9.8	515	5.6	655	9.3	995	9.6	644	12.6	989	14.6	445	9.2
High	12,328	28.5	2,505	27.5	2,096	29.9	3,207	30.9	1,493	29.2	1,992	29.3	1,035	21.5
Very High	19,069	44.1	4,853	53.2	3,304	47.1	3,878	37.3	2,180	42.6	2,036	30.0	2,818	58.4
High/Very High Subtotal	31,397	72.6	7,358	80.6	5,400	77.0	7,085	68.2	3,673	71.8	4,028	59.3	3,853	79.9
GRAND TOTAL	**43,260**	**100%**	**9,125**	**100%**	**7,017**	**100%**	**10,383**	**100%**	**5,118**	**100%**	**6,793**	**100%**	**4,824**	**100%**
Landslide and Selected Geomorphic Features	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Historically Active Landslide Features Total	2,892	6.7	682	7.5	410	5.8	618	6.0	235	4.6	205	3.0	742	15.4
Earthflow	2,492	5.8	474	5.2	331	4.7	592	5.7	199	3.9	194	2.9	701	14.5
Rock Slide	227	0.5	95	1.0	22	0.3	25	0.2	36	0.7	11	0.2	38	0.8
Debris Slide	9	0	4	0	3	0	0	0	0	0	0	0	2	0
Debris Flow	165	0.4	109	1.2	55	0.8	1	0.0	0	0.0	0	0.0	0	0.0
Dormant Landslide Features Total	15,702	36.3	5,055	55.4	2,159	30.8	2,951	28.4	2,134	41.7	2,033	29.9	1,370	28.4
Selected Geomorphic Features Total	9,070	21.0	1,414	15.5	1,329	18.9	3,094	29.8	825	16.1	767	11.3	1,641	34.0
Disrupted Ground	5,219	12.1	737	8.1	979	14.0	1,488	14.3	296	5.8	376	5.5	1,343	27.8
Debris Slide Slope	2,780	6.4	383	4.2	233	3.3	1,335	12.9	380	7.4	269	4.0	179	3.7
Inner Gorge (area)	1,071	2.5	295	3.2	116	1.7	271	2.6	149	2.9	122	1.8	118	2.4
Total of All Above Features	**27,664**	**63.9%**	**7,151**	**78.4%**	**3,898**	**55.5%**	**6,663**	**64.2%**	**3,194**	**62.4%**	**3,006**	**44.2%**	**3,752**	**77.8%**

Table IV- 88. Number and indices of streamside slides by watershed, subbasins, and planning watersheds.

Subbasin or Planning Watershed Unit of Analysis	Analysis Unit Area (sq. km.)	1984 # of Active* Slides Along Streams	2000 # of Active* Slides Along Streams	1984 Indexed** Active Slides	2000 Indexed** Active Slides	% Change 1984-2000
Upper Redwood Subbasin	175.5	274	365	156	208	33
Bradford Creek	20.7	42	45	203	217	7
Cloney Gulch	42.1	24	34	57	81	42
High Prairie Creek	27.6	28	69	101	250	146
Noisy Creek	37.1	0	24	0	65	∞
Twin Lakes Creek	19.6	155	175	791	893	13
Windy Creek	28.4	25	18	88	63	-28

**Index = (# slides/analysis unit area) X 100

Results show an increase in streamside landslides in all planning watersheds except Windy Creek. The most numerous small landslides were in Twin Lakes Creek, both in 1984 and 2000. If the density of small landslides were a predictor of future sediment storage, then elevated sediment will increase in Twin Lakes Creek (beyond its already high relative amount). Some tributaries, such as Snow Camp and Twin Lakes creeks, appear to have deteriorated between 1984 and 2000. Both tributary basins showed increases in streamside landslides and elevated sediment in channels.

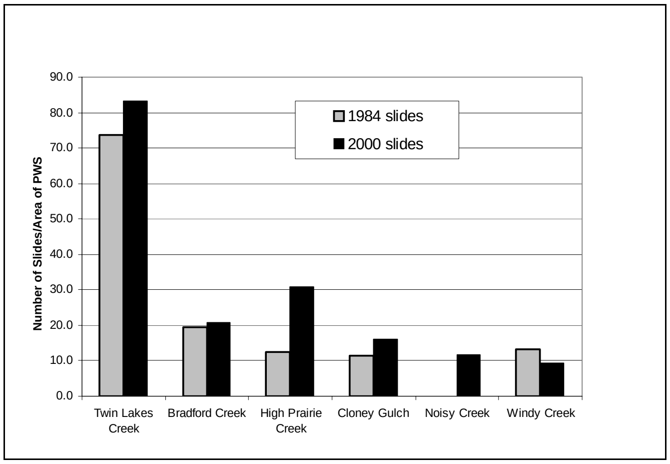

Figure IV- 52. Upper Subbasin relative density of active streamside landslides by Planning Watersheds (PWs) 1984 and 2000.

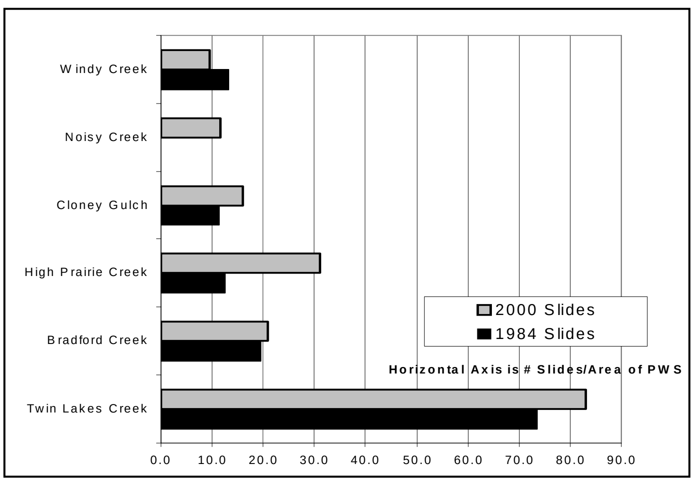

Figure IV- 53. Number of active streamside landslides mapped from 1984 and 2000 Aerial Photographs.

Plotted versus area of planning watershed (m/sq m) to make a streamside landslide "index." This chart does not indicate volumes of landslides. Twin Lakes Creek has the highest concentration of streamside landslides in both years.

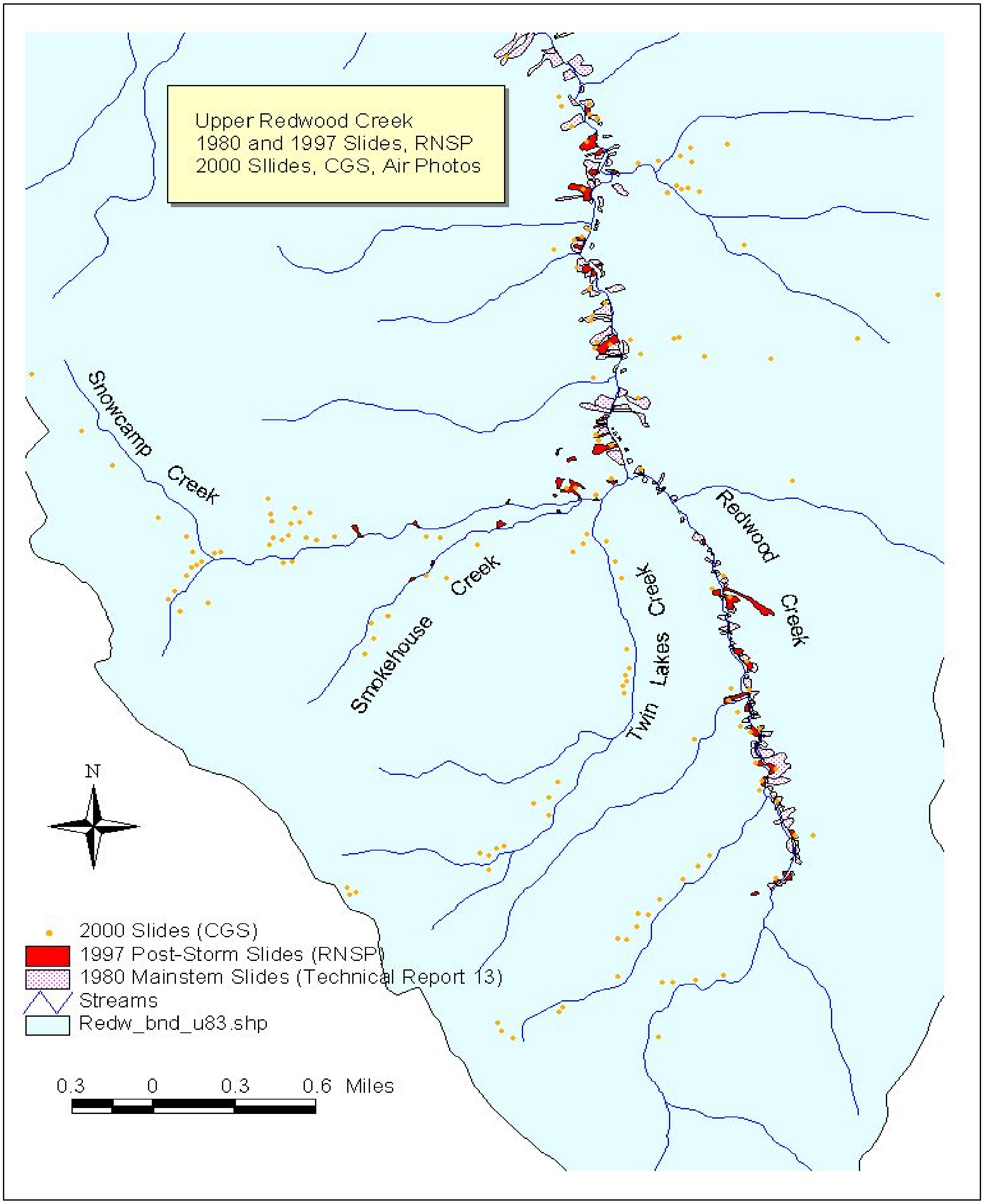

Figure IV- 54. Streamside slides in Upper Basin.
Data from CGS and RNSP.

Vegetation

Conifer dominated forests cover approximately 30,618 acres (73% of the area) within the Upper Subbasin (Table IV- 89 and Figure IV- 55). Hardwoods cover 7,308 acres (17% of the area) and grassland accounts for 3,624 acres (9% of the subbasin area). Douglas-fir is the dominant conifer cover type in the subbasin, with about 25,192 acres or 60% of the subbasin area. Pine in association with Douglas-fir form a larger component of the stands (297 acres or about 1% of the area) in this subbasin compared to other Redwood Creek subbasins. No significant barren areas are located within this subbasin. Based on field observation by CDF, The overall forest stand condition of the Upper Subbasin appears to be in good health. Productive timberland in the subbasin covers approximately 37,600 acres, or about 89% of the subbasin.

Table IV- 89. Upper Subbasin generalized cover type.

Subbasin or Planning Watershed	Cover Type								
	Agriculture	Barren	Conifer	Hard-wood	Grass-land	Shrub	Developed	Water	Total
Upper Subbasin	0	270	30,618	7,308	3,624	331	0	34	42,185
Windy Creek	0	10	3,344	955	497	4	0	6	4,816
Noisy Creek	0	22	5,172	979	495	30	0	7	6,705
Cloney Gulch	0	10	3,356	1,154	353	56	0	0	4,929
High Prairie Creek	0	61	7,025	1,716	1,437	31	0	17	10,287
Bradford Creek	0	136	4,552	1,590	404	78	0	0	6,760
Twin Lakes Creek	0	31	7,169	914	438	132	0	4	8,688

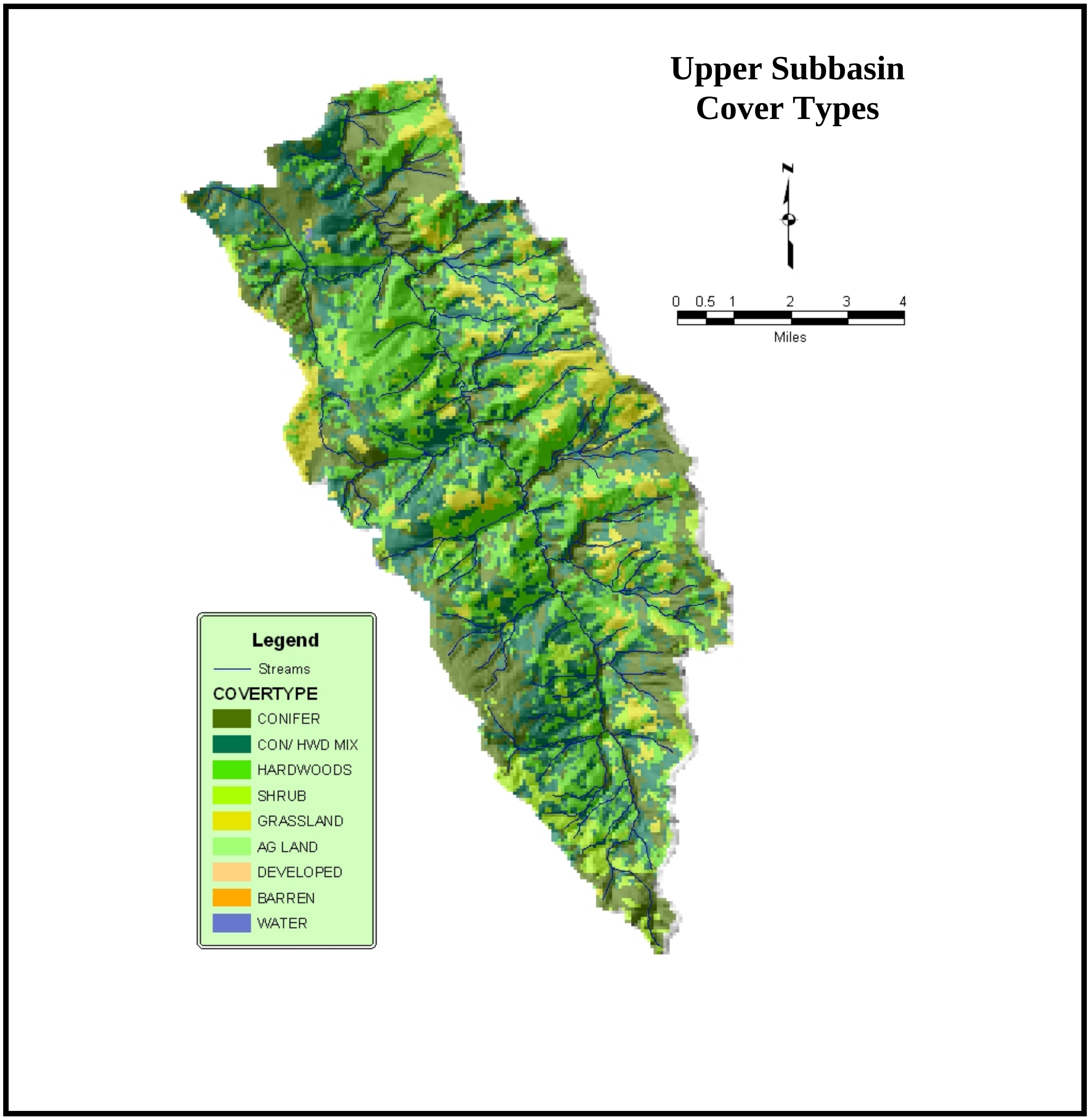

Figure IV- 55. Upper Subbasin vegetation map showing cover types.

Timber Harvest

From 1950 to 2000, 28,700 acres (94% of conifer forest) in the Upper Subbasin have had first entry timber harvests. Approximately 19% of the harvested area (5,524 acres) has been harvested with a second entry, (Table IV- 90, Table IV- 91, and Figure IV- 56). An additional 273 acres, or about 1%, of the previously harvested area has received a third harvest entry. Of the six planning watersheds within the Upper Subbasin, Windy Creek had the highest percentage of acres harvested, equivalent to over 104% of the planning watershed area. High Prairie Creek has the lowest percentage of harvested acres, 60%. This does not necessarily indicate that the area was less intensively harvested compared to some of the other planning watersheds. The planning watersheds with the lower percentage of harvested acres also support a larger land base of non-conifer vegetation types such as grasslands and oak woodlands. For the most part all portions of these planning watersheds that support conifer-growing areas have been subjected to timber harvest operations.

Clearcutting is the most common silviculture method used on the subbasin. Prior to 1978, 22,540 acres (74%) of the 30,618 acres of coniferous forest was clearcut (Best 1984). The second most utilized treatment was rehabilitation of understocked areas, i.e., converting hardwood-dominated stands to conifer stands. Yarding methods employed for timber harvesting within the Upper Subbasin are divided into three separate types for the 1990-2001 period. Ground-based skidding accounts for 86% of this total, or approximately 5,000 out of 5,800 acres.

Table IV- 90. Upper Subbasin timber harvest history, 1950-2000.

Subbasin or Planning Watershed	Harvest Acres by Period							
	1950 to 1964	1965 to 1974	1975 to 1983	1984 to 1992	1992 to 2000	Total Harvested	Total Acres	Percent Harvested
Upper Subbasin	12,958	8,393	2,829	6,494	3,857	34,531	43,336	79.7
Bradford Creek	1,747	1,455	144	1,133	451	4,930	7,032	70.1
Cloney Gulch	972	477	531	952	404	3,336	5,123	65.1
High Prairie Creek	2,200	930	107	1,232	1,780	6,249	10,405	60.0
Noisy Creek	1,723	2,857	562	873	791	6,806	6,815	99.9
Twin Lakes Creek	4,836	1005	316	1,697	310	8,164	9,162	94.0
Windy Creek	1,480	1,669	1,169	607	121	5,046	4,835	104.4

Table IV- 91. Upper subbasin multiple harvest acres.

Upper Subbasin	
Harvest Entry	Harvest Acres
First	28,734
Second	5,524
Third	273

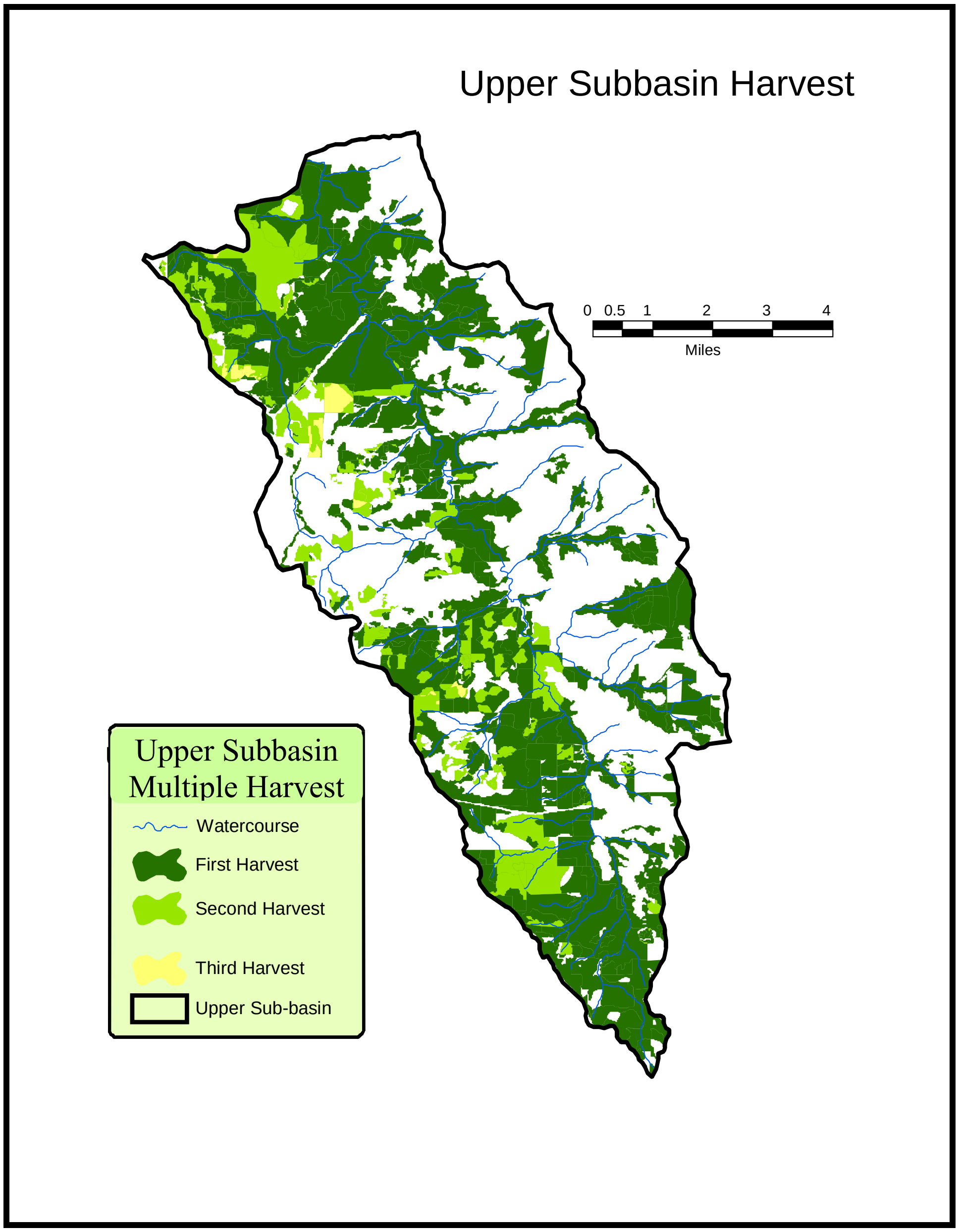

Figure IV- 56. Upper Subbasin multiple timber harvest.

Roads

Assessment of the road network in the Upper Subbasin was completed with information provided by the road assessment program in Redwood Creek. There are 553 miles of roads, of all classifications, within the Upper Subbasin of Redwood Creek. This mileage represents a relatively high road density of 8.2 miles of road per square mile of land base. Approximately 228 miles or 41% of the roads are classified as abandoned. Abandoned roads are no longer in use and do not receive any maintenance. Most of the abandoned road miles are located in the lower portions of the canyons and/or within close proximity to watercourses. Approximately 246 miles or 44% of the total road miles were constructed prior to 1958 (Figure IV- 57). Pre-1958 road construction standards were very different from the standard practices of today. Roads built in that era generally lacked sufficient culvert sizing, did not have compacted road fills, were built wider than today's standards, and lacked sufficient cross drains and ditches. Roads built to these older standards, absent any upgrading and maintenance can produce and deliver significant amounts of sediment to the stream system. About 81% of the roads were constructed prior to modern Forest Practice Rule standards and 41% of the roads miles are abandoned.

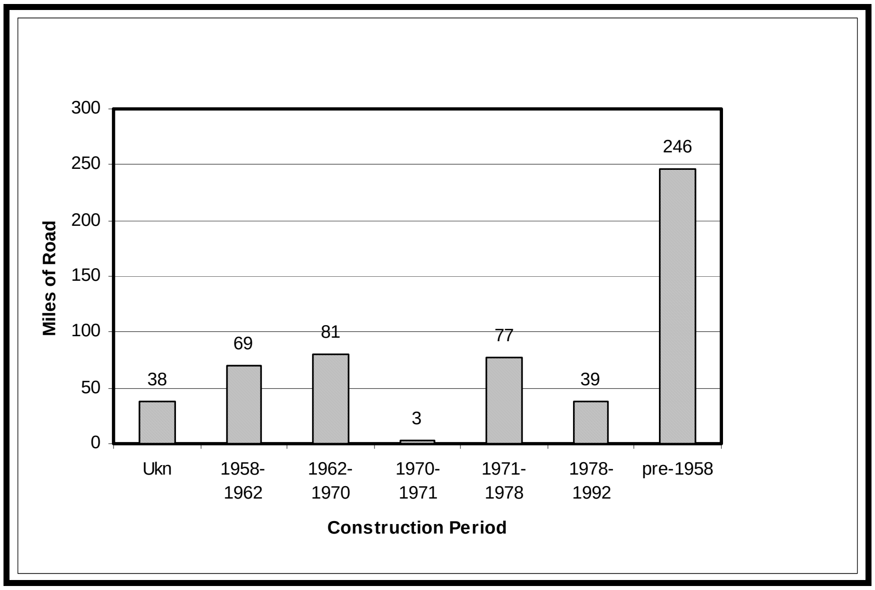

Figure IV- 57. Upper Subbasin miles of road construction by period.

Location of roads within 50 feet of a watercourse also was assessed. Abandoned roads within 50 feet of a watercourse total 52.4 miles. Approximately 67.5% of the roads near a watercourse were constructed before 1962. From this review of roads, it appears that the current road system in the Upper Subbasin has a high potential to generate and deliver sediment to stream channels.

Fire and Fuels

Looking at fire and fuels issues, the Upper Subbasin is dominated by fuels classed in the high (55% of the area) and moderate (36% of the area) ranks (Table IV- 92and Figure IV- 58). The Cloney Gulch planning watershed appears to have the largest contiguous areas of very high ranked fuels.

Table IV- 92. Upper Subbasin fuel ranks summary.

Area of Analysis	Fuel Rank								Total Acres
	Moderate		High		Very High		Not Mapped		
	Acres	% Acres	Acres	% Acres	Acres	% Acres	Acres	% Acres	
Upper Redwood Creek Subbasin	15,588	36	24,027	55	3,678	8	80	<1	43,373
Windy Creek Planning Watershed	1,841	38	2,895	60	92	2	7	<1	4,835
Noisy Creek Planning Watershed	2,440	36	3,966	58	392	6	17	<1	6,815
Cloney Gulch Planning Watershed	1,597	31	2,918	57	603	12	5	<1	5,123
High Prairie Creek Planning Watershed	3,730	36	5,848	56	806	8	21	<1	10,405
Bradford Creek Planning Watershed	2,405	34	3,789	54	828	12	10	<1	7,032
Twin Lakes Creek Planning Watershed	3,576	39	4,611	50	956	10	19	<1	9,163

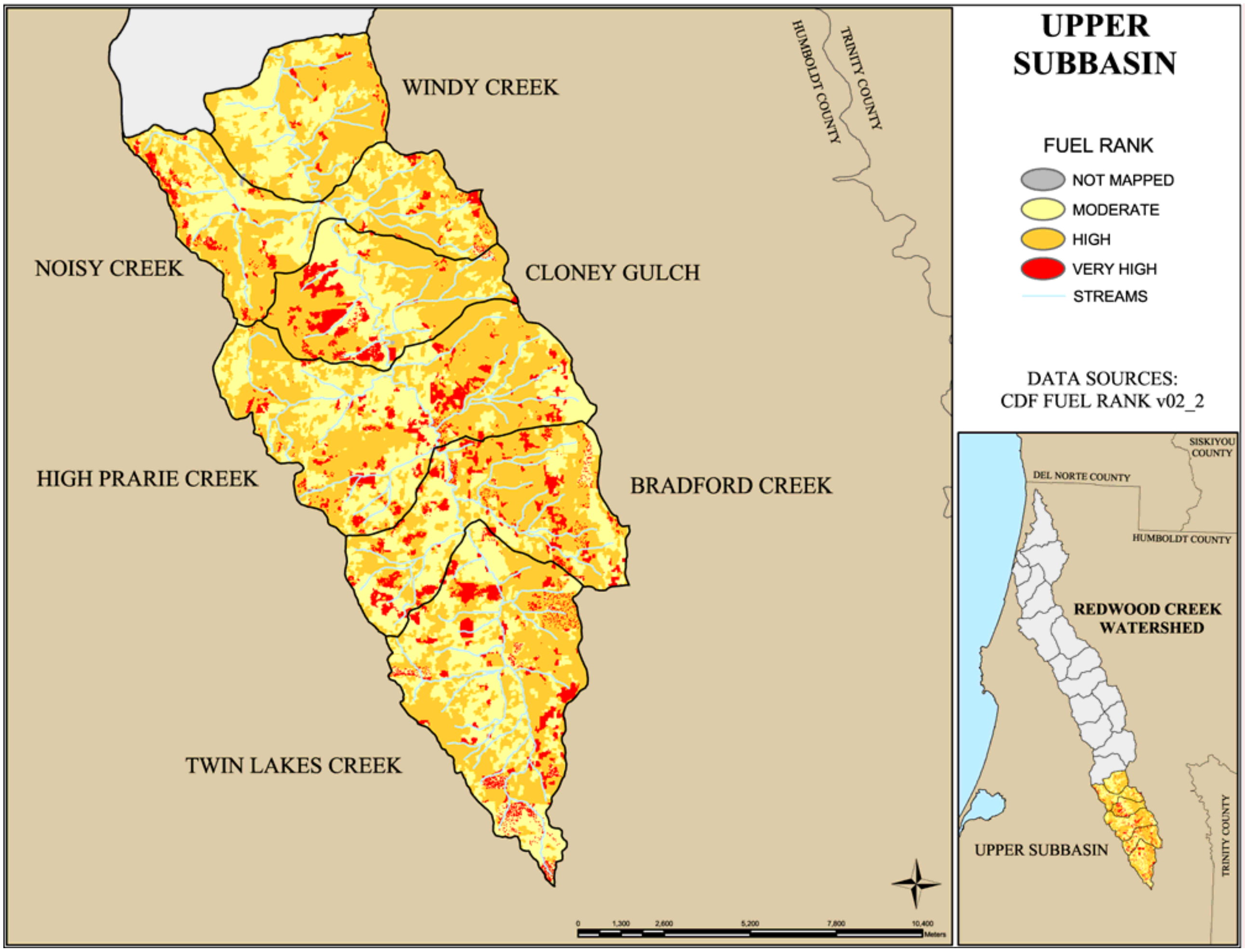

Figure IV- 58. Upper Subbasin fuel ranking map.

Fluvial Geomorphology

The Upper Subbasin contains about 120 miles of blue line tributary streams and 21 miles of mainstem Redwood Creek channel (Table IV- 93). Of these stream miles, 41% are source reaches 45% are considered transport reaches (by length). The miles of source and transport reaches in tributary streams have the potential to deliver sufficient sediment to overload the mainstem channel during large rain events, as occurred in 1964 and to some extent in smaller flood events. Response reaches are only about 14% of the total stream length and are mostly found in Redwood Creek mainstem All but the uppermost three to four miles of the mainstem channel gradient is <4% which allows anadromous fish passage to spawning areas high into the basin.

Table IV- 93. Upper Subbasin stream miles.

Planning Watershed	Area (Acres)	Miles of Blue Line Streams	Miles of Redwood Creek Mainstem	Number of Blue line Tributary Segments (Number of these that drain directly into Redwood Creek)
Windy Creek	4,835	12.8	3.7	10 (8)
Noisy Creek	6,815	14	3.2	9 (3)
Cloney Gulch	5,123	14.2	3.2	8 (5)
High Prairie Creek	10,405	28	2	12 (4)
Bradford Creek	7,032	21	1.8	13 (3)
Twin Lakes Creek	9,162	30	7.4	19 (12)

The flood of December 1964 introduced enormous volumes of sediment into the upper part of Redwood Creek (Janda and others 1975). Cut logs were washed from steep slopes into the mainstem channel (Kelsey and others

1981) to form massive log jams, which backed up sediment to depths of 20-30 ft. More than 600 streamside landslides delivered sediment directly into Redwood Creek (Kelsey and others, 1981). Channel-bed elevations increased (Madej and Ozaki 1996) and the capacity of the channel to convey peak flows was reduced. The mainstem channel banks eroded and widened in an attempt to accommodate flood peaks (Janda and others 1975). Portions of the mainstem channel in the middle and upper parts of Redwood Creek doubled in width because impacts associated with the storm and flood of 1964 (Nolan and Marron 1995).

Since 1974, the mainstem channel bed in the Upper Subbasin has degraded as large quantities of sediment were transported downstream and exposing bedrock. In 1980, staff of RNSP mapped the channel in great detail and reported their findings in a park technical report (Kelsey and others 1981). They mapped every gravel bar and streamside landslide at a scale of 1: 6,000, much as NCWAP did twenty years later and at a much smaller scale. By 1980, the flood deposits left in December of 1964 were eroded enough to expose the 1964 riparian trees killed in the flood (Madej and Ozaki 1996).

By 1984, much sediment had been transported out of the upper basin mainstem channel. A few active bars and several larger vegetated bars were apparent in aerial photographs of the uppermost parts of the basin. The large vegetated bars may be remnants from the waning stages of the pre-1984 floods, particularly the flood of 1964.

North of Roddiscroft Road, by inspection of time series photographs, channel condition appears generally similar between 1984 and 2000. However, conditions of Noisy and Twin Lakes creeks showed increases in streamside landslides (Table IV- 88 above) and elevated sediment in channels. In 1948, the area was unharvested and roadless. In the 1965 photo, the east side of the basin had been heavily harvested; steep lower eastside slopes were riddled with logging roads. The mainstem channel of 1965 was filled with continuous unvegetated sediment along its length; discrete stream bars were not visible. New streamside landslides appeared that had not existed in 1948. By 1984, discrete stream bars had formed. By 2000, revegetation hid many road scars. Compared with the 1948 photos, the 2000 channel appears wider, gravel bars appear bigger, and canopy is decreased.

Based on air-photo mapping of year 2000 photos at 1:24,000, Twin Lakes Creek, High Prairie Creek, and Noisy Creek planning watersheds in the Upper Subbasin showed an elevated amount of stored sediment. In contrast, Lake Prairie Creek appeared to have relatively less stored sediment in its channels. The mainstem contained an abundance of sediment in the area of Twin Lakes Creek and much less stored sediment downstream in the areas of Bradford and High Prairie Creeks. Farther downstream, stored sediment increased to moderate amounts along the mainstem of Redwood Creek.

The length of stream disturbance features decreased overall in the Upper Subbasin between photo years 1984 and 2000, from 23.9 mi to 15.9 miles (Table IV- 94). However, a number of tributaries gained in net stream disturbance during this time period, as described in more detail below. Tributaries that deteriorated and probably contained post-1984 sediment sources include Noisy, High Prairie, Minon, Snow Camp, Twin Lakes, and Lineament Creeks.

An example of how land use can exacerbate mass wasting was observed in Lake Prairie Creek, located in the High Prairie Creek Planning Watershed. In 1997, soon after intensive timber harvests, a bridge failure during a stressing storm is believed to be the initial cause of a debris torrent that affected Lake Prairie Creek. The bridge was deteriorating and was scheduled for replacement, but the storm came first.

The debris torrent removed riparian vegetation along the stream banks and resulted in 8 -15 feet of scour in the channel. A tremendous amount of sediment was delivered to the mainstem Redwood Creek. A large debris jam formed just upstream of the Lake Prairie Creek mouth and a large mass of sediment accumulated upstream of the jam. The debris jam and sediment accumulation at the creek mouth became a barrier to anadromous salmonids and the scouring off of riparian vegetation left the stream flow open to direct solar heating.

Comparing the number of active streamside landslides (Table IV- 88) and lengths of negative sediment (Table IV- 94) mapped in each planning watershed in 1984 and 2000. Only Windy Creek shows an improvement in both tables, decreasing in both elevated sediment and number of streamside slides. In contrast, High Prairie, Noisy, and Twin Creeks show deterioration between 1984 and 2000, with increases in both streamside landslides and negative stream features.

Table IV- 94. Upper Subbasin negative stream features, negative stream feature index, and percent change for 1984 to 2000.

Subbasin or Planning Watershed Unit of Analysis	Analysis Unit Area (sq. km.)	Negative Features 1984 (m)	Negative Features 2000 (m)	Indexed Negative Features 1984*	Indexed Negative Features 2000*	% Change 1984-2000
Upper Subbasin	175.5	37,152	27,063	212	154	-27
Bradford Creek	28.4	6,906	1,511	243	53	-78
Cloney Gulch	20.7	10,206	1,177	493	57	-88
High Prairie Cr	42.1	3,607	3,688	86	88	2
Noisy Creek	27.6	2,163	5,633	78	204	160
Twin Lakes Cr	37.1	8,384	13,427	226	362	60
Windy Creek	19.6	5,886	1,627	300	83	-72

* Index = (length of negative features in meters/area of unit of analysis in square kilometers)

Water Quality

Water Column Chemistry

Water chemistry in the Upper Basin was sampled from 1973-1975 at the USGS O'Kane gauging station at the Highway 299 bridge at the lower end of the subbasin. Data show that dissolved oxygen ranged from 8-12mg/L (water quality objective >8mg/L), pH data ranged from 7-8.5 (water quality objective 6.5-8.5) and conductance ranged from 50-150umhos (water quality objective <220umhos). This headwaters area provides important information on the base level water quality for the Redwood Creek basin. Impacts to this area may have lasting affects to water quality downstream and throughout the watershed. Although rough terrain and steep channels make sampling difficult, an effort should be made to characterize the water chemical parameters in this area, especially to monitor the potential impacts of land use activities such as herbicide applications. Data from the upper watershed obtained for this assessment show compliance with Basin Plan water quality objectives and no noticeable trends were observed. See data for the O'Kane site in the NCRWQCB Appendix.

Temperature

Water temperature of Redwood Creek in the Upper Subbasin has been monitored upstream of the confluence with Minon Creek (RM 55) and upstream of Lupton Creek at the O'Kane USGS gauging station (RM 44). Mainstem Redwood Creek water temperatures are coolest in the reach above Minon Creek, where the recent maximum MWAT was 65ºF and maximum daily temperature was 71ºF (Table IV- 95 and Table IV- 96). These temperatures are one degree above desirable levels for salmonids, but are the lowest temperatures recorded in Redwood Creek over the entire basin. The relatively cool temperatures are likely due to cold water inputs from tributaries, riparian shading, and close proximity to the cool, headwater source area. Water temperatures rise quickly along the 11.5 mile reach between Minon and O'Kane gauging station. In 1997-2001 the MWAT was 71ºF and maximum daily temperature rose to 80º F at the O'Kane site. Although these are high, this may be showing a declining trend for water temperatures. There is a lack of riparian shade along this reach below Minon Creek and the stream is exposed to direct sunlight. These high temperatures may cause stress, damage, or death to salmonids or limit their summer habitat to cool refuge sites that may occasionally occur in the Upper Subbasin.

Upper Subbasin tributaries had MWATs of 54 to 62ºF which are within a desirable range to support anadromous salmonids (Table IV- 95). Maximum daily temperatures recorded during the summers of 1996 to 2001 for the tributary sites were between 57 and 65ºF, which are considered generally good for salmonids (Table IV- 96). The highest MWAT and maximum daily temperatures are from Minon Creek and Lake Prairie Creek. The debris torrent in Lake Prairie Creek removed a large area of riparian vegetation from the banks during the winter of 1997 which led to increasing water temperature. As the riparian vegetation and shade canopy grows back, a reduction of water temperature in Lake Prairie Creek should follow.

Table IV- 95. MWATs for Upper Subbasin sites.

Site ID	Site	Subbasin	Period of Record	Max MWAT year	Max MWAT (°F)
3007, RwMin	*RedCrk upstm Minon Creek5	Upper	1997-99	1998	65
3008, RwOkn	*O'Kane gauging station RedCrk upstm Lupton Creek5, 1	Upper	1997-99,2001	1998	71
608	High Prairie Creek5	Upper	1998	1998	56
614	Upper High Prairie Creek5	Upper	1998	1998	56
611	Minon Creek mainstem5	Upper	1998	1998	62
612	Upper Minon trib5	Upper	1998	1998	54
613	Upper Minon Creek5	Upper	1998	1998	54
5041901	Lake Prairie Creek6	Upper	1996-99	1998	60
5043201	Pardee Creek6	Upper	1996-99	1996	58

Table IV- 96. Seasonal maximum temperatures for Upper Subbasin sites 1996-2001.

Site	Stream Location	Stream	Subbasin	Yr96	Yr97	Yr98	Yr99	Yr00	Yr01
3007	RedCrk upstm Minon	Redwood Creek	Upper		70°F	69°F	71°F		
3008	RedCrk@O'Kane	Redwood Creek	Upper		80°F	79°F	78°F		77°F
608	High Prairie	High Prairie	Upper			57°F			
614	Upper High Prairie	High Prairie	Upper			57°F			
611	Minon mnstm	Minon	Upper			65°F			
612	Upper Minon	Minon	Upper			57°F			
613	Upper Minon trib	Minon	Upper			57°F			
5041901	Lake Prairie	Lake Prairie	Upper	59°F	65°F	64°F	63°F		
5043201	Pardee	Pardee	Upper	59°F	59°F	59°F	58°F		

In-Channel Sediment

In-channel sediment data sampled by the RNSP on mainstem Redwood Creek upstream from Lupton Creek near the O'Kane Bridge, showed a decreasing trend in median particle size from 1979 to 1995. The D_{50} met the TMDL target of >37mm in 1979 and 1981, but fell below the target from 1982 to 1995. A decrease in particle size is often associated with an oversupply of sediment. Observations by CGS from air photo analysis indicate an increase in the amount of sediment in storage from 1984 to 2000, in the vicinity of the D_{50} sampling sites, which appears to corroborate the D_{50} findings. However, the amount and consequence of that storage at this site is not known at this time. See Appendix C for the D_{50} data from this site.

The site at the O'Kane gauging station was sampled for fine subsurface sediment in 1979, 1983 and each year from 1989 to 1992 by the RNSP and USGS. The percentage of fine sediment data presented by the RNSP and USGS are not comparable to TMDL targets due to different methods of analysis. No noticeable trends can be seen from the data at this site. See Appendix C for data from the sampling events. Without current data it is difficult to make conclusions about the distribution of in-stream sediments and how they impact salmonid habitat in the Upper Subbasin.

Salmonid Habitat

Fish Habitat Relationships

The Upper Subbasin supports populations of Chinook salmon, coastal cutthroat trout and steelhead, and summer steelhead. Chinook salmon use mainstem reaches for spawning and juvenile rearing. Although the mainstem and some tributaries may provide suitable habitat for coho salmon, there is no recent account of their presence in Upper Subbasin streams.

Approximately 17 miles of mainstem Redwood Creek are available to anadromous salmonids for spawning and juvenile rearing in the Upper Subbasin. Anadromous salmonid access is blocked by a 45-foot cascade near the confluence of Snow Camp Creek, approximately 65 miles from the river mouth. "A boulder roughs section about 2,500 feet above Pardee Creek (~RM 62) may be a barrier to salmon but not to steelhead" (CDFG 1986).

Only about 5.5 miles of tributary stream habitat are accessible to anadromous salmonids. The steep channel gradients limit access by anadromous salmonids to only the lowermost reaches of the tributary streams (Table IV- 97). Most tributaries support populations of steelhead as they are able to ascend steeper gradient streams than Chinook or coho. Coastal Cutthroats are found in both anadromous reaches and above barriers to anadromous salmonids.

Based on length of accessible habitat, the most important tributary streams in the Upper Subbasin for anadromous salmonids are Minon, Bradford (Upper Panther), Noisy, Gunrack and High Prairie Creeks. These five creeks comprise 65% of the tributary stream habitat available to anadromous salmonids in the Upper Subbasin. The remaining eleven named creeks each provide 0.3 miles or less of habitat available to anadromous fish. The smaller streams may support resident salmonid populations, but also contribute cool water, sediment, and other watershed products to the mainstem Redwood Creek.

Table IV- 97. Upper Subbasin streams, species present, and number of stream miles accessible to anadromous salmonids.

Stream	Species Observed		Stream Length Access (miles)	References
Minon Creek	steelhead Pacific giant salamander	Pacific lamprey	1.1	CDFG 2001 & 1966 stream surveys, RNP/USFS-RSL revisit of 1981 thesis sites field notes, and Brown 1988
Bradford/Up. Panther Creek	steelhead		0.99	Brown 1988
Noisy Creek	steelhead		0.50	Brown 1988
Gunrack Creek	steelhead	coastal cutthroat	0.50	Brown 1988
High Prairie Creek	steelhead	coastal cutthroat	0.43	Brown 1988, CDFG 2002.
Lake Prairie Creek	steelhead pacific giant salamander	tailed frog	0.31	Brown 1988, CDFG 2002
Emmy Lou Creek	Steelhead		0.25	Brown 1988
Windy Creek	steelhead		0.25	Brown 1988
Squirrel Tail Creek	steelhead		0.25	Brown 1988
Snowcamp/ Smokehouse Creek	steelhead		0.19	Brown 1988
Pardee Creek	steelhead		0.19	Brown 1988
Simion Creek	steelhead		0.19	Brown 1988
Cut-off Meander Creek	steelhead		0.19	Brown 1988
Fern Prairie Creek	None		0.16	CDFG 2001 stream surveys and Brown 1988
Jena Creek	steelhead		0.12	Brown 1988
Xmas Prairie Creek	None		0.06	Brown 1988
Redwood Creek	Chinook steelhead	Coastal cutthroat	17.2	CDFG 2001 stream surveys, Gerstrung 2001, Anderson 2000, and Brown 1988

Past Surveys

Data describing historic fish habitat conditions are scarce for the Upper Subbasin, but based on air photo interpretation, review of CDFG reports, and anecdotal accounts, it is clear that historic conditions were quite different than we see today. In the past, riparian forests containing large conifers lined the river banks and water temperatures were likely cooler as stream reaches with closed canopy were common throughout the subbasin.

Stream surveys from 1966 and 1972 noted severe erosion of hill slopes and stream banks, and numerous log jams in the uppermost anadromous reaches of Redwood Creek (Fisk et al. 1966, CDFG 1966, CDFG 1972, Hatzimanolis 1972). The condition of upper Redwood Creek mainstem after the 1964 flood was assessed by Fisk et al. (1966) as "severely damaged" in 1966 (CDFG 1966). In 1966 and 1972 surveys also described pools as scarce with little cover and that streams lacked in aquatic insects. The surveys also noted the spawning gravels were filled in with sand and silt while other spawning sites were considered in good condition. Fisk et al. (1966) stated that "Logging activities, particularly the construction of roads and skid trails and the removal of vegetative ground cover, have been a major factor contributing to increased erosion and land slippage" resulting in the near complete loss of pools and shelter for fish as a result of excessive sediment inputs. Hatzimanolis (1972) reiterated this as he wrote: "Redwood Creek has little to offer resident trout or juvenile salmon in using it as a nursery."

2001 Surveys

In 2001, the CDFG performed stream surveys in the Upper Subbasin along two reaches of Redwood Creek (upper reach and a lower reach), and along the anadromous reaches of Fern Prairie Creek, and Minon Creek. Limited crew access and time constraints prevented a broader survey in the Upper Subbasin. Analysis of the 2001 stream surveys and a comparison with 1966 and 1972 surveys suggest that overall stream reach characteristics in Redwood Creek have improved compared to past reports. However, the condition of most of the tributaries was not assessed. Results from the 2001 surveys are discussed below.

Pool:Riffle:Run Ratios

Significance: Productive anadromous streams are generally composed of a balance of pool, riffle and run habitat, and each plays an important role as aquatic habitat. All salmonids require access to pools, runs, and riffles for feeding, seasonal rearing or spawning to fulfill their freshwater life history requirements. These channel features are influenced by slope, channel bed and bank materials, sinuosity, discharge, flow obstructions such as LWD and boulders, and disturbance from episodic events such as major floods and large sediment inputs (Leopold 1994 and Madej 1999).

A review of the pool, riffle, and run ratios shows that Minon Creek has a suitable ratio of pools by percent occurrence but the pools are generally short in length compared to riffles and runs (Table IV- 98). Fern Prairie Creek has a fair number of pools but they comprise only 8% of the survey channel length. In contrast, the lower survey reach of Redwood Creek in the Upper Subbasin is composed of approximately two thirds pools by both occurrence and by stream length. This reach is among the best of all streams surveyed in the entire Redwood Creek basin in terms pool frequency and percent reach length of pool habitat.

Table IV- 98. Upper Subbasin percent by occurrence, length of pool:run:riffle, and dry habitats in anadromous fish reaches summer 2001.

Stream	Survey Length (ft.)	Pool:Riffle:Flat water % Occurrence (1)	Pool:Riffle:Flatwater % Total Length (1)	Dry (% Total Length)	Culvert (% Total Length)
Minon Creek	6,179	34 : 27 : 35	17 : 22 : 52	9	0
Fern Prairie Creek	876	25 : 50 : 25	8 : 54 :38	0	0
Lower reach Redwood Creek	10,748	66 : 16 : 18	64 : 15 : 21	0	0
Upper reach Redwood Creek	13,996	37 : 26 : 36	26 : 52 : 21	1	0

[1] Includes side channel and secondary channel habitats

Pool Depth

Significance: Evaluating the amount of deep pool habitat in a stream reach helps assessment of important channel characteristics for fish. Deep pools are important as year round rearing habitat for salmonids and especially important as winter habitat for coho salmon and coastal cutthroat trout and adult summer steelhead summer. Lack of deep pools may indicate a disruption to channel forming processes due to a lack of LWD or elevated levels of stored sediments.

The lower survey reach (a 4th order reach) of Redwood Creek is composed of approximately 65% pool habitat. Approximately 20% of the reach is composed of pools with maximum depths of 4 feet or greater (Figure IV-59). The combination of the number, length, and depth of pools makes this reach among the best for pool habitat in the Redwood Creek Basin. The survey reaches in Upper reach of Redwood Creek, Fern Prairie, and Minon creeks were generally lacking in deep pool habitat. Pools in Minon Creek only occupy 17% of the stream length and only a little over one-third of these had maximum depths greater than two feet. Fern Prairie Creek had approximately 6% of its length in pools and all of the pools were less than two feet deep.

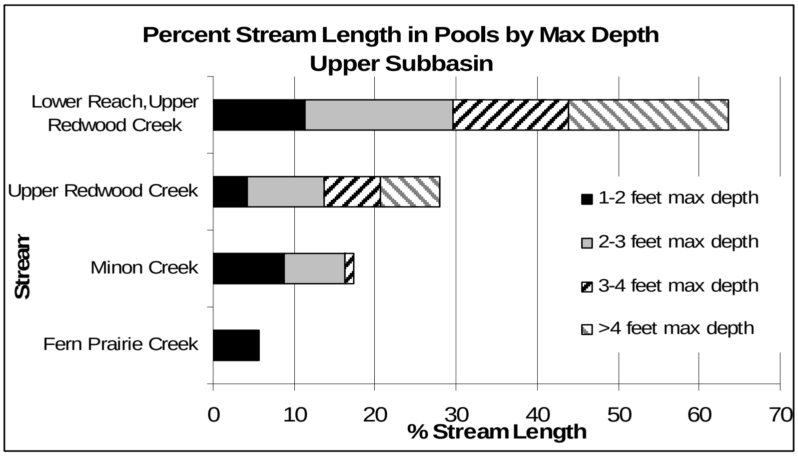

Figure IV- 59. Upper Subbasin percent survey reach in pools, grouped by maximum depth.

Pool Shelter

Significance: The pool shelter rating is a relative measure of the quantity and composition of LWD, root wads, boulders, undercut banks, bubble curtains, and submersed or overhanging vegetation. These elements serve as instream habitat, create areas of diverse velocity, provide protection from predation, and separates territorial units to reduce density related competition. The rating ranges from 0-300 do not consider factors related to changes in discharge, such as water depth. A pool shelter rating of approximately 100 is desirable (Flosi et al. 1998).

The average shelter rating values for pools surveyed in the Upper Subbasin was far below the desirable value of 100 (Figure IV- 60). Shelter in the two tributaries and two mainstem reaches of Redwood is dominated by boulders. Woody debris shelter was the subdominant cover type in all reaches except the lower reach of Redwood Creek where bedrock ledges were subdominant (Table IV- 99). Similar to most streams in Redwood Creek basin, cover in the form of woody debris is lacking in pools of the Upper Subbasin.

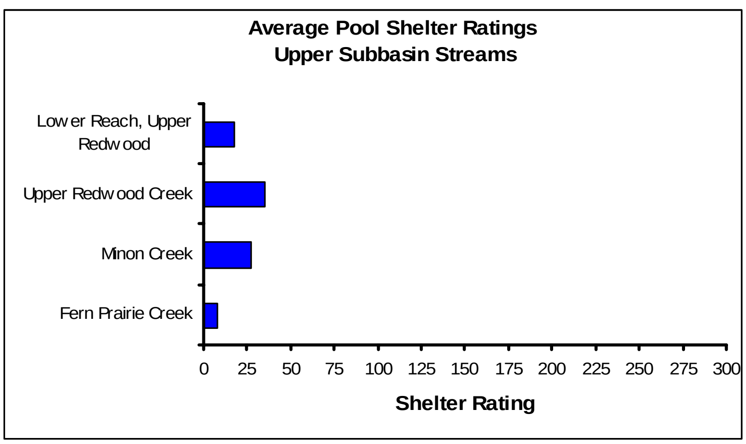

Figure IV- 60. Upper Subbasin mean shelter rating for pools surveyed.

Table IV- 99. Upper Subbasin summary of mean percent cover of dominant (1) and subdominant (2) shelter types in pool and flatwater units.

Streams	Undercut Banks	Woody Debris	Terrestrial Vegetation	Aquatic Vegetation	White-water	Boulders	Bedrock Ledges
Minon Creek		2				1	
Fern Prairie Creek		2				1	
Lower reach Redwood Creek						1	2
Upper reach Redwood Ck		2				1	

Streamside Canopy Density

Significance: Streamside canopy density is a measure of the percentage of wetted stream that is influenced by riparian tree canopy. Tree canopy provides shade to reduce direct sun light from warming water, provides a source of nutrients in the form of organic debris, and leaf litter, terrestrial insects, and is an important source of woody debris for instream habitat. The roots of riparian vegetation also help maintain soil and stream bank stability. A desirable streamside canopy should average at least 80% over a survey reach and generally be composed of a mix of coniferous and deciduous trees (Flosi et al. 1998). A shade canopy of coniferous trees is desirable because they are taller, may provide a grater amount of shade, and the overstory canopy helps moderate air temperatures and keep streams cool. Additionally LWD from large sized conifers may stay in channels and resist decay much longer than smaller deciduous or other hardwood trees.

The overall canopy density along Minon and Fern Prairie creeks provides good shade over the water, but the coniferous component is small (Figure IV- 61). Shade canopy over Redwood Creek is below desirable levels at 63% and 50% for the upper and lower reach of Redwood Creek respectively. Furthermore, the coniferous component is also small. Lack of shade over the mainstem Redwood Creek allows direct heating of water by solar radiation. The positive affects from large nearstream conifers are lacking in all surveyed streams.

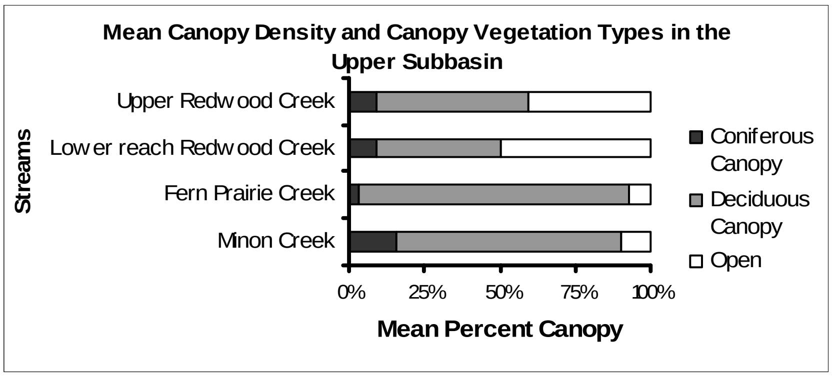

Figure IV- 61. Upper Subbasin mean canopy density and canopy vegetation types from streams surveyed.

Spawning Cobble Embeddedness

Significance: Percent cobble embeddedness helps determine suitability of substrate for salmonid spawning, egg incubation, and fry emergence. Clean gravels and cobbles, free of fine sediment are best for spawning success. Substrate less than 25% embedded in fine sediments is considered high quality salmonid spawning habitat (Flosi et al. 1998). Highly embedded spawning substrate generally indicates excessive stream bank or hillslope erosion occurring upstream and fine sediments entering the stream channel.

The majority of spawning substrate observed in pool tails of the Upper Subbasin was above 25% embedded (Figure IV- 62). Minon Creek had the highest percentage of suitable quality spawning substrate, with approximately 30% of the sample sites considered good spawning habitat.

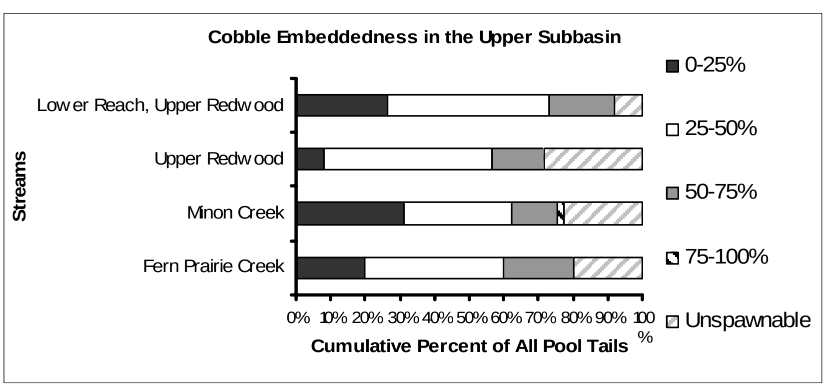

Figure IV- 62. Cobble embeddedness in Upper Subbasin streams.

Salmonid Fishery Resources

Coho Salmon

Coho were not observed in Upper Subbasin streams during 2001 surveys or in the downstream migrant trap located near the confluence of Toss Up Creek years 2000 -2003. Past stream reports do not cite evidence of coho presence in Upper Subbasin streams. Because the mainstem Redwood Creek has less than 3% gradient until the boulder roughs section about 2,500 feet above Pardee Creek (~RM 62), coho could utilize the upper mainstem and tributaries for spawning and juvenile rearing habitat. Prior to the 1964 flood, the Upper Subbasin mainstem may have supported coho. No records or anecdotal reports of their presence in the Upper Subbasin were found in our data search, but little information of any kind describing historic fish presence in the Upper subbasin is available.

Chinook Salmon

Chinook utilize the mainstem Redwood Creek of the Upper Subbasin for spawning and juvenile rearing. Although older stream reports do not cite evidence of Chinook presence in the Upper Subbasin tributary streams, it is likely that they occasionally use the lower reaches of some tributaries for spawning.

Ninety-five Chinook redds or 5.3 redds per mile were counted in eighteen miles of surveyed reach above Toss Up Creek in 2000-2001. The uppermost eight of these miles are within the Upper Subbasin which represents approximately half of the total length of spawning habitat available to Chinook in the Upper Subbasin. In general, fewer redds were observed per mile as surveyors proceeded upstream. The survey reach ended before the end of available Chinook spawning habitat. Further discussions of recent Chinook studies that include the Upper Subbasin are provided in the Middle Subbasin and Watershed Profile sections of this report.

Steelhead

Steelhead have been observed in 16 tributary streams and are the most commonly observed and widely distributed species found in the anadromous reaches of the Upper Subbasin streams. The best mainstem Redwood Creek juvenile steelhead rearing habitat is thought to be above Minon Creek. Water temperatures in this reach are generally considered good for steelhead production.

Electrofishing efforts in 2001 in the Upper Subbasin tributaries were limited to Minon Creek. The survey efforts yielded 109 steelhead (73 age 0+, 34 age 1+, and 2 age 2+) for approximately 400 feet of electrofishing in pool type habitat exclusively. These data indicate that the relatively modest amount of pool habitat present in Minon creek is suitable for the advancement of 0+ to 1+ year classes. However, the advancement of age 1+ to 2+ may be limited by habitat conditions in Minon Creek. Alternatively, due to the shortage of deep pool habitat, the larger and older steelhead of Minon Creek may move downstream and take up residence in the suitable reaches of mainstem Redwood Creek.

Summer Steelhead

The summer steelhead is a unique stock of steelhead that migrate from the ocean into Redwood Creek from March through June, but do not spawn until the following rainy season. Summer steelhead depend upon deep, complex and cool pools of the Upper Subbasin for over summer habitat, as they wait for the fall rains to complete the spawning run.

Dive surveys of Redwood Creek from 1981-2000 produced counts of adult summer steelhead that ranged from 3 fish in 2000 to 37 fish in 1997 (see Figure III-44). The low counts of summer steelhead indicates that they are likely the most threatened by extirpation of all the anadromous stocks in the Redwood Creek basin. The main reason for the decline is summer steelhead is likely due to a drastic reduction of deep, complex pools that persisted for years after the flood of December 1964 and other similar events. Elevated water temperatures and loss of juvenile rearing habitat may also play a role in their decline.

Coastal Cutthroat

The abundance and distribution of coastal cutthroat in the Upper Subbasin is not well known. They have been observed in mainstem Redwood Creek, Gunrack and High Prairie creeks, but it is unclear whether these are resident or anadromous stocks. Resident populations of coastal cutthroat and rainbow trout are found upstream of anadromous tributary reaches in High Prairie Creek. The downstream migrant trapping efforts in the Middle Subbasin yielded 17 cutthroats from the 2000 to 2002 trapping years.

Upper Subbasin General Issues

The Upper Subbasin is highly susceptible to erosion:

- Seventy-two percent of the subbasin has high or very high land slide potential;
- Land use such as timber harvest activities exacerbate erosion potential;
- Recently the Upper Subbasin has produced more sediment than the Middle and Lower Subbasins combined;
- The Upper Subbasin generates and exports sediments that contribute to aggradation and persistent impairment of salmonid habitat in the Lower and Estuary subbasins.

Land management can influence watershed processes:

- Land uses, such as timber harvest activities, increase erosion potential over much of the Upper Subbasin;
- High road density of both abandoned and useable roads adds to instream sediment delivery potential;
- Debris slides and debris flows are often initiated by management activities (such as road construction) that take place on existing earthflows or rockslides.

Riparian and near stream forests have been altered by timber harvests and bank erosion:

- Timber harvests have caused significant levels of disturbance to riparian and near stream forest areas causing a reduction in both overstory shade canopy and LWD input potential;
- In response to aggraded channels, stream banks erode, channels widen, and riparian vegetation becomes less affective to provide shade over the water.

Impairments to freshwater habitat needed to complete salmonid freshwater life cycles have been identified as a leading factors in the decline of Redwood Creek's anadromous salmonids:

- Water temperatures increase quickly to above desirable levels in the upper mainstem Redwood Creek due to the widened stream channel and lack of riparian shade canopy;
- Water temperature in monitored tributary streams is generally suitable for anadromous salmonids;
- Mainstem Redwood Creek, Fern Prairie Creek and Minon Creek provide some deep pools, but these streams are below desirable target levels for amount of deep pool habitat;
- Instream shelter is lacking in Redwood, Minon, and Fern Prairie creeks.

Integrated Analysis and Cumulative Effects

The Upper Subbasin includes approximately 19 miles of Redwood Creek beginning in the headwaters and extending through the Windy Creek Planning Watershed near the Highway 299 Bridge. Due to its inland location, the Upper Subbasin is generally not influenced by coastal fog or marine air masses. Thus, air temperatures of the Upper Subbasin vary between over 100°F in the summer to below freezing in the winter months. The Upper Subbasin receives an average of 98 inches of rainfall per year. The high elevations the Upper Subbasin are also capable of receiving and storing a substantial amount of snowfall. The high amount of precipitation, unstable geology, and steep relief make the Upper Subbasin vulnerable to landsliding and other forms of mass wasting. Land uses, such as timber harvest activities, increase erosion potential over much of the Upper Subbasin.

These land use and weather factors came together in December of 1964 when the rain on snow flood, triggered landslides, road failures, gully erosion, and other erosion processes across the recently clear cut timber lands of the Upper Subbasin. Excessive amounts of sediment were delivered to the mainstem channel. In order to maintain channel capacity and accommodate flood flows, stream banks eroded and the channel within the Upper Subbasin widened up to 150% from its former width. In addition, newly formed gravel terraces grew so voluminous that riparian vegetation was buried and many trees near the stream banks died.

Presently the Redwood Creek channel has returned to pre 1964 bed elevations over much of its length as much of the instream sediment has moved to downstream reaches. However, compared to conditions prior to 1964, the channel is still considerably wider, the stream is shallower, shade over the stream is largely absent, and large stores of sediment that impair re-growth of tress are still present in terraces adjacent to the stream channel.

A cumulative effect from the wide and shallow mainstem channel and lack of shade canopy is the stream is exposed to direct dun light which rapidly heats stream flows during the summer months. Water temperatures measured by MWATs increase from 65°F just above Minon Creek to 71°F at the O'Kane gauging site (near Highway 299) which is well above desirable target values to support salmonids. The distance between the two sites is approximately 11.5 miles. Most of the warming of all Redwood Creek occurs along this reach. There is a series of pools located along the lower reach within the Upper Subbasin that would provide better salmonid habitat if the cool water extended to the O'Kane site.

Subbasin-wide, 2,892 acres or 6.7% of the area is comprised of historically active landslide features with earthflows as the predominant landslide feature type (Table IV- 100). Sixty-one percent of the active landslide features are located on grasslands and woodlands and the remaining 39% is located on forestlands. Windy Creek Planning Watershed has the highest percentage of area (15%) in historically active landslide features followed by Twin Lakes Creek (7%). Noisy Creek Planning Watershed has the least percentage of area in active landslide features (3%). The majority of recent timber harvests on active landslide features have been conducted in the Windy Creek (90 acres) and High Prairie (45 acres) creek planning watersheds.

There are approximately 22 miles of roads located on active landslide features within the Upper Subbasin or five miles of roads per square mile. The highest road density on active landslide features is in the Windy Creek Planning Watershed where there are approximately eight miles of road per square mile of active landslide features.

Analysis and comparisons at the planning watershed scale are complicated because the planning watersheds span across the Grogan fault and are composed of more than one major bedrock units. However, these data suggest a potential concern because of the amount of current land use and the amount of active landslide features within the planning watersheds. Windy Creek Planning Watershed has the highest percentage of active landslide features in the subbasin and with its high road density on landslide features and highest amount of recent timber harvest activity on landslide features.

Table IV_ 101 broadens the view of potential slope instability and land use interactions by addressing relative landslide potential. Seventy-two percent of the Upper Subbasin falls into high and very high relative landslide potential classes. The bulk of this area is comprised of timberlands with no recent harvest (48%), followed by recent THPs (18%) and woodland or grassland (5%). Windy and Twin Lakes planning watersheds share the greatest percentage (80%) of area in the two highest relative landslide potential classes, followed by Bradford Creek (77%). The planning watershed with the smallest percent of their area in the highest two relative landslide potential classes is Noisy Creek (59%). Approximately 75% of the high and very high landslide potential terrain is located on forestlands leaving 25% on grasslands and woodlands.

Ten percent of the Upper Subbasin was in recent THPs (1991– 2000) with half of the harvest on areas with high or very high relative landslide potential. The Lake Prairie Planning Watershed had the most timber harvest activity with 18% of the planning watershed in recent THPs during the 1991-2000 decade. In the Lake Prairie Planning Watershed 12% of the area in THPs is on land in the highest landslide potential classes. Three percent of the Windy Creek Planning Watershed was recently in THPs while Noisy Creek had 9% of its area in THPs.

Table IV- 100. Upper Subbasin acres and percent area of historically active landslide features associated with land type or use.

Subbasin or Planning Watershed	Historically Active Landslide Feature[1]	Subbasin or Planning Watershed		Woodland and Grassland[2]		THPs 1991 - 2000[5]		Timberland, No Recent Harvest[3]		Roads[4]	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Upper Redwood Creek Subbasin (43,343 acres) (501.2 road miles)	Earthflow	2,492	5.7%	1,743	4.0%	137	0.3%	542	1.3%	18	3.5%
	Rock Slide	165	0.4%	4	0.0%	0	0.0%	160	0.4%	1	0.3%
	Debris Slide	227	0.5%	8	0.0%	10	0.0%	208	0.5%	2	0.5%
	Debris Flow	9	0.0%	1	0.0%	0	0.0%	9	0.0%	0	0.0%
	All Features	2,892	6.7%	1,756	4.1%	147	0.3%	919	2.1%	22	4.3%
Bradford Creek (7,027 acres) (72.3 road miles)	Earthflow	331	4.7%	267	3.8%	0	0.0%	52	0.7%	1.5	2.1%
	Rock Slide	55	0.8%		0.0%		0.0%	55	0.8%	0.4	0.6%
	Debris Slide	22	0.3%	0	0.0%		0.0%	21	0.3%	0.5	0.6%
	Debris Flow	3	0.0%	0	0.0%		0.0%	3	0.0%	0.1	0.1%
	All Features	410	5.8%	267	3.8%	0	0.0%	130	1.9%	2	3.5%
Cloney Gulch (5,119 acres) (55.5 road miles)	Earthflow	199	3.9%	104	2.0%		0.0%	31	0.6%	1.5	2.6%
	Rock Slide		0.0%		0.0%		0.0%		0.0%		0.0%
	Debris Slide	36	0.7%	1	0.0%	0	0.0%	35	0.7%	0.2	0.4%
	Debris Flow	0	0.0%		0.0%		0.0%	0	0.0%		0.0%
	All Features	235	4.6%	105	2.0%	0	0.0%	66	1.3%	2	3.0%
High Prairie (10,398 acres) (113.3 road miles)	Earthflow	592	5.7%	487	4.7%	44	0.4%	87	0.8%	0.7	0.7%
	Rock Slide	1	0.0%		0.0%		0.0%	1	0.0%	0.0	0.0%
	Debris Slide	25	0.2%	2	0.0%	2	0.0%	22	0.2%	0.2	0.2%
	Debris Flow	0	0.0%		0.0%		0.0%	0	0.0%		0.0%
	All Features	618	5.9%	489	4.7%	45	0.4%	110	1.1%	1	0.8%
Noisy Creek (6,810 acres) (86.9 road miles)	Earthflow	194	2.9%	115	1.7%	3	0.0%	71	1.0%	1.2	1.4%
	Rock Slide		0.0%		0.0%		0.0%		0.0%		0.0%
	Debris Slide	11	0.2%		0.0%		0.0%	11	0.2%	0.0	0.0%
	Debris Flow		0.0%		0.0%		0.0%		0.0%		0.0%
	All Features	205	3.0%	115	1.7%	3	0.0%	82	1.2%	1	1.4%
Twin Lakes Creek (9,156 acres) (104.3 road miles)	Earthflow	474	5.2%	270	3.0%	1	0.0%	184	2.0%	4.7	4.5%
	Rock Slide	109	1.2%	4	0.0%	0	0.0%	104	1.1%	1.0	0.9%
	Debris Slide	95	1.0%	2	0.0%	7	0.1%	85	0.9%	0.7	0.6%
	Debris Flow	4	0.0%	0	0.0%		0.0%	4	0.0%	0.0	0.0%
	All Features	682	7.4%	277	3.0%	9	0.1%	377	4.1%	6	6.1%
Windy Creek (4,831 acres) (68.8 road miles)	Earthflow	701	14.5%	499	10.3%	90	1.9%	118	2.4%	8.0	11.6%
	Rock Slide		0.0%		0.0%		0.0%		0.0%		0.0%
	Debris Slide	38	0.8%	4	0.1%		0.0%	35	0.7%	0.8	1.2%
	Debris Flow	2	0.0%	0	0.0%		0.0%	1	0.0%	0.0	0.0%
	All Features	742	15.3%	503	10.4%	90	1.9%	154	3.2%	9	12.8%

[1] Refer to Plate 1 and California Geological Survey appendix. Areas of disrupted ground are not included as active landslide features in this analysis. These areas are likely underlain by earthflow or rockslide complexes. If so, this would substantially increase the miles of roads and area of land type and land use on active landslide features.
[2] Woodland and grassland includes areas mapped in 1998 as grassland and non-productive hardwood.
[3] Area of timberlands that were not contained in a THP during the 1991 to 2000 period.
[4] Roads layer is from the Information Center for the Environment (ICE) at UC Davis.
[5] THPs are complete or active between the 1991 and 2000 timeframe.
Empty cells denote zero. Percent of area is based on the unit of analysis: subbasin or planning watershed.

Of the 500 miles of roads in the subbasin, 316 miles (7.4 mi/ mi^2) are located on slopes with high or very high relative landslide potential. Twin Lakes and Lake Prairie planning watershed have the most roads built in the highest relative landslide potential classes, with 76 miles (6.4 mi/mi^2) and 63 miles (5.7 mi/mi^2) respectively.

Table IV- 101. Upper Subbasin acres and percent of area by relative landslide potential and land use classes.

Subbasin or Planning Watershed	Relative Landslide Potential[1]	Entire Subbasin or Planning Watershed		Woodland or Grassland[2]		THPs 1991 - 2000[5]		Timberland, No Recent Harvest[3]		Roads[4]	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Upper Redwood Creek Subbasin (43,343 acres) (501.2 road miles)	Very Low	3,302	7.6%	533	1.2%	521	1.2%	2,012	4.6%	57.3	11.4%
	Low	4,318	10.0%	530	1.2%	672	1.6%	2,966	6.8%	67.8	13.5%
	Moderate	4,243	9.8%	397	0.9%	603	1.4%	3,159	7.3%	60.0	12.0%
	High	12,328	28.4%	2,418	5.6%	1,121	2.6%	8,557	19.7%	145.9	29.1%
	Very High	19,069	44.0%	5,300	12.2%	1,235	2.9%	12,259	28.3%	170.2	34.0%
	High/Very High Subtotal	31,397	72.4%	7,718	17.8%	2,357	5.4%	20,816	48.0%	316.1	63.1%
	TOTAL	**43,260**	**100%**	**9,178**	**21%**	**4,153**	**10%**	**28,953**	**67%**	**501.2**	**100%**
Bradford Creek (7,027 acres) (72.3 road miles)	Very Low	427	6.1%	20	0.3%	90	1.3%	262	3.7%	8.2	11.3%
	Low	535	7.6%	34	0.5%	103	1.5%	359	5.1%	9.5	13.1%
	Moderate	655	9.3%	46	0.7%	179	2.5%	388	5.5%	8.4	11.6%
	High	2,096	29.8%	368	5.2%	199	2.8%	1,442	20.5%	20.2	27.9%
	Very High	3,304	47.0%	1,073	15.3%	28	0.4%	2,121	30.2%	26.1	36.1%
	High/Very High Subtotal	5,400	76.8%	1,441	20.5%	227	3.2%	3,563	50.7%	46.3	64.0%
	TOTAL	**7,017**	**100%**	**1,541**	**22%**	**599**	**9%**	**4,572**	**65%**	**72.4**	**100%**
Cloney Gulch (5,119 acres) (55.5 road miles)	Very Low	375	7.3%	20	0.4%	94	1.8%	239	4.7%	4.7	8.5%
	Low	426	8.3%	64	1.3%	74	1.4%	263	5.1%	6.0	10.8%
	Moderate	644	12.6%	57	1.1%	100	2.0%	464	9.1%	8.4	15.1%
	High	1,493	29.2%	468	9.1%	104	2.0%	900	17.6%	16.2	29.2%
	Very High	2,180	42.6%	678	13.2%	123	2.4%	1,309	25.6%	20.1	36.2%
	High/Very High Subtotal	3,673	71.8%	1,146	22.4%	227	4.4%	2,209	43.2%	36.3	65.4%
	TOTAL	**5,118**	**100%**	**1,287**	**25%**	**496**	**10%**	**3,175**	**62%**	**55.4**	**100%**
High Prairie Creek (10,398 acres) (113.3 road miles)	Very Low	1,076	10.3%	366	3.5%	215	2.1%	459	4.4%	16.7	14.7%
	Low	1,227	11.8%	275	2.6%	304	2.9%	662	6.4%	18.1	16.0%
	Moderate	995	9.6%	142	1.4%	193	1.9%	660	6.3%	15.5	13.7%
	High	3,207	30.8%	673	6.5%	549	5.3%	2,054	19.8%	36.9	32.6%
	Very High	3,878	37.3%	1,377	13.2%	658	6.3%	1,996	19.2%	25.9	22.9%
	High/Very High Subtotal	7,085	68.1%	2,050	19.7%	1,207	11.6%	4,050	38.9%	62.8	55.4%
	TOTAL	**10,383**	**100%**	**2,833**	**27%**	**1,919**	**18%**	**5,831**	**56%**	**113.1**	**100%**
Noisy Creek (6,810 acres) (86.9 road miles)	Very Low	807	11.9%	69	1.0%	113	1.7%	574	8.4%	15.1	17.4%
	Low	969	14.2%	97	1.4%	158	2.3%	688	10.1%	15.5	17.8%
	Moderate	989	14.5%	111	1.6%	108	1.6%	762	11.2%	13.7	15.8%
	High	1,992	29.3%	466	6.8%	112	1.6%	1,409	20.7%	23.3	26.8%
	Very High	2,036	29.9%	430	6.3%	103	1.5%	1,490	21.9%	19.3	22.2%
	High/Very High Subtotal	4,028	59.1%	896	13.2%	215	3.2%	2,899	42.6%	42.6	49.0%
	TOTAL	**6,793**	**100%**	**1,173**	**17%**	**594**	**9%**	**4,923**	**72%**	**86.9**	**100%**
Twin Lakes Creek (9,156 acres) (104.3 road miles)	Very Low	363	4.0%	19	0.2%	9	0.1%	272	3.0%	8.0	7.7%
	Low	889	9.7%	47	0.5%	33	0.4%	737	8.0%	13.3	12.8%
	Moderate	515	5.6%	17	0.2%	23	0.2%	465	5.1%	7.5	7.2%
	High	2,505	27.4%	235	2.6%	153	1.7%	1,938	21.2%	31.7	30.4%
	Very High	4,853	53.0%	704	7.7%	206	2.3%	3,678	40.2%	44.0	42.2%
	High/Very High Subtotal	7,358	80.4%	939	10.3%	360	3.9%	5,616	61.3%	75.7	72.6%
	TOTAL	**9,125**	**100%**	**1,022**	**11%**	**424**	**5%**	**7,090**	**77%**	**104.5**	**100%**
Windy Creek (4,831 acres) (68.8 road miles)	Very Low	254	5.3%	39	0.8%		0.0%	206	4.3%	4.6	6.7%
	Low	272	5.6%	13	0.3%		0.0%	257	5.3%	5.4	7.8%
	Moderate	445	9.2%	24	0.5%		0.0%	420	8.7%	6.5	9.4%
	High	1,035	21.4%	208	4.3%	4	0.1%	814	16.8%	17.6	25.6%
	Very High	2,818	58.3%	1,038	21.5%	117	2.4%	1,665	34.5%	34.8	50.6%
	High/Very High Subtotal	3,853	79.8%	1,246	25.8%	121	2.5%	2,479	51.3%	52.4	76.2%
	TOTAL	**4,824**	**100%**	**1,322**	**27%**	**121**	**3%**	**3,362**	**70%**	**68.9**	**100%**

[1] Refer to Plate 1 and California Geological Survey appendix.
[2] Woodland and grassland includes areas mapped in 1998 as grassland and non-productive hardwood.
[3] Area of timberlands that were not contained in a THP during the 1991 to 2000 period.
[4] Roads layer is from the Information Center for the Environment (ICE) at UC Davis.
[5] THPs are complete or active between the 1991 and 2000 timeframe.
Empty cells denote zero. Percent of area is based on the unit of analysis: subbasin or planning watershed.

Table IV- 102 presents an integrated information summary for the upper subbasin. It provides the reader the opportunity to compare a large number of factors across the watershed and subbasins and, for some of the subbasins, to look at potential interactions between potential disturbance factors and watershed condition.

Table IV- 102. Upper Subbasin integrated information summary for the.

Factor	Upper Redwood Subbasin		Planning Watersheds												
			Twin Lakes		Bradford		High Prairie		Cloney Gulch		Noisy Creek		Windy Creek	
Relative Landslide Potential[1]	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Very Low	3,302	7.6%	363	4.0%	427	6.1%	1,076	10.4%	375	7.3%	807	11.9%	254	5.3%
Low	4,318	10.0%	889	9.7%	535	7.6%	1,227	11.8%	426	8.3%	969	14.3%	272	5.6%
Moderate	4,243	9.8%	515	5.6%	655	9.3%	995	9.6%	644	12.6%	989	14.6%	445	9.2%
High	12,328	28.5%	2,505	27.5%	2,096	29.9%	3,207	30.9%	1,493	29.2%	1,992	29.3%	1,035	21.5%
Very High	19,069	44.1%	4,853	53.2%	3,304	47.1%	3,878	37.3%	2,180	42.6%	2,036	30.0%	2,818	58.4%
High/Very High Subtotal	31,397	72.6%	7,358	80.6%	5,400	77.0%	7,085	68.2%	3,673	71.8%	4,028	59.3%	3,853	79.9%
GRAND TOTAL	**43,260**	**100%**	**9,125**	**100%**	**7,017**	**100%**	**10,383**	**100%**	**5,118**	**100%**	**6,793**	**100%**	**4,824**	**100%**
Landslide and Selected Geomorphic Features	**Acres**	**% Area**	**Acres**	**% Area**	**acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Historically Active Landslide Features Total	2,892	6.7%	682	7.5%	410	5.8%	618	6.0%	235	4.6%	205	3.0%	742	15.4%
Earthflow	9	0.0%	4	0.0%	3	0.0%	0	0.0%	0	0.0%	0	0.0%	2	0.0%
Rock Slide	227	0.5%	95	1.0%	22	0.3%	25	0.2%	36	0.7%	11	0.2%	38	0.8%
Debris Slide	2,492	5.8%	474	5.2%	331	4.7%	592	5.7%	199	3.9%	194	2.9%	701	14.5%
Debris Flow	165	0.4%	109	1.2%	55	0.8%	1	0.0%	0	0.0%	0	0.0%	0	0.0%
Dormant Landslide Features Total	15,702	36.3%	5,055	55.4%	2,159	30.8%	2,951	28.4%	2,134	41.7%	2,033	29.9%	1,370	28.4%
Selected Geomorphic Features Total	9,070	21.0%	1,414	15.5%	1,329	18.9%	3,094	29.8%	825	16.1%	767	11.3%	1,641	34.0%
Disrupted Ground	5,219	12.1%	737	8.1%	979	14.0%	1,488	14.3%	296	5.8%	376	5.5%	1,343	27.8%
Debris Slide Slope	2,780	6.4%	383	4.2%	233	3.3%	1,335	12.9%	380	7.4%	269	4.0%	179	3.7%
Inner Gorge (area)[2]	1,071	2.5%	295	3.2%	116	1.7%	271	2.6%	149	2.9%	122	1.8%	118	2.4%
Total of All Above Features	**27,664**	**63.9%**	**7,151**	**78.4%**	**3,898**	**55.5%**	**6,663**	**64.2%**	**3,194**	**62.4%**	**3,006**	**44.2%**	**3,752**	**77.8%**
Timber Harvest 1991 -2000[3]	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**acres**	**% area**	**acres**	**% area**	**acres**	**% area**
Silviculture Category 1														
Tractor	2,006	4.6%	113	1.2%	298	4.3%	919	8.9%	314	6.1%	361	5.3%		
Cable	227	0.5%	91	1.0%	4	0.1%	102	1.0%	29	0.6%	2	0.0%		
Helicopter	380	0.9%	69	0.8%	21	0.3%	271	2.6%	19	0.4%				
TOTAL	**2,613**	**6.0%**	**273**	**3.0%**	**323**	**4.6%**	**1,292**	**12.4%**	**362**	**7.1%**	**363**	**5.3%**	**0**	**0.0%**
Silviculture Category 2														
Tractor	582	1.3%	142	1.6%	57	0.8%	75	0.7%	55	1.1%	132	1.9%	121	2.5%
Helicopter	0	0.0%												
Cable	24	0.1%					24	0.2%						
TOTAL	**606**	**1.4%**	**142**	**1.6%**	**57**	**0.8%**	**100**	**1.0%**	**55**	**1.1%**	**132**	**1.9%**	**121**	**2.5%**
Silviculture Category 3														
Tractor	949	2.2%	55	0.6%	224	3.2%	494	4.8%	76	1.5%	99	1.5%		
Helicopter	17	0.0%	8	0.1%	9	0.1%								
Cable	47	0.1%	6	0.1%	4	0.1%	34	0.3%	4	0.1%				

Factor	Upper Redwood Subbasin		Planning Watersheds											
			Twin Lakes		Bradford		High Prairie		Cloney Gulch		Noisy Creek		Windy Creek	
TOTAL	**1,013**	**2.3%**	**69**	**0.8%**	**236**	**3.4%**	**528**	**5.1%**	**79**	**1.6%**	**99**	**1.5%**	**0**	**0.0%**
TOTAL SILVICULTURE	**4,232**	**9.8%**	**485**	**5.3%**	**616**	**8.8%**	**1,921**	**18.5%**	**495**	**9.7%**	**594**	**8.7%**	**121**	**2.5%**
Other Land Uses	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**	**Acres**	**% Area**
Grazing	986	2.3%	104	1.1%			630	6.1%	69	1.4%	146	2.2%	36	0.7%
Agriculture	0	0.0%												
Development	0	0.0%												
Timberland, No Recent Harvest	28,953	66.9%	7,090	77.7%	4,572	65.2%	5,831	56.2%	3,175	62.0%	4,923	72.5%	3,362	69.7%
TOTAL	**29,939**	**69.2%**	**7,194**	**78.8%**	**4,572**	**65.2%**	**6,461**	**62.2%**	**3,244**	**63.4%**	**5,069**	**74.6%**	**3,398**	**70.4%**
Roads														
Road Density (miles/sq. mile)	7.4		7.4		6.6		7.0		6.9		8.2		9.2	
Density of Road Crossings (#/stream mile)	1.2		1.7		1.4		1.5		1.0		1.1		1.3	
Roads within 200' of Stream (miles/stream mile)	0.3		0.3		0.2		0.2		0.2		0.3		0.3	
Factor	**Upper Redwood Subbasin**		**Planning Watersheds**											
			Twin Lakes		**Bradford**		**High Prairie**		**Cloney Gulch**		**Noisy Creek**		**Windy Creek**	
Streams	**% stream length**		**% stream length**		**% stream length**		**% stream length**		**% stream length**		**% stream length**		**% stream length**	
% Stream by Gradient														
< 1% (Response Reach)		7.0%		1.3%		0.0%		1.9%		20.1%		4.1%		30.8%
1-4% (Response Reach)		9.8%		9.1%		12.4%		16.5%		9.0%		4.1%		1.9%
4-20% (Transport Reach)		43.7%		38.2%		40.7%		60.1%		43.7%		47.8%		20.4%
>20% (Source Reach)		39.5%		51.4%		46.8%		51.4%		27.2%		43.9%		47.0%
Historically Active and Dormant Landslide and Selected Geomorphic Features4	**% Area**	**% Stream Length**	**% Area**	**% Stream Length**	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**	**% area**	**% stream length**
Within 180' of Blue Line Stream	6.8%	70.2%	5.9%	45.0%	4.1%	83.0%	6.8%	79.4%	4.3%	55.3%	10.6%	80.2%	7.6%	74.2%

[1] Refer to California Geological Survey appendix for landslide map (Plate 1), relative landslide potential map (Plate 2) and description.
[2] Area based on inner gorges captured as polygons plus inner gorges captured as linear features, which are treated as having an average width of 100 feet.
[3] Category 1 includes clearcut, rehab, seed tree step, and shelterwood seed step prescriptions; Category 2 includes shelterwood prep step, shelterwood removal step, and alternative prescriptions; Category 3 includes selection, commercial thin, sanitation salvage, transition, and seed tree removal step prescriptions.
[4] Landslide features and selected geomorphic features include earth flow, rock slide, debris slide, debris flow, debris slide slopes, disrupted ground, eroding banks and inner gorges

EMDS Potential Sediment Production Results

The EMDS potential stream sediment production model is based on the data distribution of factors at the planning watershed level. While we believe that this model has utility based on the model structure, we caution that it be interpreted only as being indicative of relative conditions and not as a definitive assessment of absolute conditions. We encourage readers to see the EMDS Appendix to review the sediment production model structure, hierarchy, and weighting system.

Table IV- 103 presents the top three levels of the EMDS sediment model. This analysis shows potential sediment production is related to both natural processes and land management sources, but a greater potential was indicated for streamside erosion due to management related sources compared to natural process. A review of the following tables helps explain the results for natural processes and management related potential sediment sources.

Table IV- 103. Upper Subbasin EMDS ratings for potential stream sediment production; top three levels of model.

Subbasin or Planning Watershed	All Sources	Natural Processes				Management-Related Sources			
		All	Surface Erosion	Streamside Erosion	Mass Wasting	All	Surface Erosion	Streamside Erosion	Mass Wasting
Upper Redwood Subbasin	-	-	U	+	-	-	-	-	-
Bradford Creek	-	--	U	+	---	-	+	-	-
Cloney Gulch	-	-	U	+	-	-	-	-	--
High Prairie Creek	-	-	U	-	-	-	+	-	-
Noisy Creek	+	+	U	+	+	-	+	-	+
Twin Lakes Creek	-	+	U	+	+	-	-	--	--
Windy Creek	--	--	U	--	---	-	-	--	-

The “+++” score represents the least amount of potential sediment delivery to streams on a relative scale; the “---“ score represents the most potential sediment delivery to streams. A “U” represents data that lie in between suitable and unsuitable conditions, or there is a lack of data to categorize.

In terms of potential surface erosion, all planning watersheds show a relatively high potential for sediment delivery from roads, and most show relatively high sediment production potential from timber land use (Table IV- 104). The Windy Creek Planning Watershed stands out as having the high density of roads close to stream and on steep hillslopes. Cloney Gulch Planning Watershed shows the greatest sediment delivery potential from timber harvests. Potential stream sediment production from management related streamside erosion sources only considers roads as sediment sources (Table IV- 105). The high density of road crossings and roads near streams are both relatively high potential sediment delivery sources in the Upper Subbasin especially in Windy Creek and Twin Lakes Creek planning watersheds. Potential sediment delivery from timber harvest and road related mass wasting sources are highest in Twin Lake Creek and Cloney Gulch planning watershed (

Table IV- 106).

Table IV- 104. Upper Subbasin potential stream sediment production from management-related surface erosion sources.

Subbasin or Planning Watershed	All Mgmt.-Related Surface Sources	Road Related			Land Use Related	
		All Road Related	Density of Roads by Hillslope Position	Density of Roads Proximate to Streams	All Land Use Related	Timber Land Use
Upper Redwood Subbasin	-	-	--	--	-	-
Bradford Creek	+	-	-	-	+	+
Cloney Gulch	-	-	-	-	--	--
High Prairie Creek	+	-	-	-	+	-
Noisy Creek	+	-	--	--	++	-
Twin Lakes Creek	-	-	--	--	-	+
Windy Creek	-	--	---	---	-	-

The “+++” score represents the least amount of potential sediment delivery to streams on a relative scale; the “---“ score represents the most potential sediment delivery to streams.

Table IV- 105. Upper Subbasin potential stream sediment production from management related streamside erosion sources.

Subbasin or Planning Watershed	All Management-Related Streamside Sources	Road Related	
		Density of Roads Proximate to Streams	Density of Road Crossings
Upper Redwood Subbasin	-	--	--
Bradford Creek	-	-	--
Cloney Gulch	-	-	-
High Prairie Creek	-	-	--
Noisy Creek	-	--	-
Twin Lakes Creek	--	--	---
Windy Creek	--	---	--

The “+++” score represents the least amount of potential sediment delivery to streams on a relative scale; the “---“ score represents the most potential sediment delivery to streams.

Table IV- 106. Upper Subbasin potential stream sediment production from management-related mass wasting sources.

Subbasin or Planning Watershed	All Mgmt.-Related Mass Wasting Sources	Road Related				Land Use Related	
		All Road Related	Density of Roads Crossings	Density of Roads by Hillslope Position	Density of Roads on Unstable Slopes	All Land Use Related	Timber Land Use
Upper Redwood Subbasin	-	-	--	--	-	-	-
Bradford Creek	-	--	--	-	-	+	+
Cloney Gulch	--	-	-	-	-	--	--
High Prairie Creek	-	-	--	-	-	+	-
Noisy Creek	+	-	-	--	++	++	-
Twin Lakes Creek	--	--	---	--	-	-	+
Windy Creek	-	--	--	---	-	-	-

The “+++” score represents the least amount of potential sediment delivery to streams on a relative scale; the “---“ score represents the most potential sediment delivery to streams.

EMDS Stream Reach Condition Results and Limiting Factors Analysis

The overall reach condition for streams of the Upper Subbasin is considered “somewhat unsuitable” for salmonid production by EMDS. The maps display (Figure IV-63) results at the stream reach scale while Table IV- 107 shows the average condition for each stream. In the tributaries, the somewhat unsuitable rating is largely due to the lack of deep, complex pools. The Canopy density generally evaluated as suitable and pool tail substrate embeddedness was in mixed condition.

In some instances, the EMDS results alone do not provide the most accurate description of the stream condition in terms of pool depth. For example, the lower reach (a 4th order reach) of mainstem Redwood Creek Reach had over 65% of its length in pools, 20% of the reach length was in pools ≥ 4 feet in maximum residual pool depth (Figure IV- 63). This was at the lower limit of the suitability curve for a fourth order streams, thus the reach received the lowest EMDS rating of fully unsuitable. Considering that an additional 12% of the pools have depths of 3 to 4 feet, the EMDS evaluation for pool depth is conservative. Therefore the amount of deep pool habitat in the lower mainstem reach should not be viewed as fully unsuitable as the EMDS indicates and the amount of deep pool habitat should probably evaluate to a slightly more positive value. Overall, the lack of deep, complex pools and lack riparian canopy density contributed to the EMDS results for the mainstem Redwood Creek.

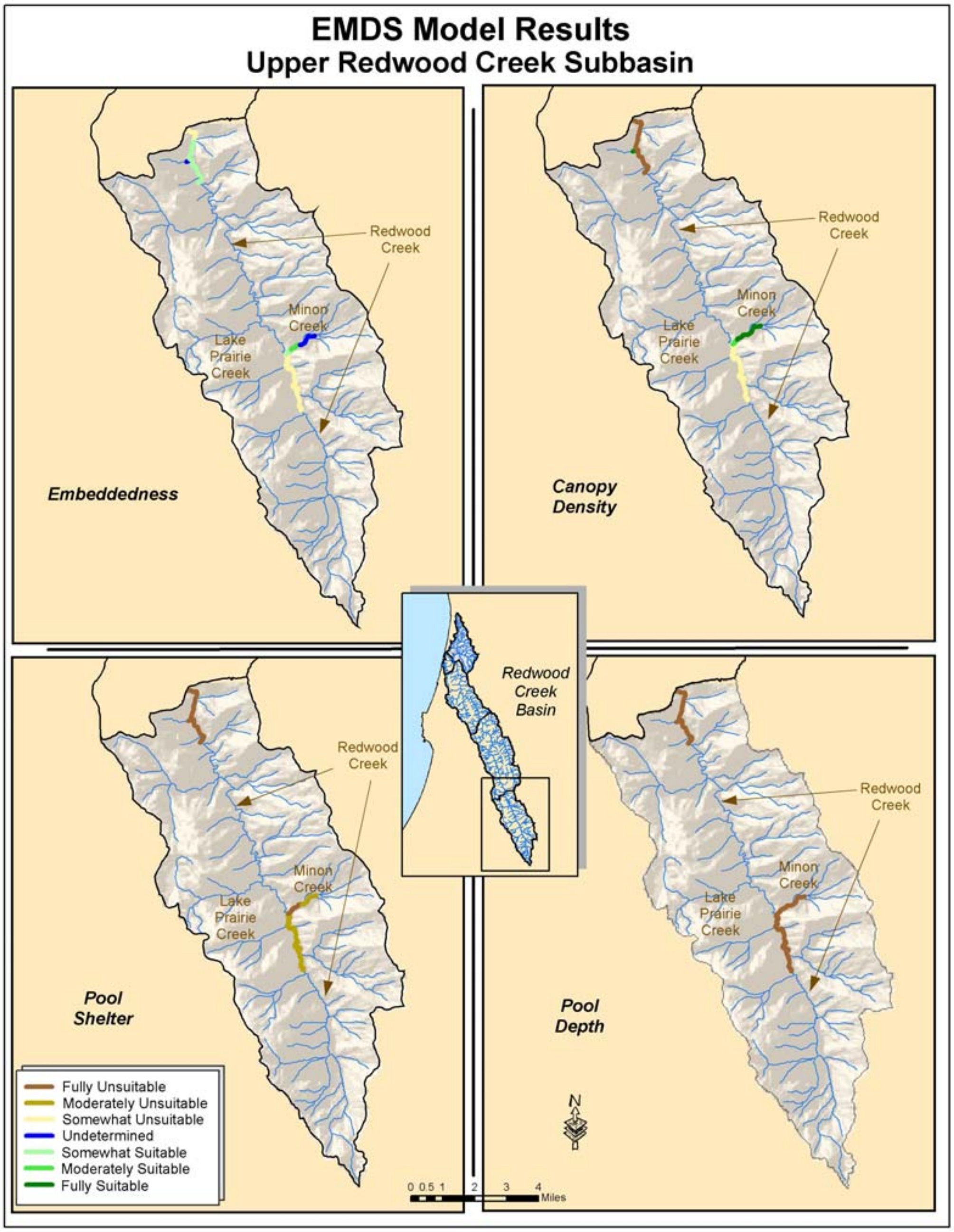

Figure IV- 63. Upper Subbasin EMDS results.

Table IV- 107. Summary results from the Upper Subbasin EMDS stream reach evaluation.

Stream	Reach Length (ft)	Reach number	Reach Condition	Canopy Density	Pool Quality	Pool Depth	Pool Shelter	Embeddedness
Fern Prairie Creek	852	1	-	+ + +	- - -	- - -	- - -	0
Minon Creek	1101	1	-	+ +	- - -	- - -	- - -	+
Minon Creek	1784	2	-	+ + +	- - -	- - -	- - -	+ +
Minon Creek	3294	3	-	+ + +	- -	- - -	- -	0
Redwood Creek (lower)	8425	1	-	- - -	- - -	- - -	- - -	+
Upper Redwood Ck	13996	2	-	-	- -	- - -	- - -	-

\+ Somewhat Suitable ++ Moderately Suitable +++ Fully Suitable
\- Somewhat Unsuitable -- Moderately Unsuitable --- Fully Unsuitable 0 Uncertain

These scores provide a general overview of current stream conditions and may be used to identify limiting habitat factors to anadromous salmonid production and to focus on areas for habitat improvements.

Refugia Areas

The NCWAP team and staff from RNSP and Green Diamond Timber Company classified the streams of the Upper Subbasin in terms of refuge habitat for anadromous salmonids. The upper reach of Redwood Creek (above Minon Creek) provides the best refuge type habitat of the mainstem (Table IV- 108). This reach provides the coolest water of all Redwood Creek, but lacks in the number of deep, complex pools. The reach below Minon Creek has some good pools, but is currently too warm. There is potential to cool water by increasing shade canopy over this reach which would increase its refugia value. Simon, Minon, and Fern Prairie creeks were also classed as potential refuge based on the cool water temperature and fair condition of the stream habitat. Lake Prairie Creek is passage barrier limited as a large debris jam exists at the mouth of the creek. Most tributary streams could not be assigned a refugia class because of data limitations.

Table IV- 108. Upper Subbasin anadromous salmonid refugia designations for streams.

Stream	Refugia Categories				Other Categories		
	High Quality	High Potential	Potential	Low Quality	Passage Barrier Limited	Critical Contributing Area/Function	Data Limited
Minon Creek			X				
Fern Prairie Creek			X				
Bradford/Up. Panther Creek							
Noisy Creek							X
Gunrack Creek							X
High Prairie Creek							X
Lake Prairie Creek					X		
Emmy Lou Creek							X
Windy Creek							X
Squirrel Tail Creek							X
Snowcamp/Smokehouse Creek							X
Pardee Creek							X
Simon Creek		X					
Cut-off Meander Creek							X
Jena Creek							X
Xmas Prairie Creek							X
Redwood Creek			X				

Responses to Assessment Questions

<u>What are the history and trends of the size, distribution, and relative health and diversity of salmonid populations?</u>

- Streams in the Upper Subbasin support populations of Chinook salmon, steelhead, summer steelhead and coastal cutthroat trout;
- The mainstem provides suitable habitat for coho salmon in the uppermost reach, but there is no recent account of their presence in the Upper Subbasin streams;
- Neither the historic abundance or current trends of anadromous salmonid populations of the Upper Subbasin are well documented by anecdotal accounts or by scientific studies;
- Recent trapping studies and spawning surveys have shown that Chinook salmon are successfully spawning in the upper reach of mainstem Redwood Creek, although the spawning success varies considerably among years;
- Juvenile steelhead are the most widely distributed and abundant salmonid found throughout the upper subbasin;
- Resident rainbow trout populations exist above barriers to anadromous salmonids. The status of resident rainbow trout is not known;

- Summer steelhead is a unique stock of steelhead that depends upon deep pools of the upper subbasin mainstem Redwood Creek for over summer habitat. Summer steelhead populations are greatly reduced from historic abundance;
- Coastal cutthroat are found within and above upstream limits of anadromous tributary reaches. The status of coastal cutthroat is unknown.

What are the current salmonid habitat conditions? How do these conditions compare to desired conditions?

- The Upper Subbasin provides critical habitat for anadromous salmonids;
- Much of Redwood Creek that flows through the Upper Subbasin is considerably wider today than it was before the flood of December 1964;
- Riparian vegetation is less capable of shading due to the channel widening and also from removal of large conifers during timber harvests;
- Mainstem Redwood Creek water temperatures are coolest in the reach above the confluence with Minon Creek, where a recent MWAT was 65ºF and maximum daily temperature was 71ºF. A MWAT of < 64 ºF is desirable for salmonids;
- Approximately 11 miles downstream from Minon Creek (at O'Kane gauging site) the temperature rises to a MWAT of 71°F, which is well above desirable levels. Maximum daily temperatures on the mainstem Redwood Creek at the O'Kane gauging site ranged from 77 to 80 °F in 1997 to 2001, exceeding lethal limits;
- There is little information to make statements about habitat condition in most tributary streams;
- Suitable water temperatures (MWATs) were noted in the tributaries High Prairie, Minon, Lake Prairie and Pardee creeks;
- Streamside canopy providing shade over tributaries is sufficient, to provide shade in Fern Prairie and Minon creeks, but overstory canopy provided by large conifers is lacking;
- Over 60% of lower reach length of Redwood Creek in the Upper Subbasin is pool habitat, but these pools are relatively shallow, and lack shelter elements;
- Minon and Fern Prairie creeks are generally lacking in the desirable numbers of deep pools with adequate shelter complexity;
- Approximately 30% of the pool tail substrate in the lower reach of Redwood Creek is considered in high quality for salmonid spawning. Approximately 10% of the pool tail substrate in the upper reach of Redwood Creek is considered high quality for salmonid spawning;
- Approximately 30% of the pool tail substrate in Minon Creek is considered in good quality for salmonid spawning. Approximately 10% of pool tail substrate in Fern Prairie Creek is considered in good quality for salmonid spawning;
- There is a debris jam at the mouth of Lake Prairie Creek which is a passage barrier to anadromous salmonids. The jam originated from a debris torrent that impacted miles of Lake Prairie Creek habitat.

What are the past and present relationships of geologic, vegetative, and fluvial processes to stream habitat conditions?

- The Upper Subbasin terrain is naturally unstable. Approximately 73% of the Upper Subbasin is classified in either high or very high relative landslide potential;
- Upon receiving heavy winter rains, much of the subbasin becomes prone to erosion;
- Relatively minor actions, such as undercutting the toes of slopes, increasing the duration of ground saturation, or reducing soil shear strength by a relatively small amount, can trigger extensive landslides in this subbasin;

- The flood of December 1964 introduced enormous volumes of sediment into the upper part of Redwood Creek. More than 600 streamside landslides delivered sediment directly into Redwood Creek. Cut logs were washed from steep slopes into the mainstem channel forming jams, which backed up sediment to depths of 20-30 ft. As channel-bed elevations increased and the capacity of the channel to convey peak flows was reduced, the mainstem channel banks eroded and widened up to 150% in an attempt to accommodate flood flows;
- Well developed gully networks are common within the more active earthflow areas and these are considered significant sediment sources because they are directly connected to the drainage system;
- Gravel terraces built during the 1964 flood were so voluminous and riparian vegetation was buried so deep, many trees in the flood plain died;
- Much of the warm character of the mainstem Redwood Creek comes from the lack of shade and widened channel as it flows through the Upper Subbasin;
- Much of the benefits (including shade, microclimate, and LWD recruitment potential) from a mature near stream forest are lacking in most Upper Subbasin mainstem and the surveyed tributary streams;
- The major modes of mass wasting in the Upper Subbasin are earthflows and near-channel debris slides. Abundant near channel debris slides flanking the mainstem Redwood Creek are major sources of sediment delivery to stream channels;
- The large earthflow at the confluence of Twin Lakes and Redwood Creeks has a long history of recurrent streamside slides along both creeks (particularly the mainstem) that deliver sediment to both channels on an ongoing basis. Small active debris slides were mapped in Twin Lakes Creek and Bradford Creek;
- The Upper Subbasin contains the highest length of stream channels adjacent to landslides in the Redwood Creek Basin. Overall, the Upper Subbasin showed a 33% increase in the number of streamside slides observed on aerial photos, from 274 in 1984 to 365 in 2000;
- The Upper Subbasin is comprised of (by length) about 41% source reaches, 45% transport reaches and 14% response reaches;
- The Upper Subbasin has begun to yield more suspended sediment to the mainstem of Redwood Creek than the middle and lower subbasins combined;
- In photo year 2000, excessive amounts of sediment was present in Cloney Gulch, High Prairie Creek, Minon, Snow Camp, Twin Lakes, and Windy creeks.

How has land use affected these natural processes?

- Past logging activities, particularly the construction of roads and skid trails and the removal of vegetative ground cover, have been a major factor contributing to erosion and sediment delivery to streams;
- Road construction, timber harvest activities, and other land use exacerbate slope instability and contribute to chronic and episodic sediment input to the stream system;
- There are 553 miles of roads, of all classifications, within the Upper Subbasin. This represents a relatively high road density of 8.2 miles of road per square mile of land base. Approximately 228 miles or 41% of roads are classified as abandoned and do not receive any maintenance. Most of the abandoned road miles are located in the lower portions of the canyons and/or within close proximity to watercourses where they may contribute to streamside landslides, gullies or other forms of sediment delivery;
- Twin Lakes and Lake Prairie planning watersheds have the most roads built in the highest relative landslide potential classes with 76 miles (6.4 mi/mi2) and 63 miles (5.7 mi/mi2) respectively;
- Approximately 80% of the Upper Subbasin was tractor logged between 1948 and 1978;
- Large conifer trees that once grew along the mainstem stream banks were removed during timber harvests. Much of the beneficial characteristics attributed to a mature near stream conifer forest (including shade, microclimate, and LWD recruitment potential) are not provided by existing vegetation;

- The change in riparian and near stream forest conditions contributes to an increase in summer stream temperatures that affect the entire length of Redwood Creek.

Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?

- High water temperature in portions of mainstem Redwood Creek is the most critical limiting factor affecting salmonid production in the Upper Subbasin;
- The lack of shelter complexity and lack of deep pools in mainstem likely limits anadromous fish production;
- Lack of deep pools and shelter complexity provided by LWD may be limiting factors to salmonid production in Fern Prairie and Minon creek and other tributaries of the Upper Subbasin;
- The sparse amount of instream LWD in Redwood Creek and most anadromous fish bearing tributary reaches limits pool development, nutrient inputs, and channel diversity and complexity needed to increase carrying capacity and increase production of anadromous salmonids;
- The low recruitment potential for LWD in Redwood Creek and many of the tributary streams will impede future pool formation, sediment routing and likely act to constrain channel diversity and complexity for decades;
- Spawning success may be impaired by excessive fine sediments in some streams;
- The naturally steep channel gradient limits the amount of habitat in tributary streams to approximately 9 miles.

What watershed and habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

Barriers to Fish Passage

- Modify sediment deltas or boulder and/or debris accumulations that impede upstream migration into tributaries. A barrier is located at the confluence of Lake Prairie Creek. Consider building step pools in the lower reaches where sediment accumulations may restrict or delay access to migrating salmonids.

Flow and Water Quality Improvement Activities:

- Maintaining and improving good water temperatures in tributaries and in the upper reach of Redwood Creek is essential to improve of salmonid habitat condition in the Upper Subbasin and also will provide benefits to downstream reaches;
- A high priority should be placed on re-establishing riparian shade and reducing the channel width along portions of the upper reach of Redwood Creek. This will help extend the benefits of cool water flowing from the headwaters reach.

Riparian and Instream Improvement Activities:

- In appropriate locations along the upper reach of mainstem Redwood Creek, consider installing live willow baffles or other habitat structure to help establish shade over water and to encourage channel width reduction;
- The riparian corridor and near stream forest along the upper reach of Redwood Creek should be managed to encourage growth and retention of coniferous trees. The shade provided by large trees will help maintain cool water temperatures, their stems will provide large woody debris and provide nutrient inputs to the stream, and roots will add stability to banks and buffer against sediment delivery. This may require more than the minimum protection provided by Forest Practice Rules;
- In tributaries with an abundance of shade, consider cautious thinning from below of hardwoods in riparian areas to hasten the development of large near stream conifers;

- Design and engineer pool enhancement structures to increase the number of pools or increase the size, deepen, or add shelter complexity to existing pools in Redwood Creek and Fern Prairie Creek and Minon Creek and other tributaries;
- Consider adding shelter complexity with wood and large boulders to existing cool temperature refuge sites on upper Redwood Creek. This could be done on a seasonal basis using small woody debris to provide escape cover for adult summer steelhead and juvenile salmonids during summer season. The cool patches may be located in temperature stratified pools or adjacent cool water inputs from tributary flows, springs, and seeps;
- To address the lack of complex pools add large woody debris in Redwood and Minon and Fern Prairie creeks, consider direct placement of large woody debris in existing pool habitat, especially where the average size of near stream conifers is less than 2 feet DBH;
- Consider the use of conservation easements along the upper reach of Redwood Creek to protect valuable riparian and near stream forest from development or timber harvests.

Erosion and Sediment Delivery Reduction Activities:

- In streams where the majority of pool tail spawning substrate is highly embedded with fine sediment, sediment sources should be located, rated according to their potential sediment yields, and treated;
- Upgrade or decommission roads in accordance with existing or future road assessment surveys, especially roads located on unstable slopes and roads near streams. These are found throughout the subbasin but are most frequent in Windy Creek, Twin Lakes Creek, Bradford Creek, and High Prairie Creek Planning Watersheds;
- Consider bank stabilization projects in tributary streams throughout the Upper Subbasin;
- Throughout the Upper Subbasin, timberland managers should avoid the use of tractor yarding on slopes steeper than 35% (19 degrees) and instead use full suspension cable or helicopter yarding on steep and/or highly unstable slopes.

Education, Research, and Monitoring Activities:

- Conduct stream surveys in tributaries and mainstem reaches not addressed in this report;
- Continue temperature monitoring at the current locations to observe changes in temperature as effects from mainstem fluvial conditions, such as aggradation, degradation, channel widening, and riparian function adjust through time;
- Monitoring for in-channel sediment (e.g., sediment size distribution, turbidity, V*, photo points, etc.) should be continued and tracking of streambed levels (i.e., stream channel cross sections) should be continued at upper Redwood Creek study sites;
- A long term, concerted monitoring effort between the land owners, interested parties and responsible agencies is needed to determine the abundance and trends of anadromous fish populations of Upper Subbasin streams;
- Summer steelhead dive counts should be conducted on an annual basis along the upper reach of mainstem Redwood Creek.

Subbasin Conclusions

The Upper Subbasin provides important spawning grounds and year round rearing habitat for anadromous salmonids. High water temperature and a shortage of deep, complex pool habitat are factors limiting salmonid production in the mainstem Redwood Creek below Minon Creek. The lack of deep and complex pool habitat was also identified as potential limiting factors in tributary streams.

The Upper Subbasin was severely affected by the combination of intensive land use activity and the 1964 and other recent flood events. The channel more than doubled in width and shade benefits of riparian vegetation and moderating air temperatures from near stream forests were lost leading to increased water temperatures. Habitat impairments associated with channel widening and high stream temperature still adversely effect habitat suitability throughout much of the upper Redwood Creek mainstem.

While habitat conditions certainly differ from those of pre-management days, it does appear that aspects of the upper mainstem have recovered from the impacts of land management and floods. Much sediment has moved downstream, pools have re-formed and the channel substrate has improved in spawning suitability. However, excessive erosion continues to be a problem as the Upper Subbasin currently yields more suspended sediment to the mainstem of Redwood Creek than the Middle and Lower subbasins combined.

The Upper Subbasin offers good opportunities for implementing watershed improvement activities. Watershed management strategies aimed at reducing sediment inputs by reducing erosion will help address landscape issues that contribute to impairment of aquatic habitat. Stream habitat improvement projects should focus on preserving cool water flowing from the headwaters reach of Redwood Creek re-establishing riparian shade and reducing the channel width along mainstem Redwood Creek. Restoration projects such as tree planting and adding LWD and shelter complexity to stream channels may increase the rate of stream recovery. Adding shelter complexity to cool water refuge sites will provide summer steelhead protective cover needed during their summer holding stage. In tributary watersheds, stream habitat improvement activities should focus on increasing frequency, depth and complexity to pool habitats, adding instream shelter complexity, and promoting nearstream coniferous forest growth retention.

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