Section III
Basin Profile and Overview
Table of Contents

REDWOOD CREEK PROFILE AND SYNTHESIS 1

SUBBASIN SCALE 1
CLIMATE 4
HYDROLOGY 5
Stream Flow 5
Water Diversions and Dams 7
GEOLOGY 10
Faulting 12
Roads, Timber Harvest, and Mass Wasting 14
Results and Analysis from Landslide and Relative Landslide Potential Mapping 15
FLUVIAL GEOMORPHOLOGY 19
Stream Gradient and Reach Classification 20
Suspended Sediment, Channel Cross Sections, and Sediment Budget 24
Cross Section Monitoring 25
Sediment Budget 27
Primary Sediment Sources 28
Streamside Landslides 28
Stream Disturbance Features 31
VEGETATION 40
FIRE HISTORY AND FIRE HAZARD 48
LAND USE 50
Pre-European Settlement 50
European Settlement 51
FOREST MANAGEMENT AND TIMBER HARVESTING 53
ROADS 56
WATER QUALITY 56
Water Column Chemistry 56
Water Temperature 57
In-Channel Sediment 60
ANADROMOUS SALMONID FISHERY RESOURCES 62
Historical Fishery Information 67
Anadromous Salmonid Status and Life History Notes 69
Chinook salmon 69
Coho Salmon 75
Steelhead 78
Summer Steelhead 82
Coastal Cutthroat Trout 83

BASIN ISSUES, INTEGRATED ANALYSIS, AND CUMULATIVE EFFECTS 86

REDWOOD CREEK GENERAL ISSUES AND SUMMARY FINDINGS 86
Integrated Analysis and Cumulative Effects 88
EMDS POTENTIAL SEDIMENT PRODUCTION MODEL 96
LIMITING FACTORS ANALYSIS AND STREAM REACH EMDS 99
IN-STREAM AND RIPARIAN ZONE RECOMMENDATIONS FOR EACH OF THE REDWOOD CREEK SUBBASINS 100
SALMONID REFUGIA IDENTIFICATION AND CLASSIFICATION 103
BASIN SCALE RESPONSES TO ASSESSMENT QUESTIONS 105

Table of Figures

Figure III- 1. The Redwood Creek basin and major stream network. 2
Figure III- 2. The five subbasins of the Redwood Creek basin and their planning watersheds. 3
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. 5
Figure III- 4. Peak Flows (cfs) at Orick, near the mouth of Redwood Creek, from 1954 through 2000. 6
Figure III- 5. Precipitation and streamflow (Discharge) at the O'Kane and Orick gaging stations, 1971 to 200. 7
Figure III- 6. Streamflow (Discharge) and suspended sediment at O'Kane and Orick, 1971 to 2000. 8
Figure III- 7. Redwood Creek water rights location map. 9
Figure III- 8. Generalized geologic map for the Redwood Creek basin showing distribution of major bedrock units. 11
Figure III- 9. Overall landslide potential in the Redwood Creek basin. 16
Figure III- 10. Rate of failure of all types of landslides by slope and geologic unit. 19
Figure III- 11. Distribution (percent by length) of stream gradients. 21
Figure III- 12. Redwood Creek basin channel reaches by channel gradient classes. 23
Figure III- 13. Suspended-sediment load per area from 1974 to 2000 at Orick and O'Kane (Hwy 299) stations. 25
Figure III- 14. Ratio between suspended sediment load at O'Kane (Highway 299) and Orick, 1973-1998. 25
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). 26
Figure III- 16. Lower Redwood Creek basin and Prairie Creek Basin elevated sediment deposition, 1984 and 2000. 33
Figure III- 17. Middle Subbasin elevated sediment deposition, 1984 and 2000. 34
Figure III- 18. Upper Redwood Creek Subbasin elevated sediment deposition, 1984 and 2000. 35
Figure III- 19. Change in the proximity between active streamside landslides and negative stream features between 1984 and 2000. 36
Figure III- 20. Number of active streamside landslides in 1984 and in 2000. 37
Figure III- 21. Fuel rankings for Redwood Creek basin and subbasins. 50
Figure III- 22. Redwood Creek ownership map, 2001. 53
Figure III- 23. Numbers of timber harvest plans per year and acres harvested for the Middle and Upper subbasins, 1978 though 2001. 55
Figure III- 24. MWATs for all stations in the Redwood Creek basin, 1994 to 2001. 59
Figure III- 25. Seasonal maximum temperatures for all stations in Redwood Creek basin, 1994 to 2001. 59
Figure III- 26. Location of temperature monitoring sites. 60
Figure III- 27. Median surface particle size in-channel substrate data from mainstem Redwood Creek, 1979 to 1995. 61
Figure III- 28. U.S. Fish and Wildlife Service estimates of adult salmonid populations in the Redwood Creek basin, 1960. 66
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. 71
Figure III- 30. Yearly juvenile Chinook population estimates based on trapping results on Redwood Creek, 2000 to 2003. 73
Figure III- 31. Temporal pattern of 0+ Chinook catches. 74
Figure III- 32. Average weekly fork lengths for 0+ Chinook. 74
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. 77
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). 78
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). 78
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. 80
Figure III- 37. Yearly juvenile steelhead population estimates, 2000-2002. Adapted from trapping results on Redwood Creek (Sparkman 2000, 2001, and 2002). 81
Figure III- 38. Summer steelhead dive counts on Redwood Creek, 1981-2000. 83
Figure III- 39. Number of coastal cutthroat trout observed during summer steelhead snorkel surveys on Redwood Creek mainstem, 1992-2000. 85
Figure III- 40. Refugia designations for select streams of the Redwood Creek basin. 104

List of Tables

Table III- 1. Redwood Creek subbasin summary. 4
Table III- 2. Agricultural land, water source, and water use within the Redwood Creek basin. 9
Table III- 3. Population and water use within the Redwood Creek basin. 9
Table III- 4. Historically active landslide features of the Redwood Creek basin and subbasins. 15
Table III- 5. Combined indicators of slope instability. 15
Table III- 6. Relative landslide potential of the Redwood Creek basin, by acres and percent of area. 17
Table III- 7. Gradient distribution for the mainstems of Redwood and Prairie creeks, and other tributaries. 22
Table III- 8. Length and percent of stream reaches in source, transport, and response categories. 24
Table III- 9. Sediment source category estimates. Adapted from USEPA (1998). 27
Table III- 10. Length of stream disturbance features, stream disturbance feature index, and percent change for 1984 to 2000. 32
Table III- 11. Number and indices of streamside slides by basin, subbasins, and Planning Watersheds. 38
Table III- 12. Proximity of landslide and selected geomorphic features to watercourses.[1] 39
Table III- 13. Acres of Redwood Creek basin vegetation types, by subbasin. 42
Table III- 14. Generalized cover type acres by basin and subbasin. 43
Table III- 15. Generalized cover type by percentage of basin or subbasin area. 43
Table III- 16. Vegetation cover type for the three buffer zones 44
Table III- 17. Vegetation size classes for three buffer zone widths. 44
Table III- 18. Canopy density classes for three buffer zone widths. 45
Table III- 19. Vegetation density of the 150 foot watercourse buffer zone for the basin, subbasins, and CalWater Planning Watersheds within Redwood Creek. 45
Table III- 20. Changes in the amount of stream length that is bordered by open or sparse canopy, 1948-1997 (Urner and Madej 1998). 46
Table III- 21. Riparian characteristics, by percent of area, along Redwood Creek, 1948-1997. 46
Table III- 22. Vegetation attributes within 150-feet of fish bearing streams. 47
Table III- 23. Acres burned and the number of reported fires by responsible agency since 1950. 49
Table III- 24. Fuel ranks summary for Redwood Creek, subbasins, and Planning Watersheds. 49
Table III- 25. Current acres and percentage of area by ownership within Redwood Creek. 52
Table III- 26. Cumulative first entry harvest in the Redwood Creek basin. 54
Table III- 27. Timber harvest estimates by subbasin, 1950-2000, including acres with multiple harvests. 54
Table III- 28. Average annual number of timber harvesting plans and plan acres per decade or period, 1980-1999, Middle and Upper subbasins. 55
Table III- 29. Maximum MWATs and seasonal maximum temperatures for stations in the Redwood Creek basin from 1974 to 2001. 58
Table III- 30. Fishery resources of the Redwood Creek basin. 63
Table III- 31. Number of stream miles accessible to anadromous salmonids in each of the Redwood Creek subbasins. 63
Table III- 32. Anadromous salmonid distribution in the Redwood Creek basin. 65
Table III- 33. Historical events affecting fishery resources of Redwood Creek. 68
Table III- 34. Comparison of Chinook fork length (FL) and population estimates. 75
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). 81
Table III- 36. Juvenile steelhead population estimates and average fork lengths. 82
Table III- 37. Historically active landslide features associated with vegetation type and land use. 91
Table III- 38. Relative landslide potential and land use or type classes, Redwood Creek basin and subbasins. 93
Table III- 39. Relative landslide potential by silvicultural system and yarding method, 1991-2000 THPs. 95
Table III- 40. EMDS ratings for potential stream sediment production; top three levels of model. 96
Table III- 41. Potential stream sediment production from management-related surface erosion sources. 97
Table III- 42. Potential stream sediment production from management-related streamside erosion sources. 97
Table III- 43. Potential stream sediment production from road-related mass wasting sources. 97
Table III- 44. Integrated information for the Redwood Creek basin and subbasins. 98
Table III- 45. Results from EMDS Stream Reach Condition subbasin analysis. 100
Table III- 46. Prioritization of steps to address limiting factors. 101
Table III- 47. Top three ranking recommendation categories by number of tributaries and mainstem reaches in the Redwood Creek basin. 102
Table III- 48. Refugia designations for streams of the Redwood Creek basin. 103

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.

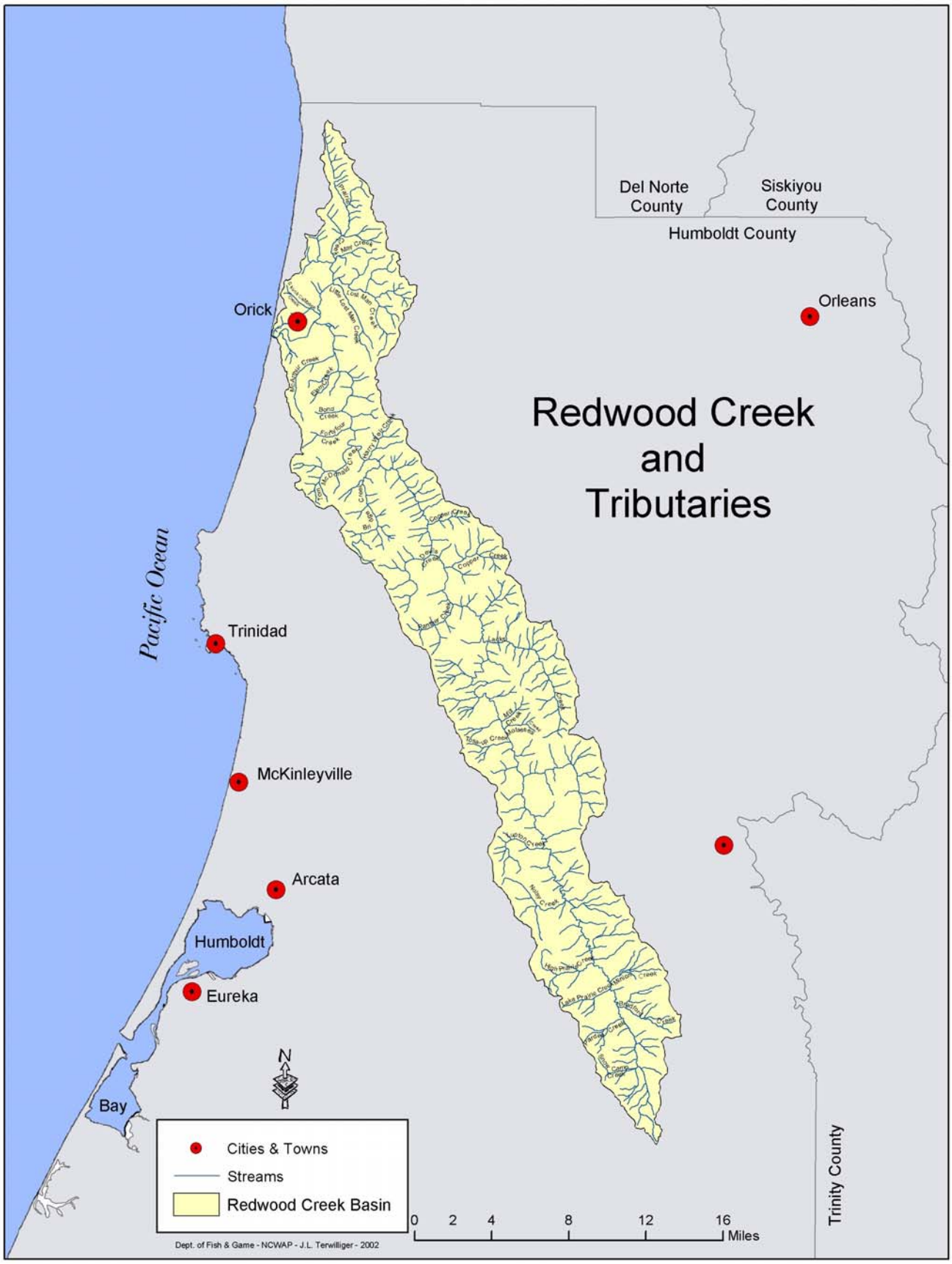

Figure III- 1. The Redwood Creek basin and major stream network.

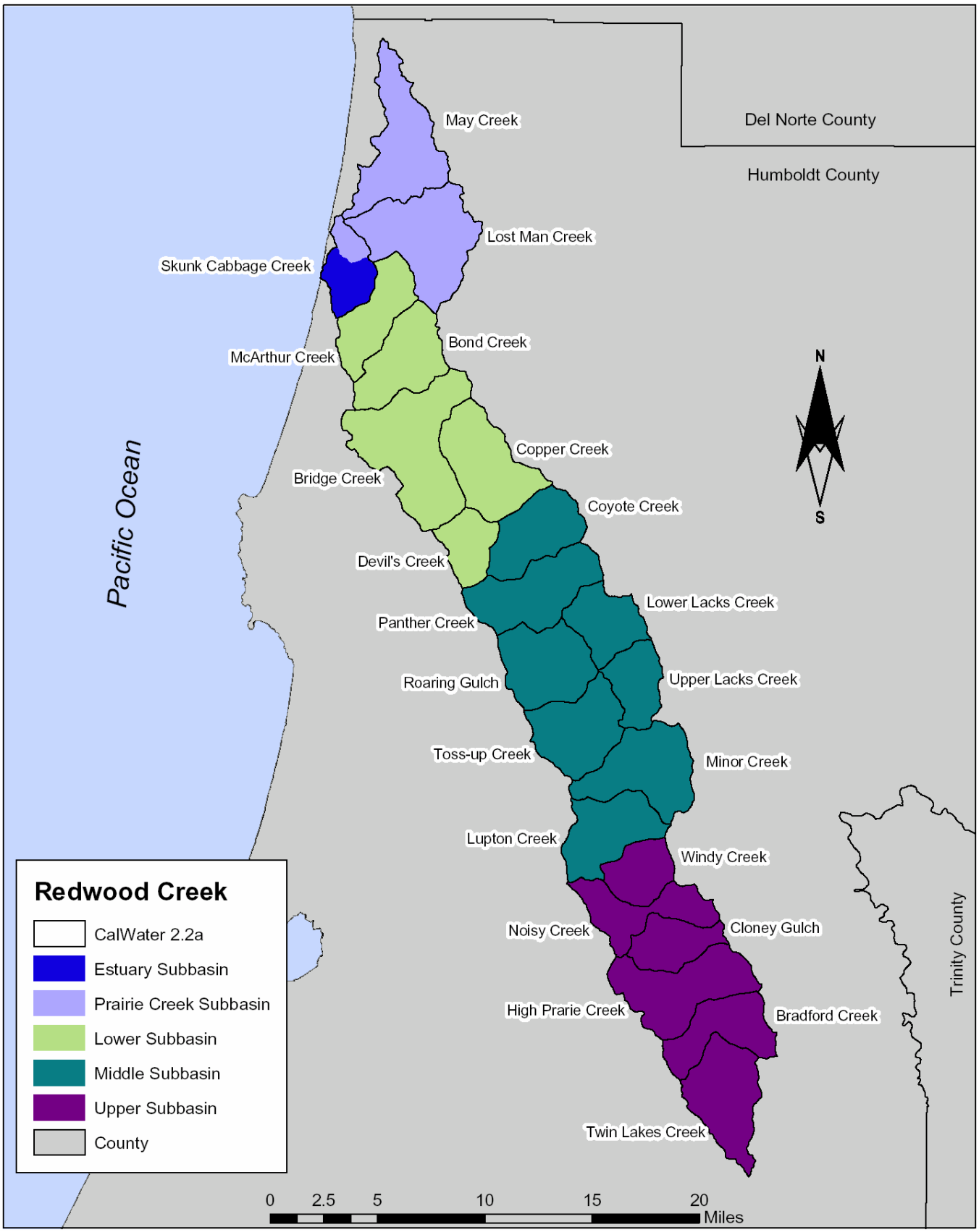

Figure III- 2. The five subbasins of the Redwood Creek basin and their planning watersheds.

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.

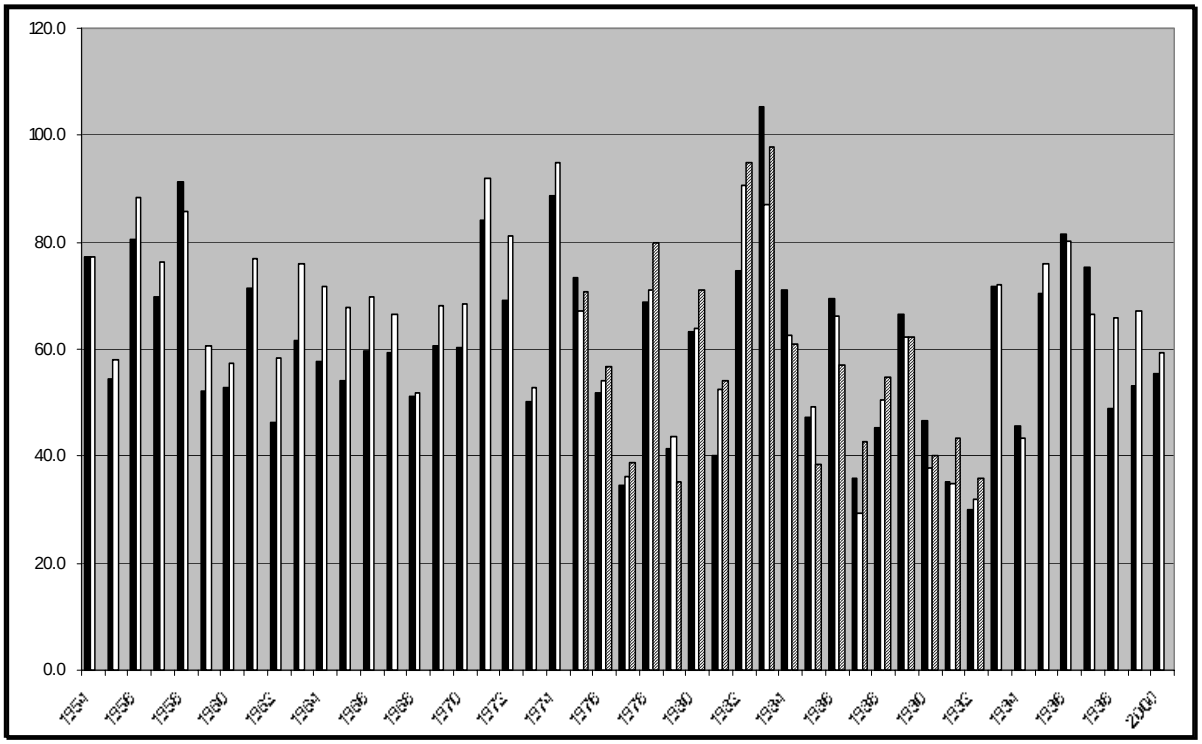

Figure III- 3. Estimated annual precipitation (inches per year), 1954-2000, at Highway 299 (O'Kane, black), Orick (white), and Little Lost Man Creek (striped), Redwood Creek, Humboldt County, California.

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.

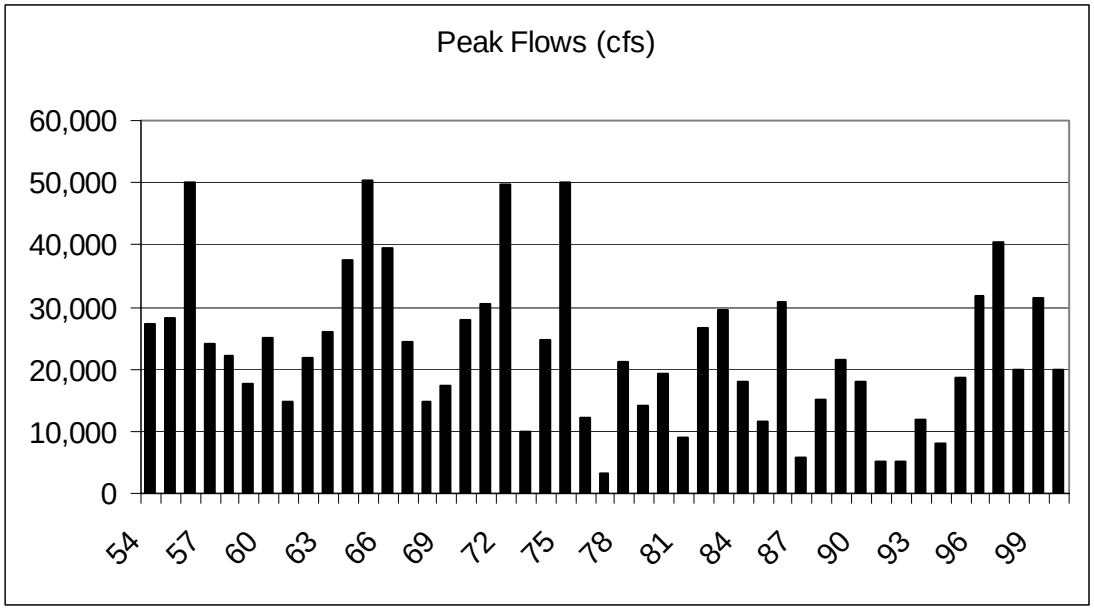

Figure III- 4. Peak Flows (cfs) at Orick, near the mouth of Redwood Creek, from 1954 through 2000.

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.

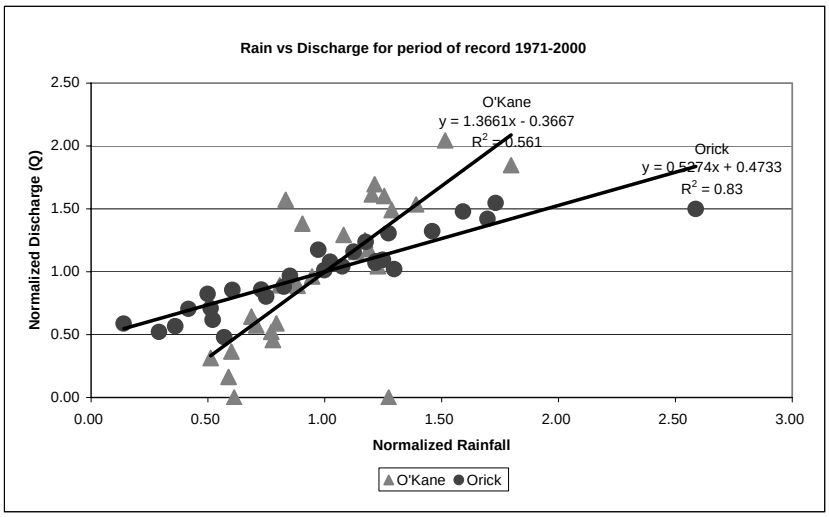

Figure III- 5. Precipitation and streamflow (Discharge) at the O'Kane and Orick gaging stations, 1971 to 200.

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.

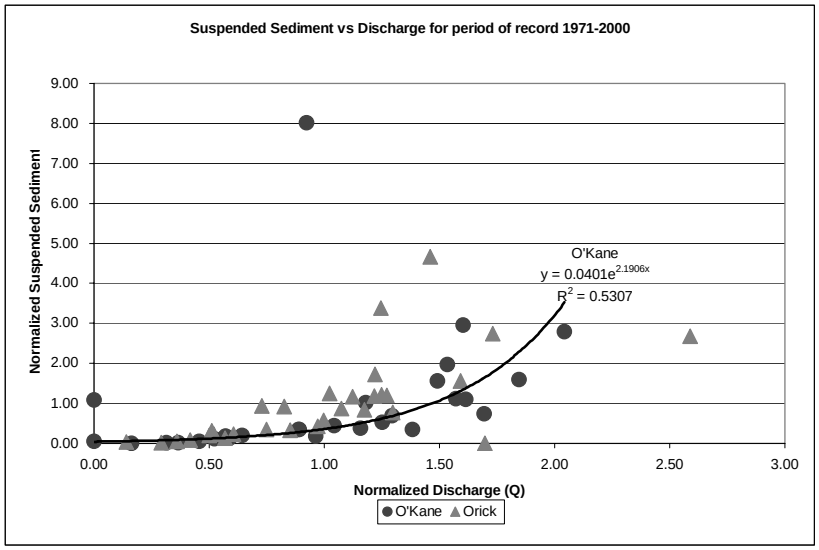

Figure III- 6. Streamflow (Discharge) and suspended sediment at O'Kane and Orick, 1971 to 2000.

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

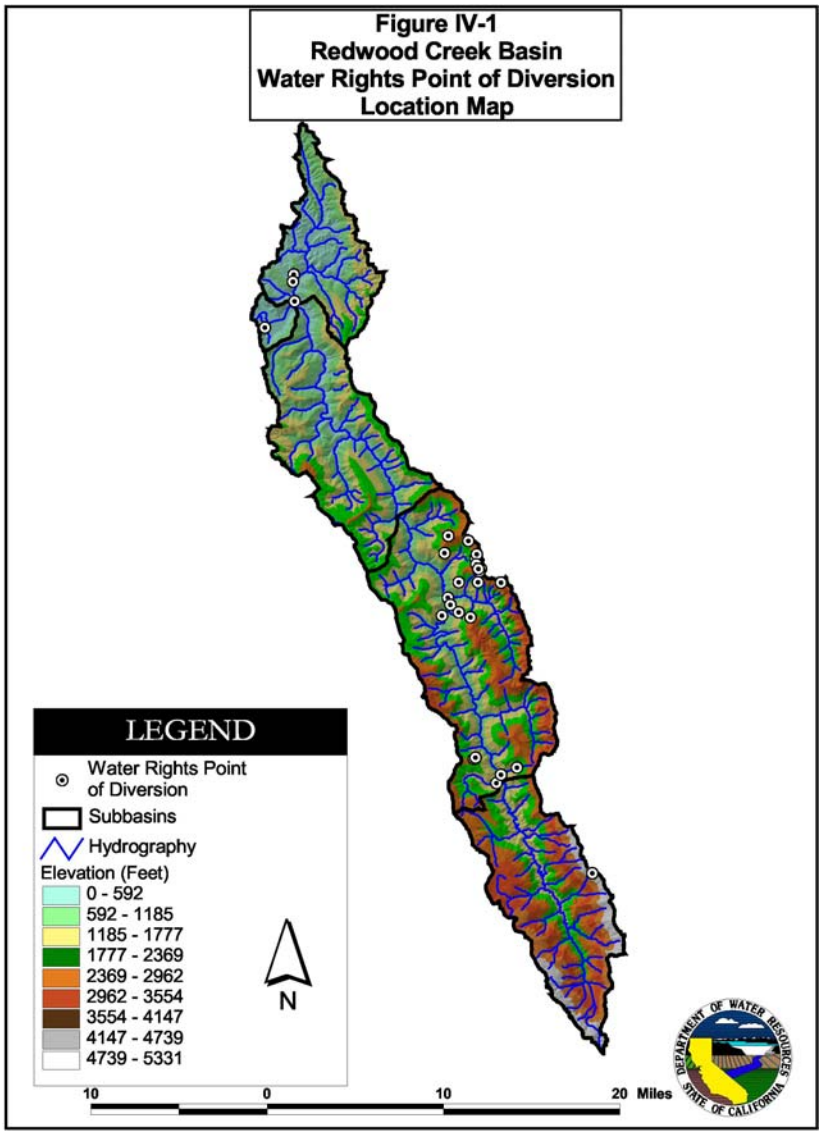

Figure III- 7. Redwood Creek water rights location map.

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.

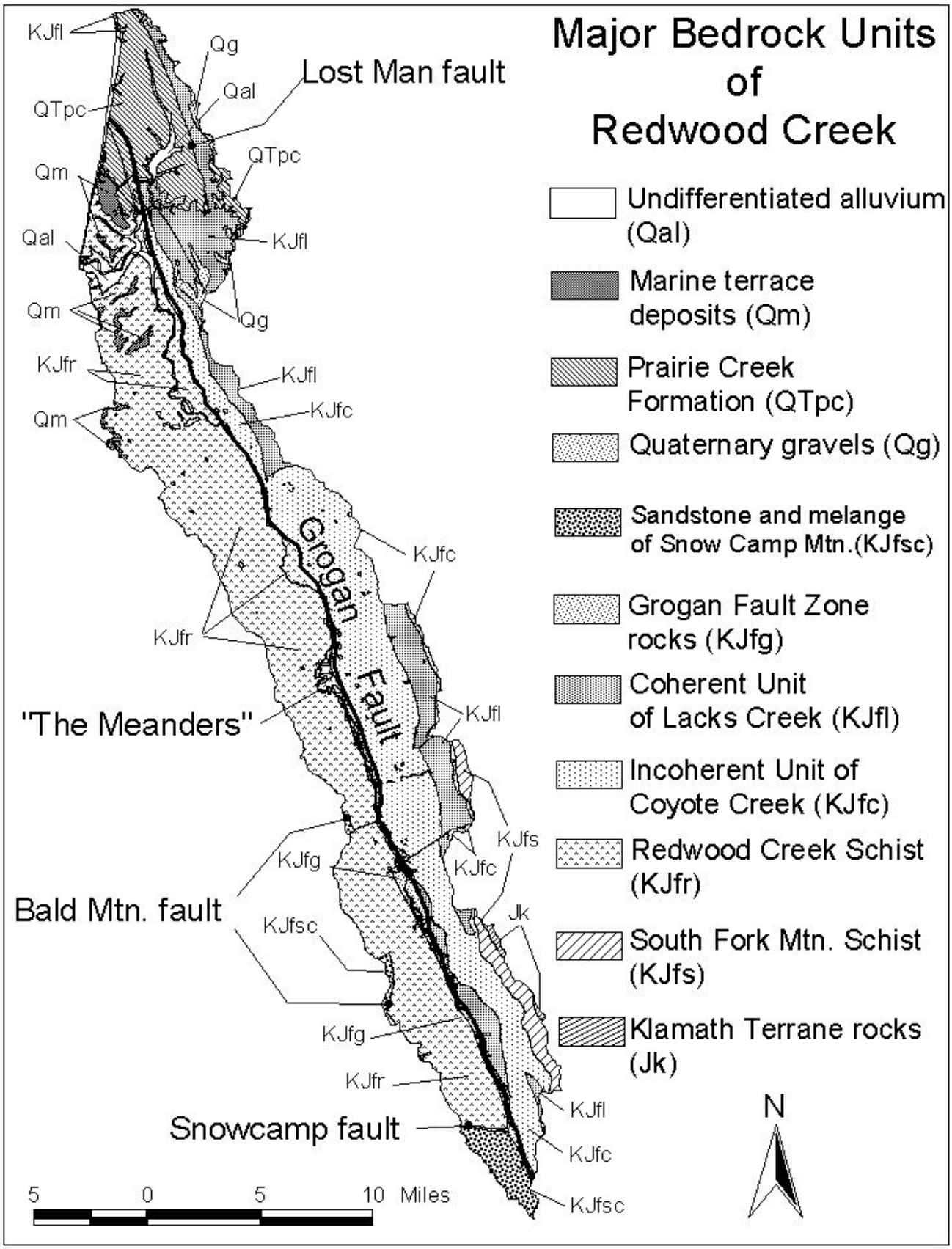

Figure III- 8. Generalized geologic map for the Redwood Creek basin showing distribution of major bedrock units.

Coherent unit of Lacks Creek (KJfl) Eastern Belt Franciscan Complex. 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.

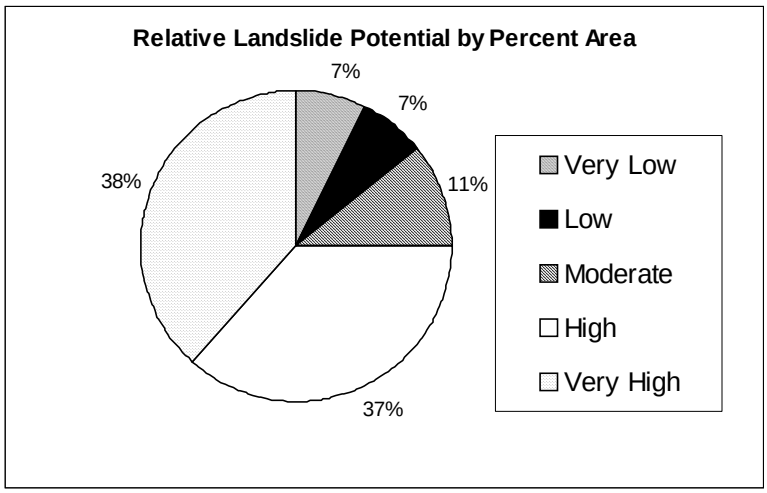

Figure III- 9. Overall landslide potential in the Redwood Creek basin.

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.

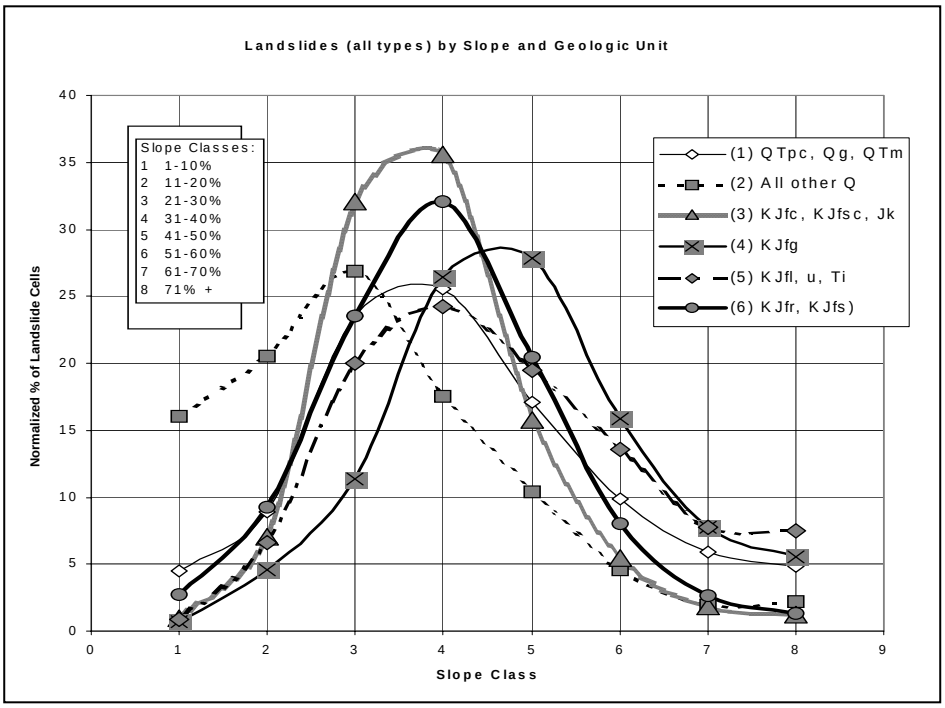

Figure III- 10. Rate of failure of all types of landslides by slope and geologic unit.

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.

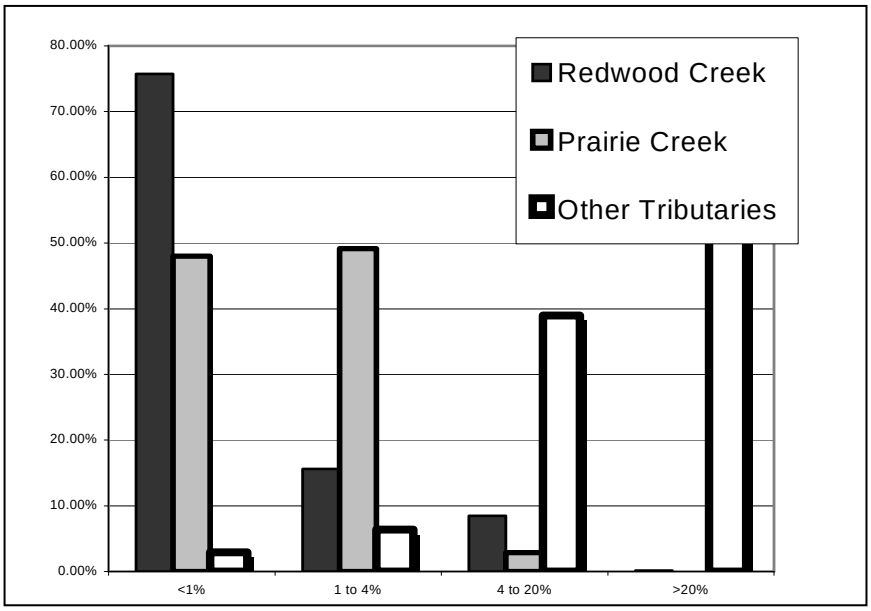

Figure III- 11. Distribution (percent by length) of stream gradients.

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.

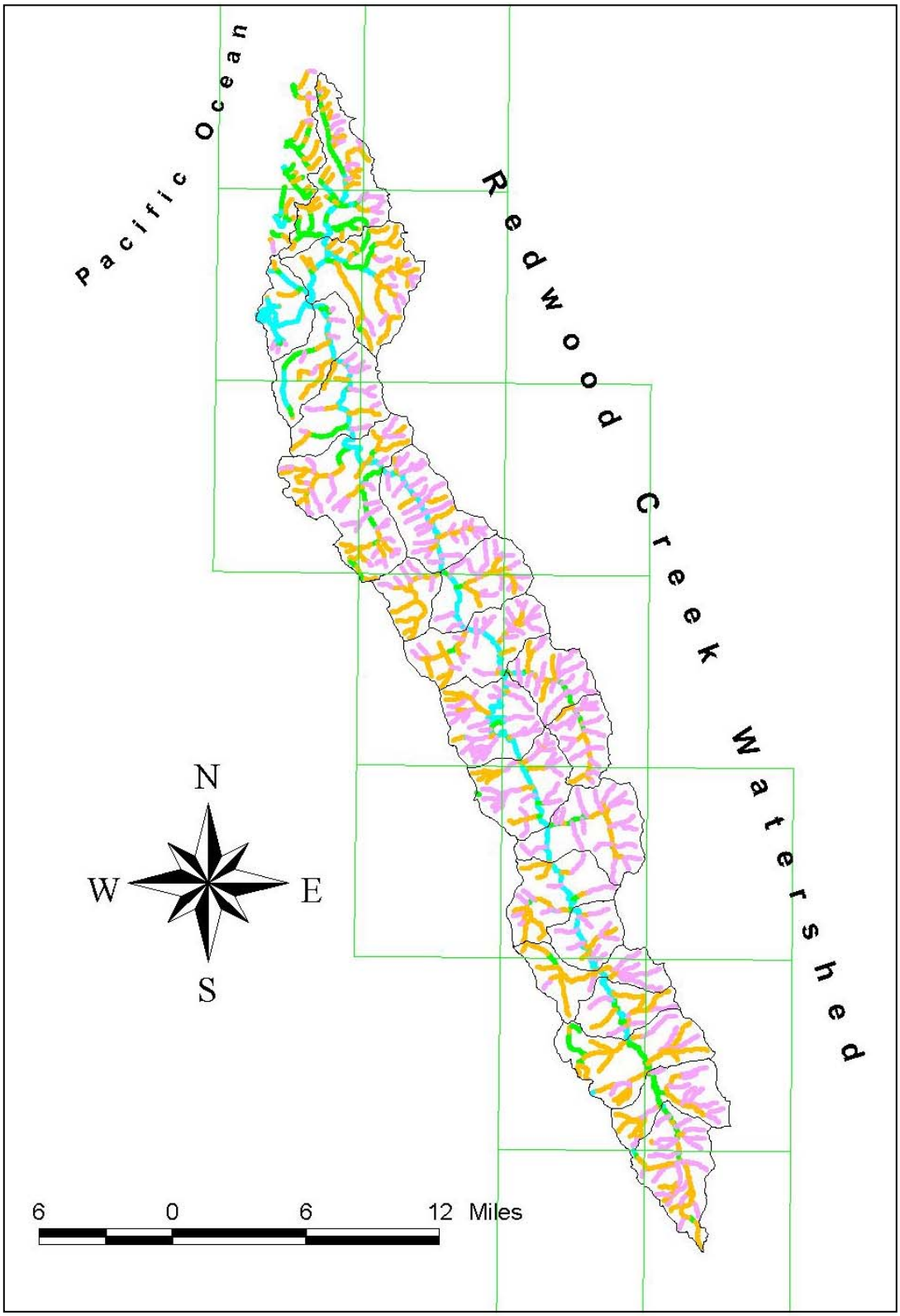

Figure III- 12. Redwood Creek basin channel reaches by channel gradient classes.

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.

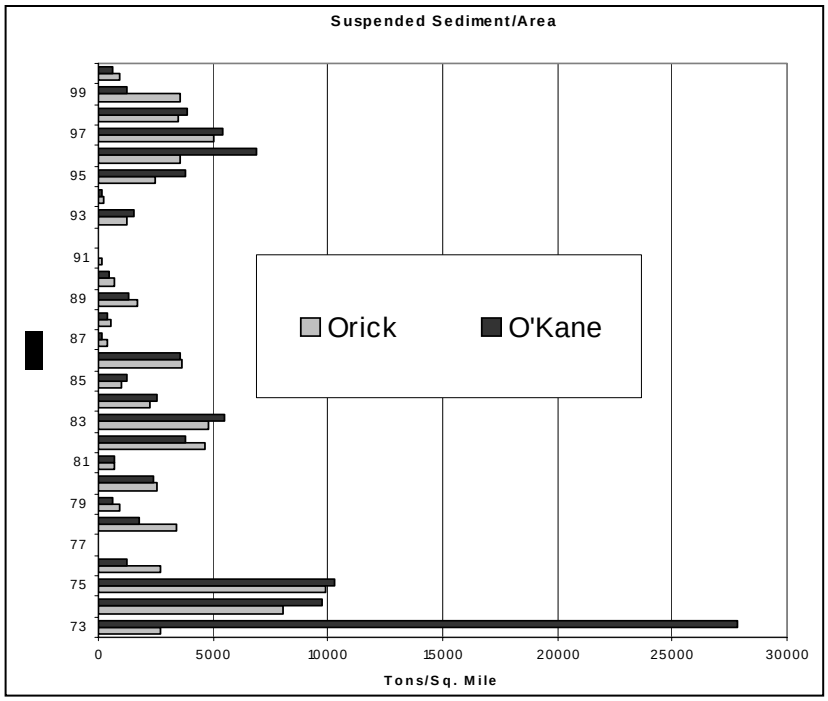

Figure III- 13. Suspended-sediment load per area from 1974 to 2000 at Orick and O'Kane (Hwy 299) stations.

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

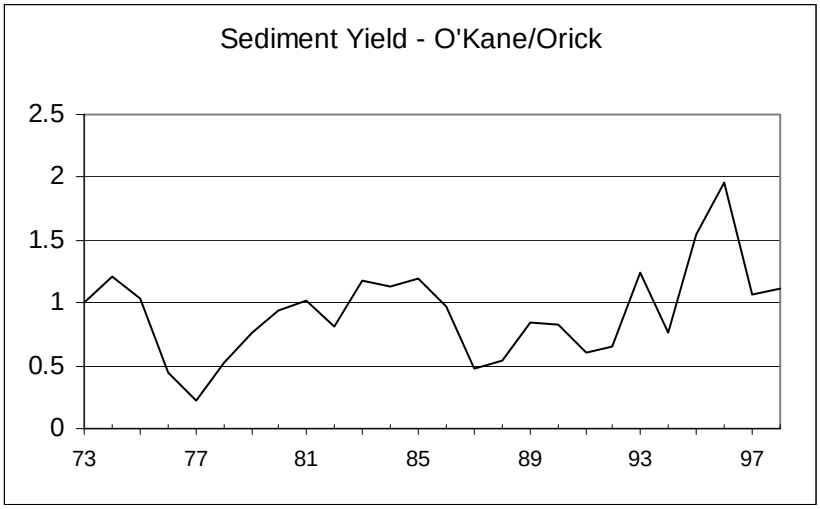

Figure III- 14. Ratio between suspended sediment load at O'Kane (Highway 299) and Orick, 1973-1998.

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).

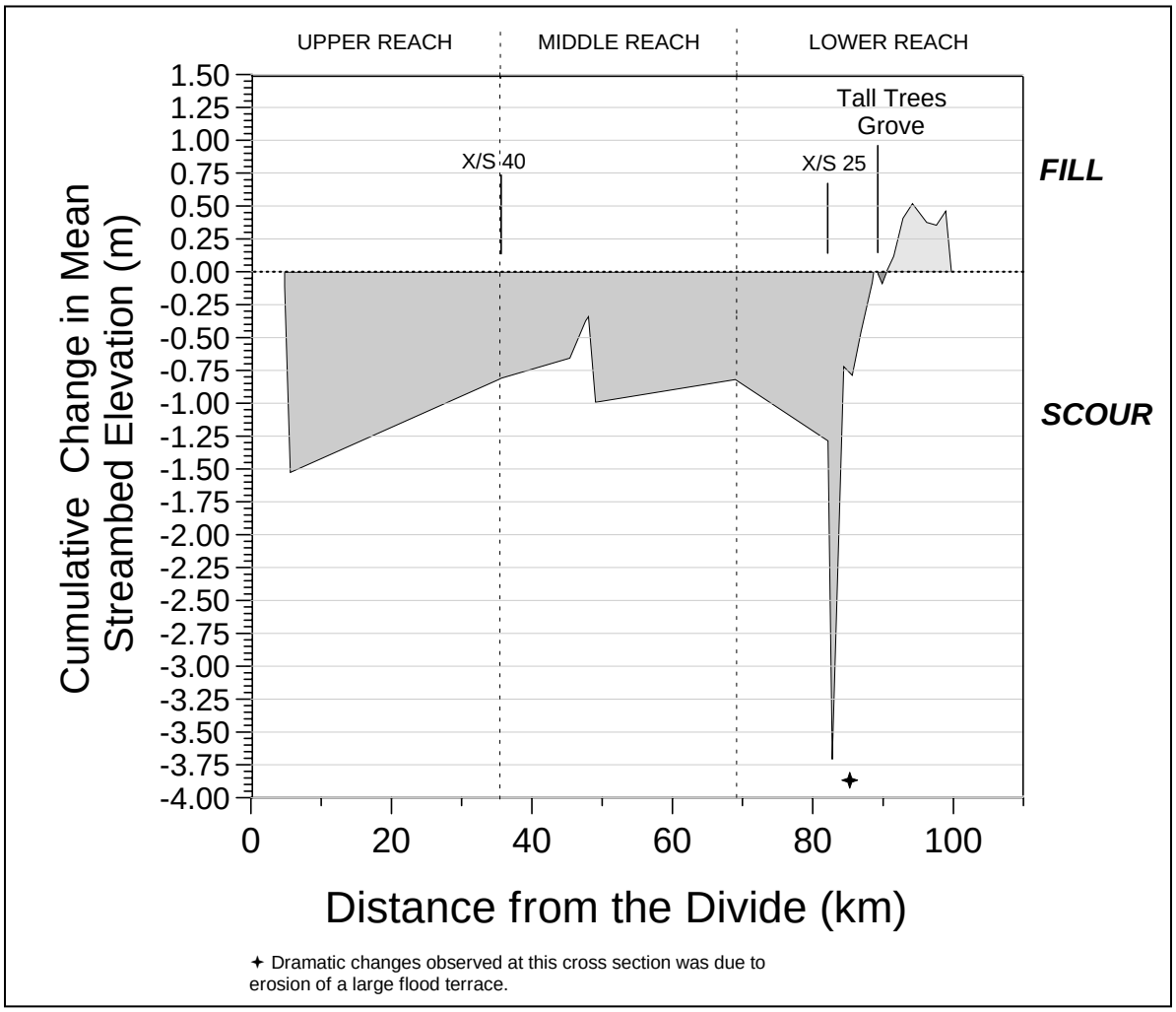

Figure III- 15. Longitudinal trend in changes in stream bed elevation at cross sections along Redwood Creek, 1973 – 1997 from the headwaters divide (RNSP 1999).

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.

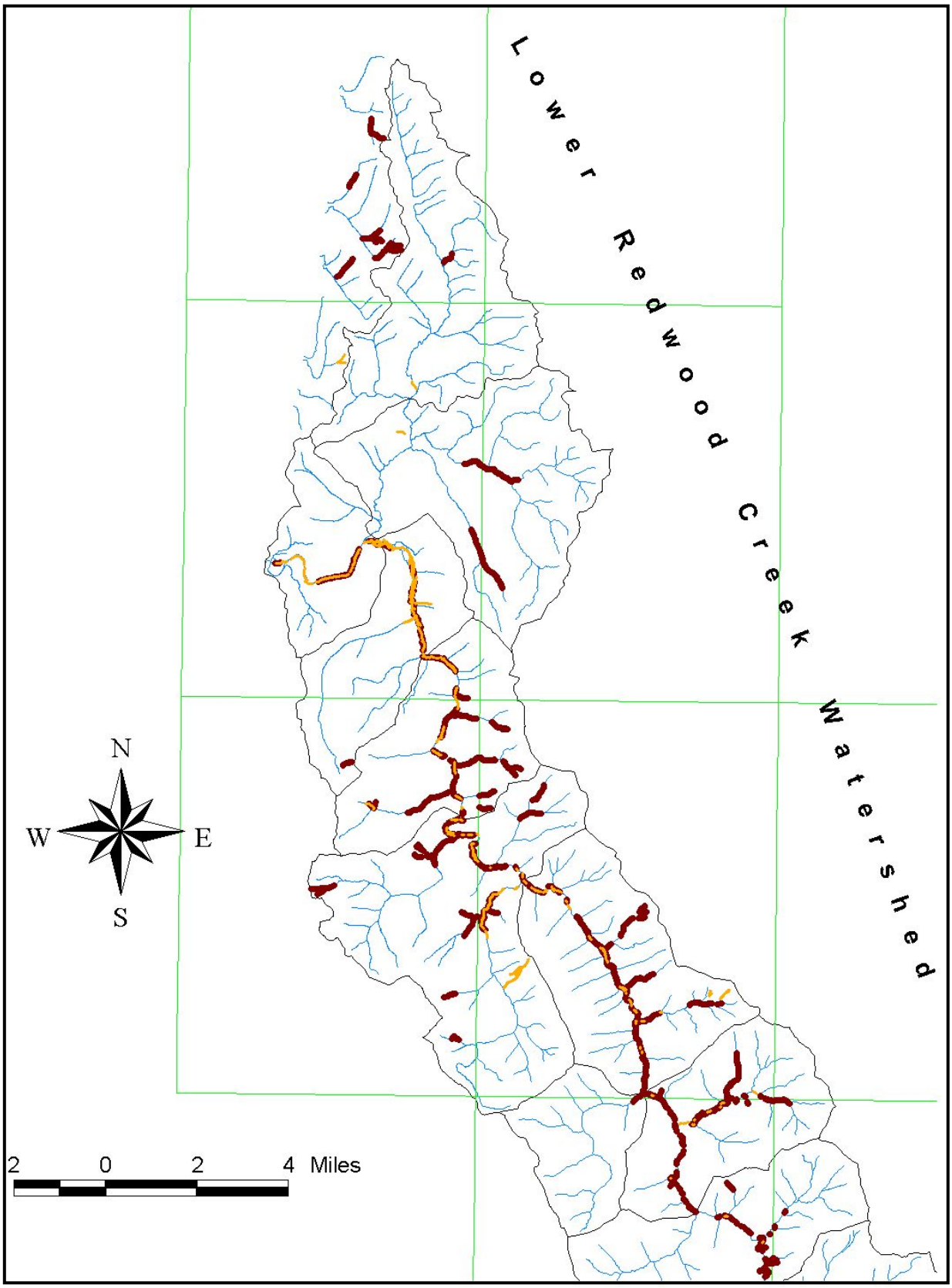

Figure III- 16. Lower Redwood Creek basin and Prairie Creek Basin elevated sediment deposition, 1984 and 2000.

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.

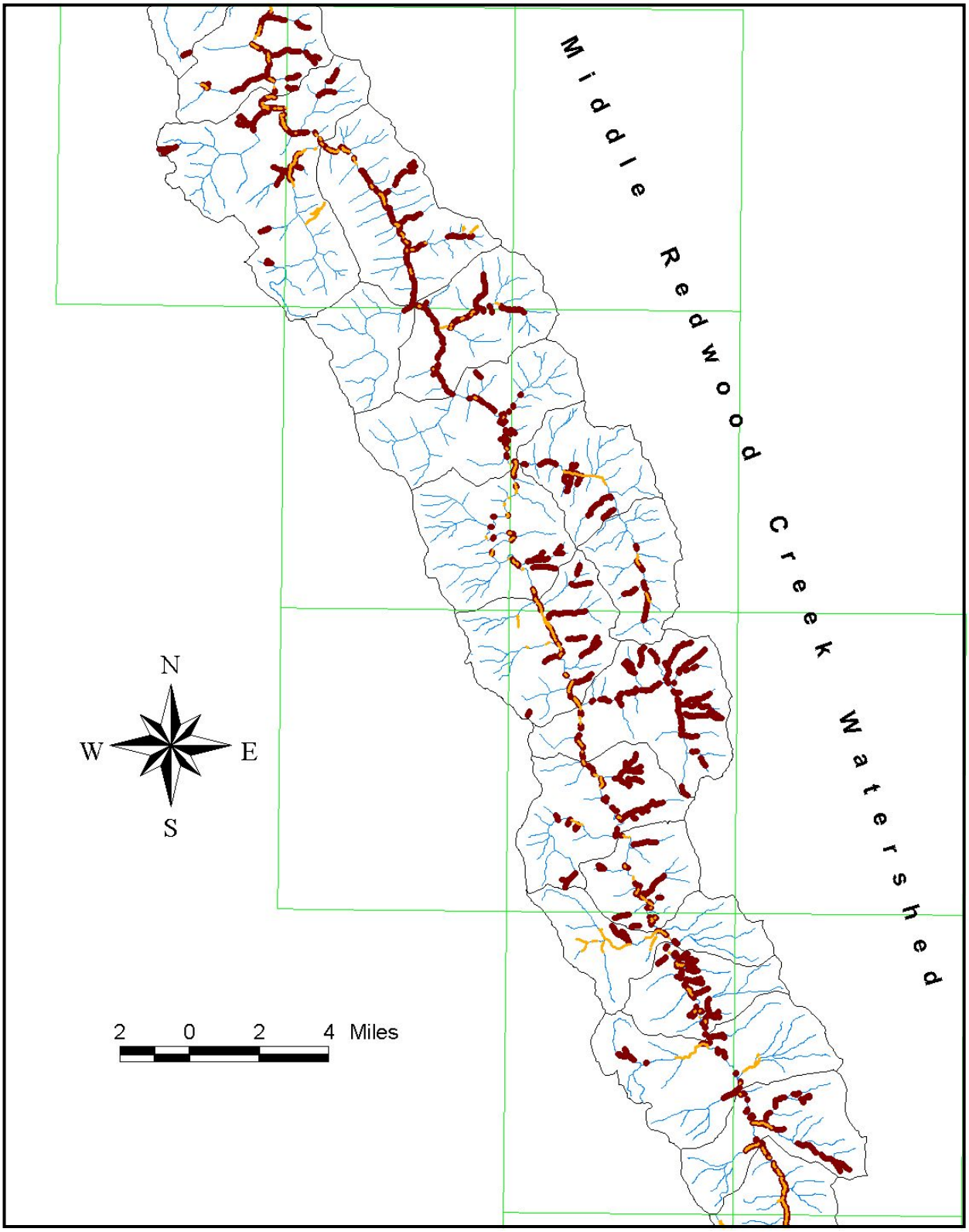

Figure III- 17. Middle Subbasin elevated sediment deposition, 1984 and 2000.

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.

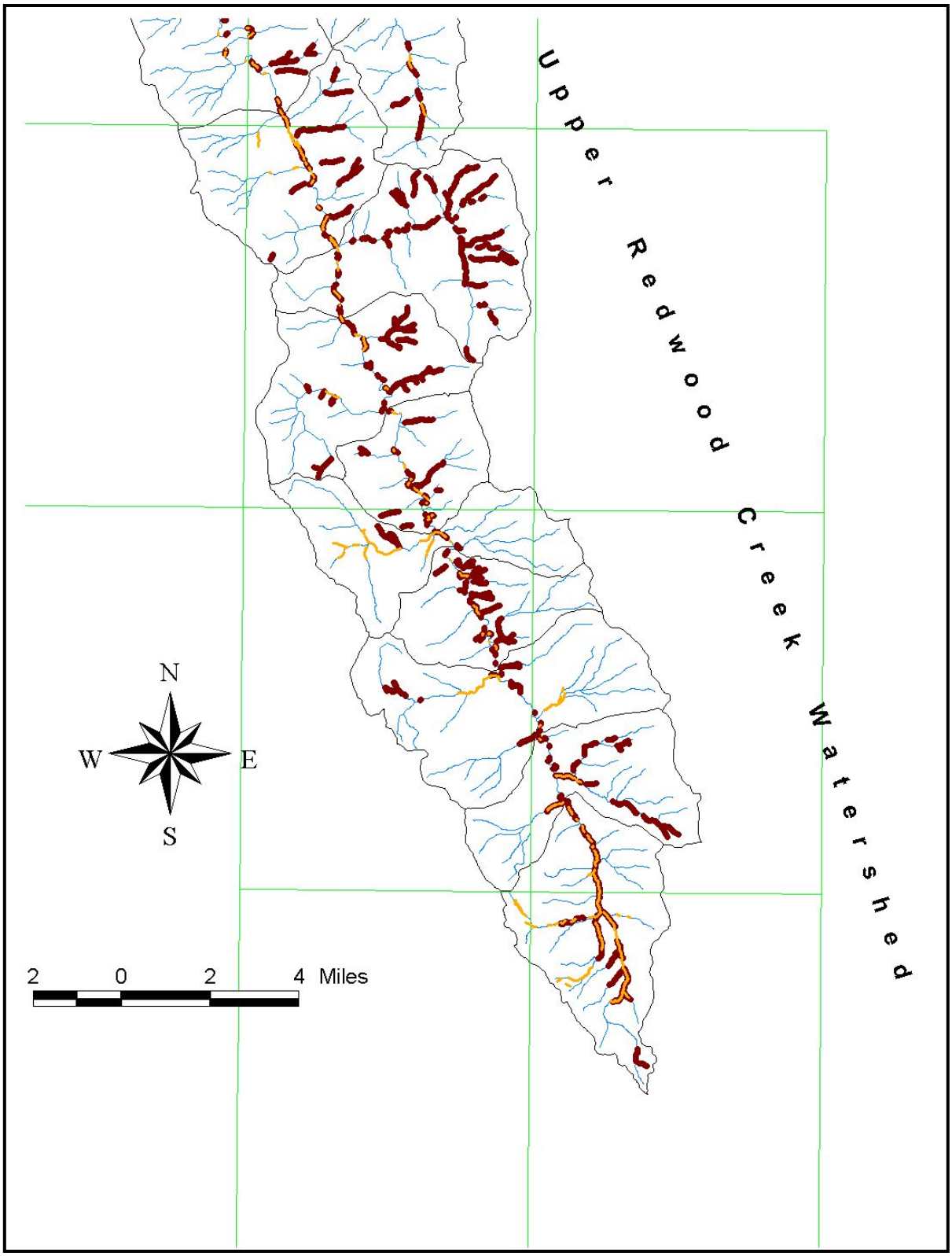

Figure III- 18. Upper Redwood Creek Subbasin elevated sediment deposition, 1984 and 2000.

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.

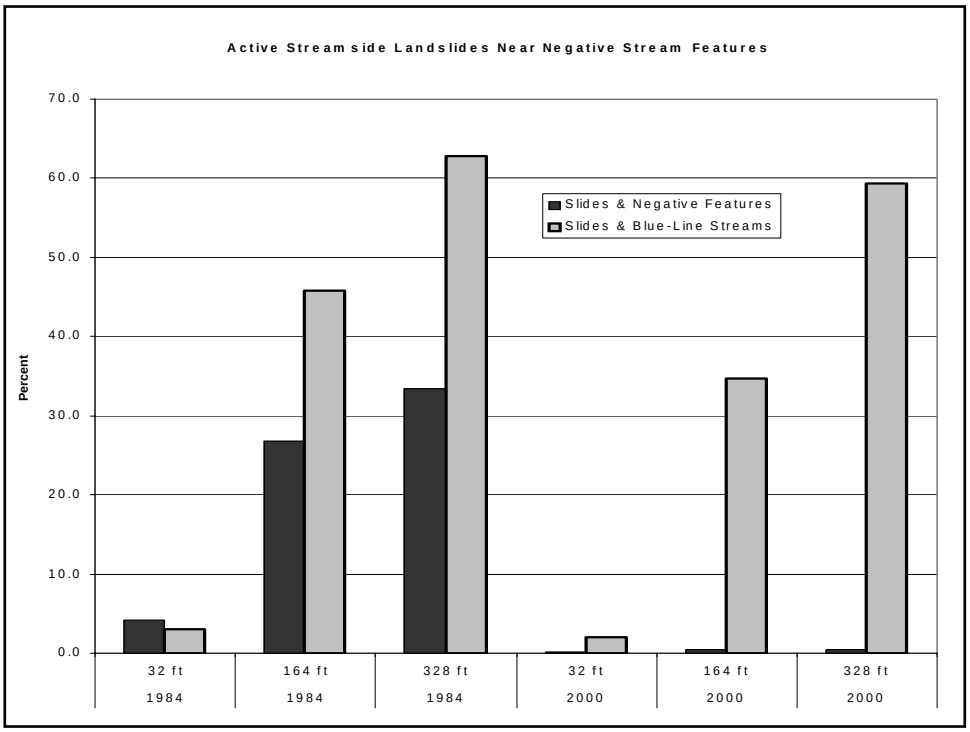

Figure III- 19. Change in the proximity between active streamside landslides and negative stream features between 1984 and 2000.

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.

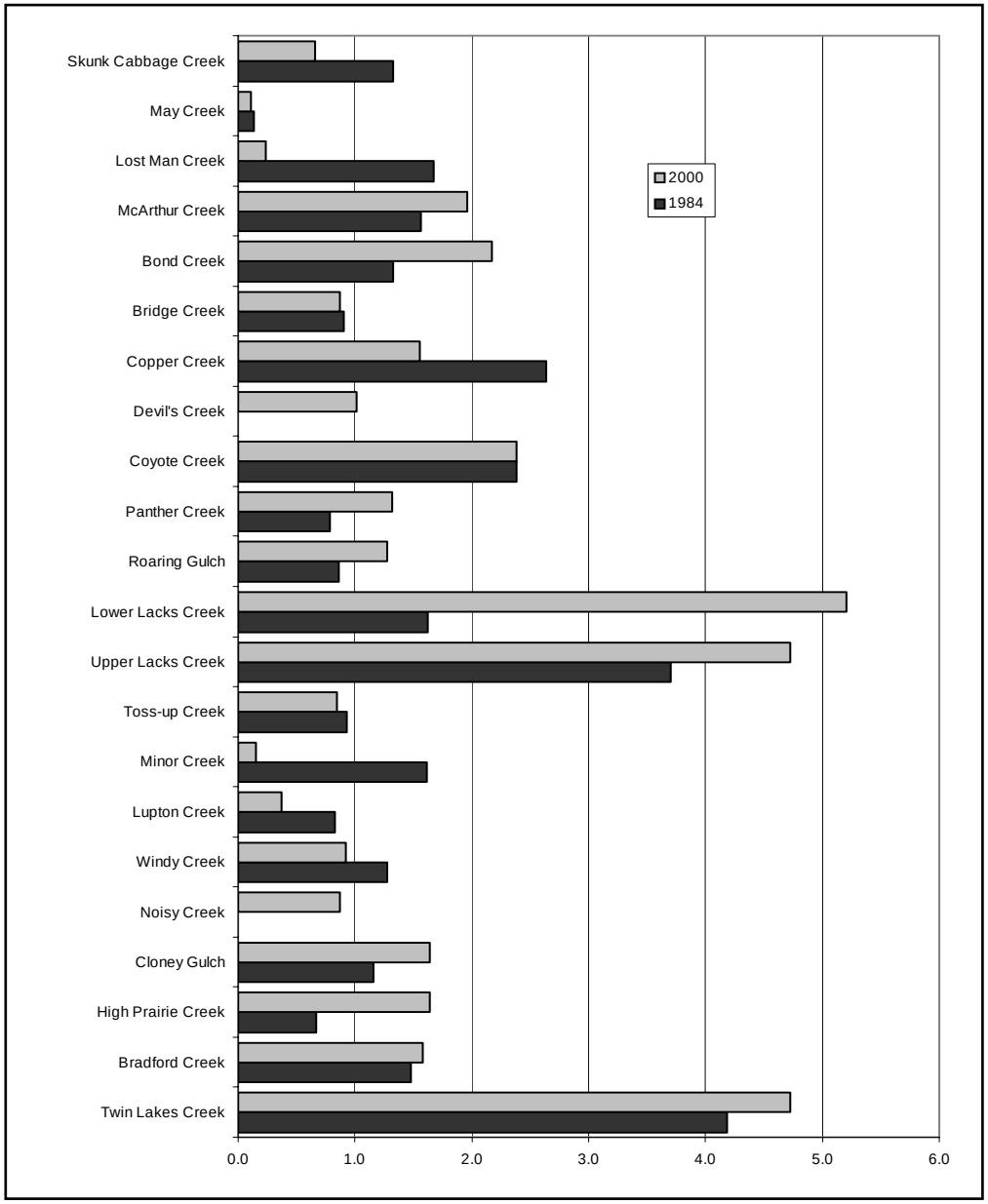

Figure III- 20. Number of active streamside landslides in 1984 and in 2000.

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

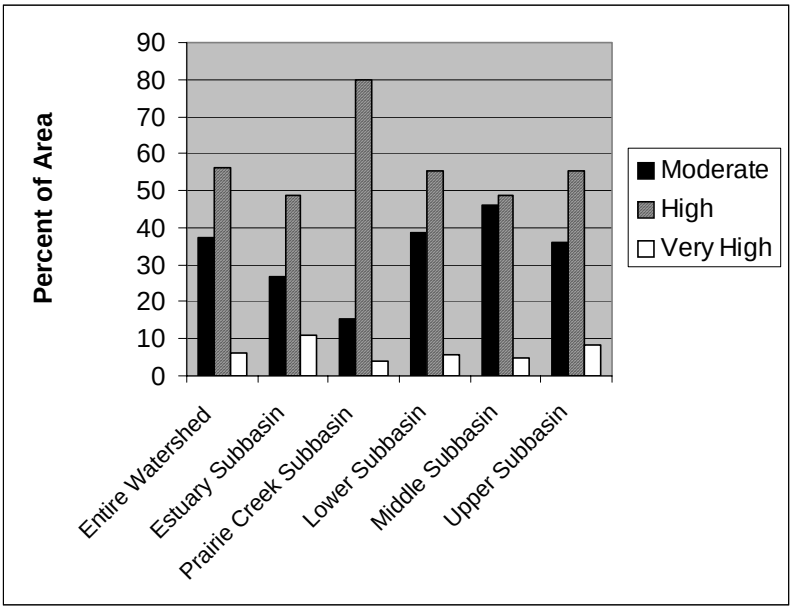

Figure III- 21. Fuel rankings for Redwood Creek basin and subbasins.

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.

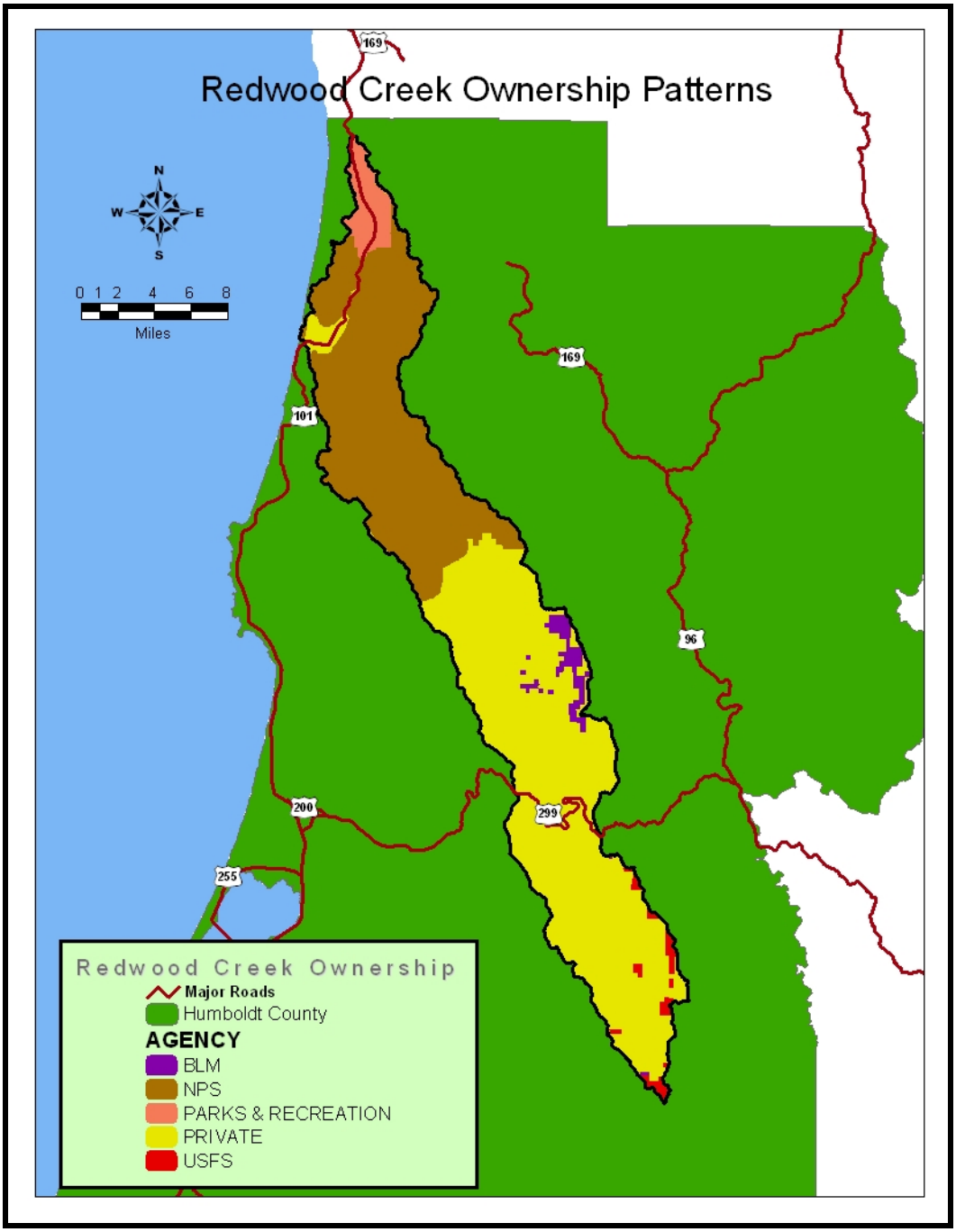

Figure III- 22. Redwood Creek ownership map, 2001.

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.

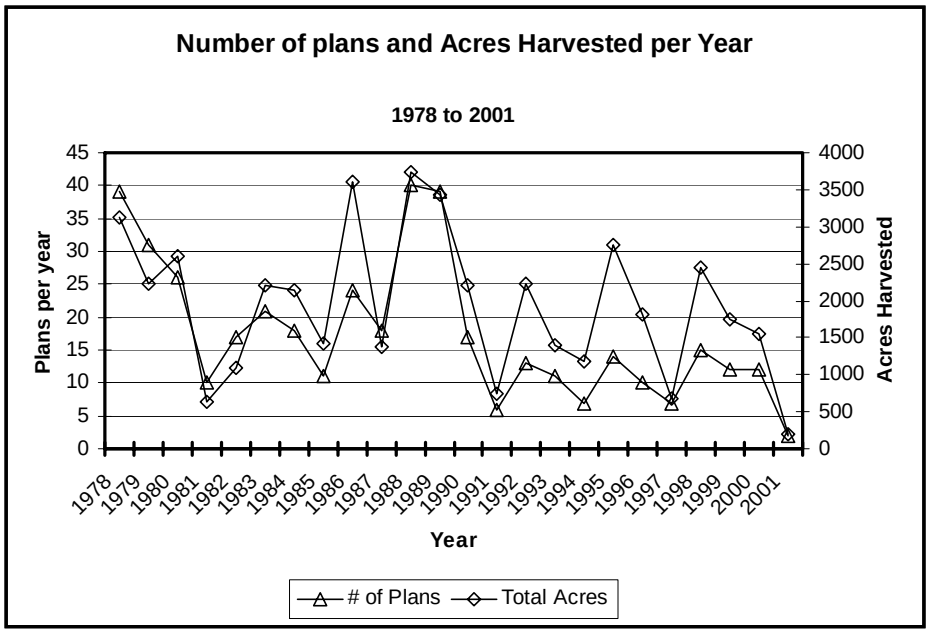

Figure III- 23. Numbers of timber harvest plans per year and acres harvested for the Middle and Upper subbasins, 1978 though 2001.

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.

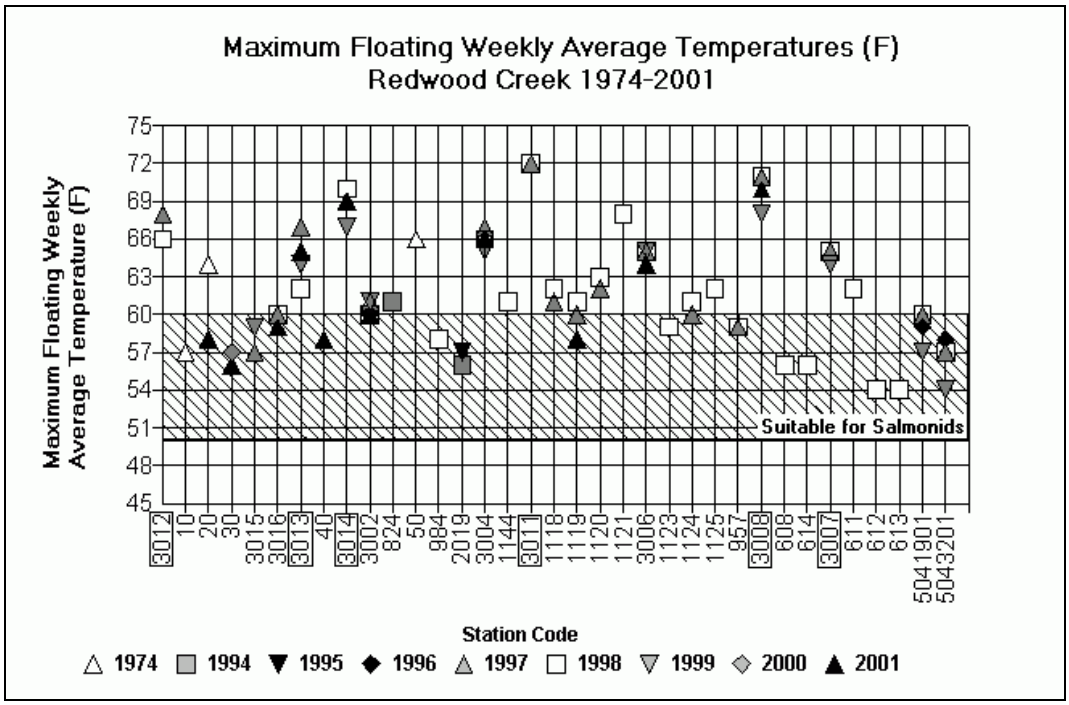

Figure III- 24. MWATs for all stations in the Redwood Creek basin, 1994 to 2001.

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.

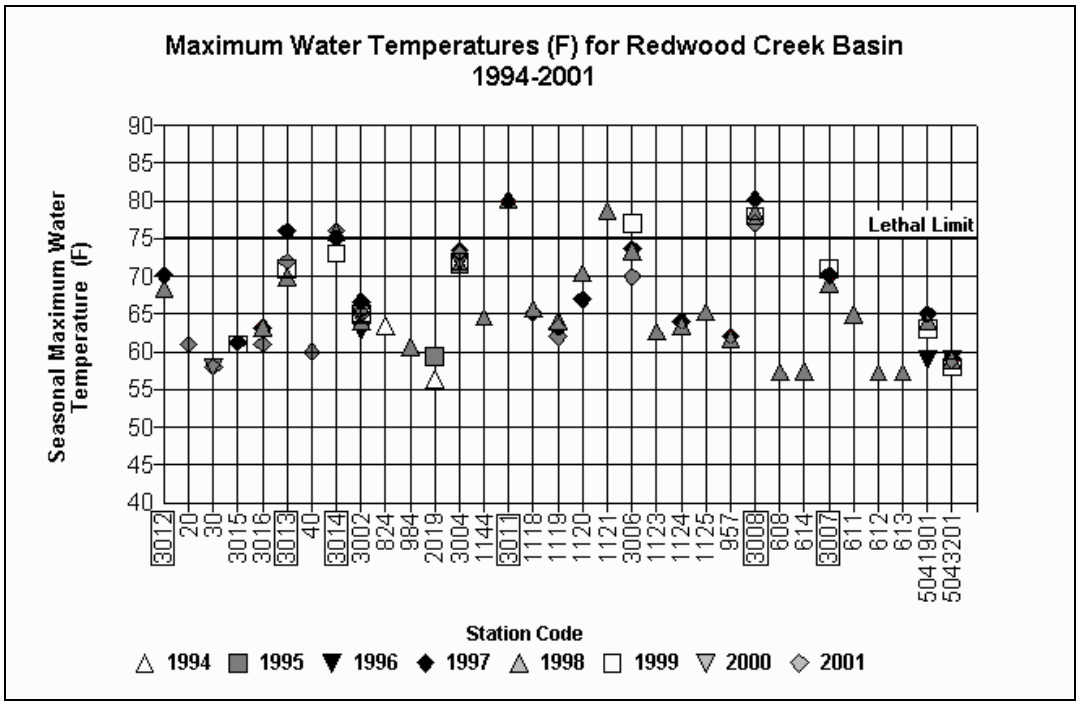

Figure III- 25. Seasonal maximum temperatures for all stations in Redwood Creek basin, 1994 to 2001.

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.

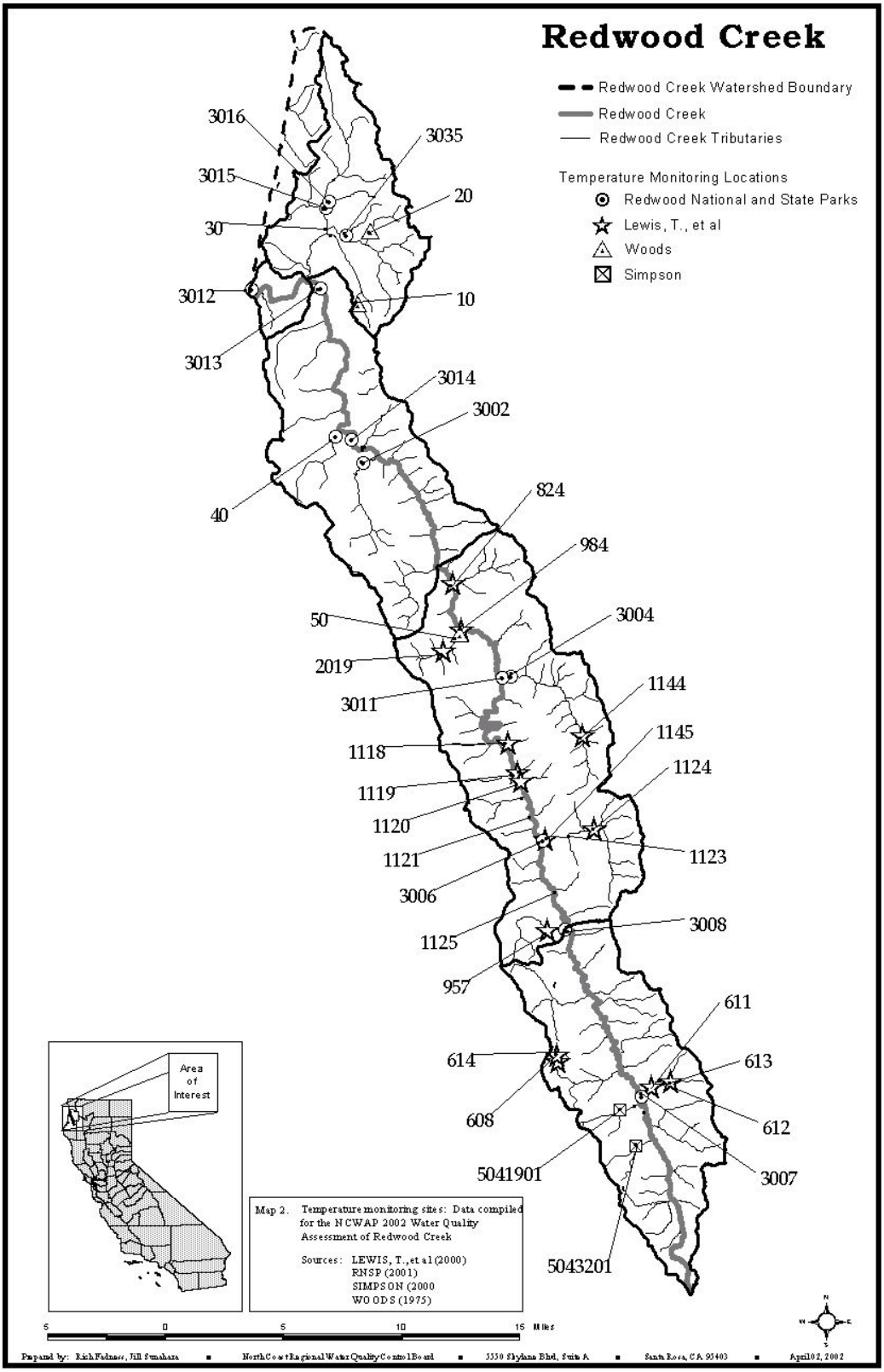

Figure III- 26. Location of temperature monitoring sites.

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.

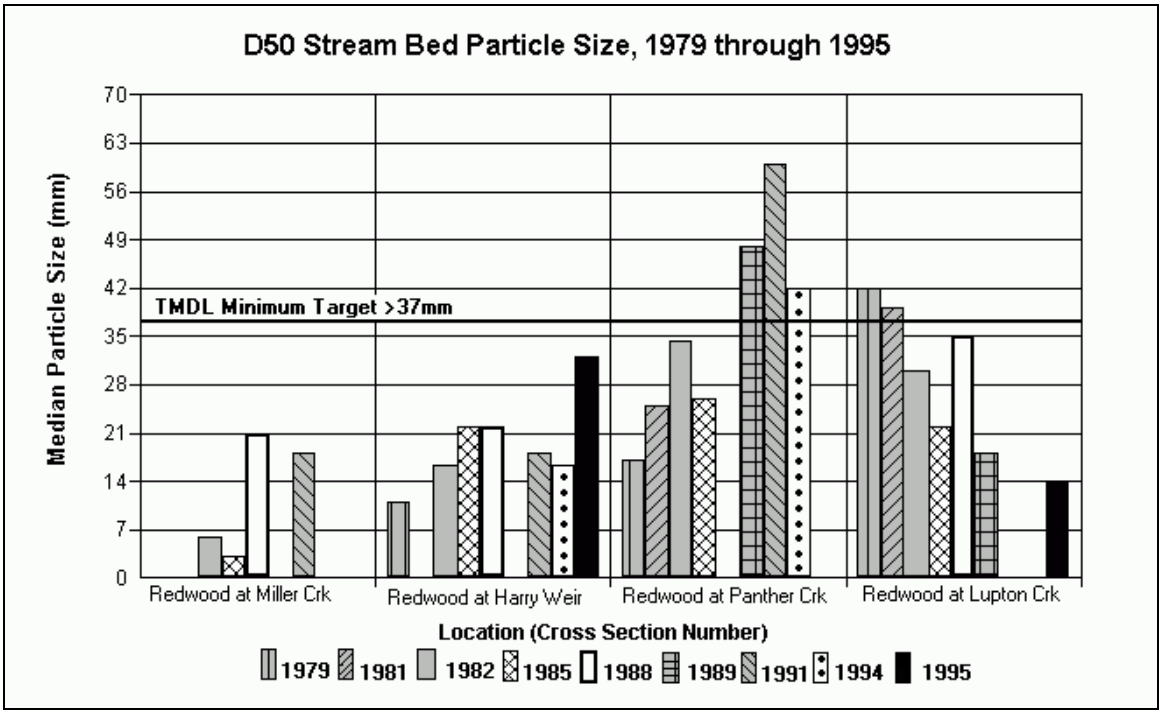

Figure III- 27. Median surface particle size in-channel substrate data from mainstem Redwood Creek, 1979 to 1995.

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.

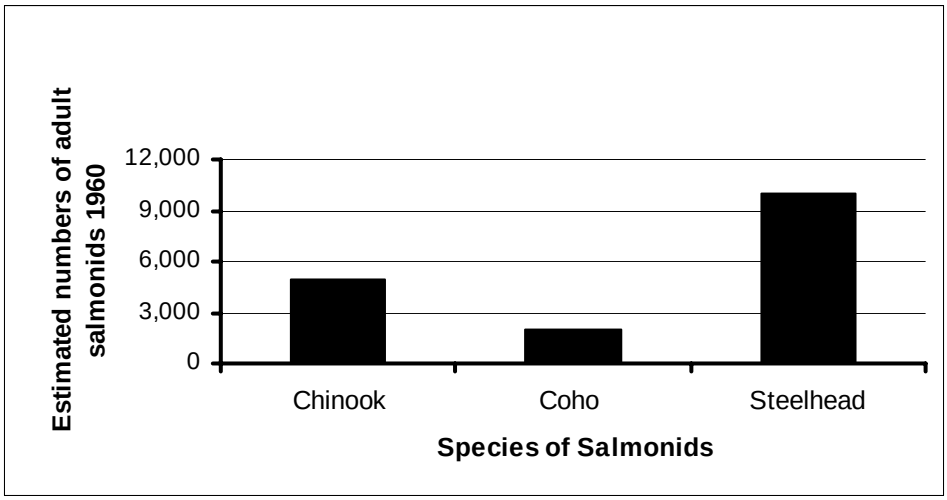

Figure III- 28. U.S. Fish and Wildlife Service estimates of adult salmonid populations in the Redwood Creek basin, 1960.

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.

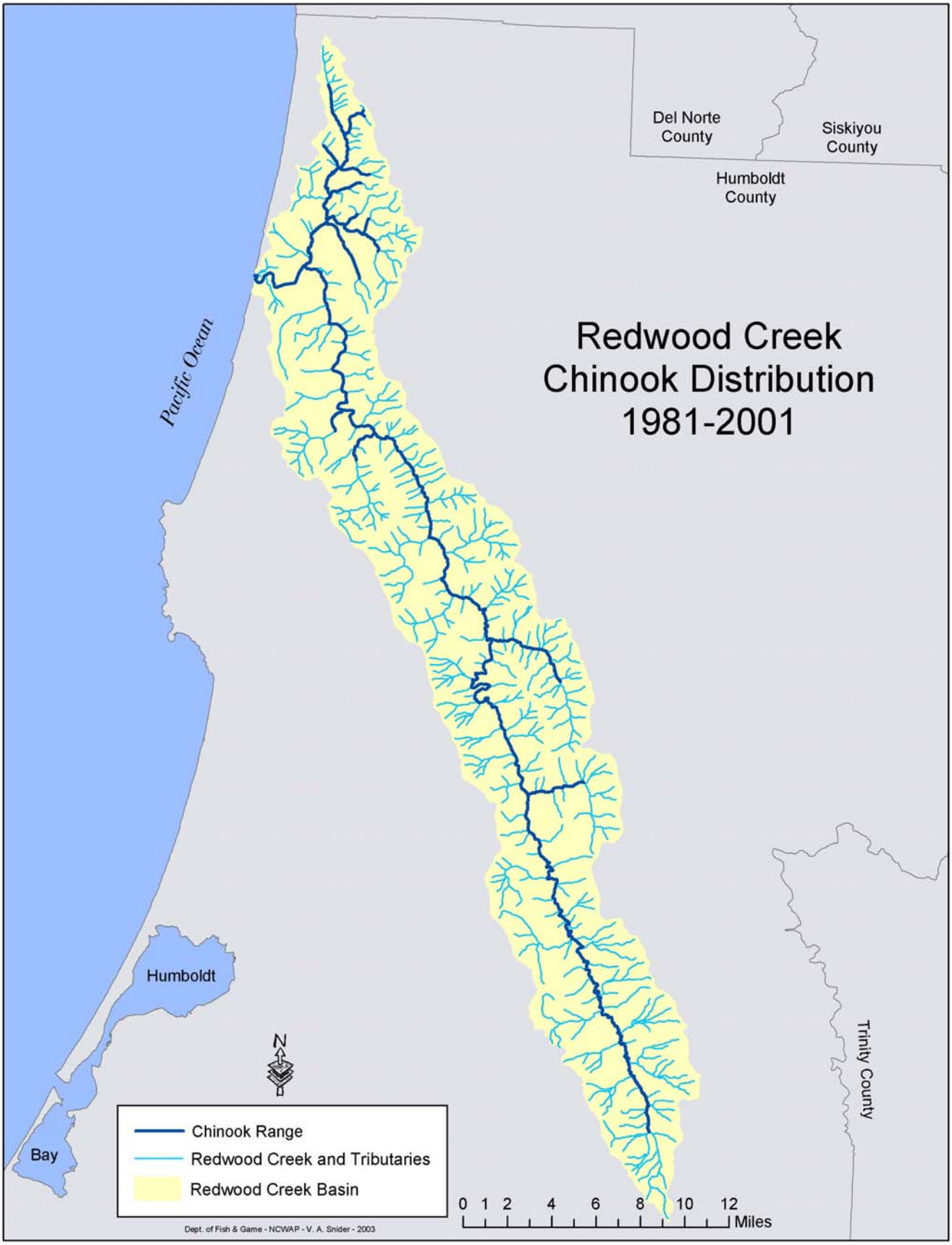

Figure III- 29. Stream habitat used by Chinook salmon for migration routes, spawning and juvenile rearing in the Redwood Creek basin. Adapted from Cal EPA and RNSP.

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.

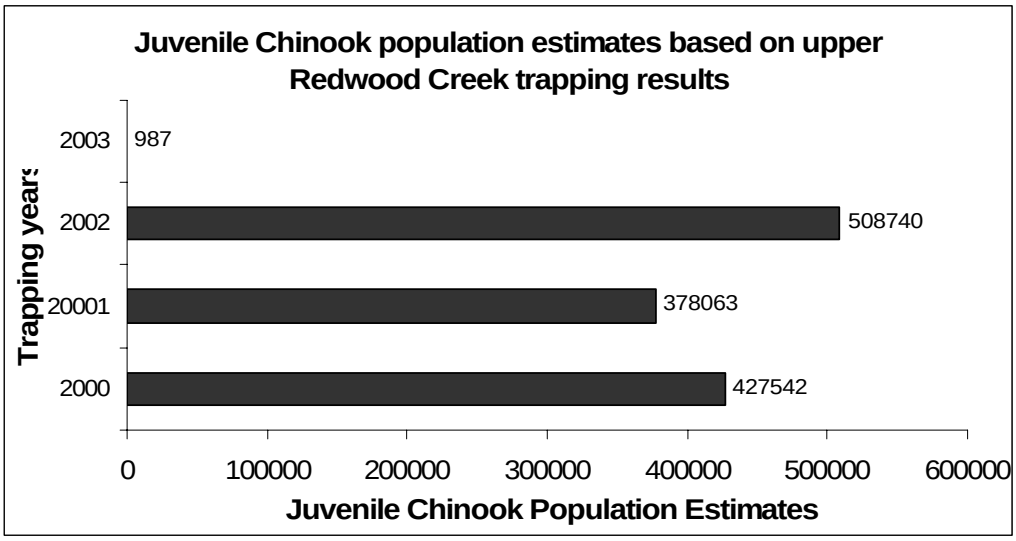

Figure III- 30. Yearly juvenile Chinook population estimates based on trapping results on Redwood Creek, 2000 to 2003.

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.

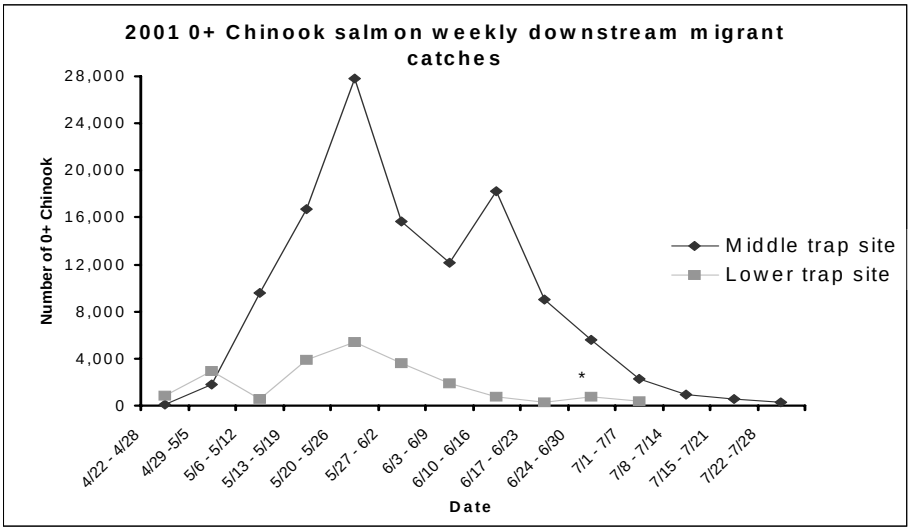

Figure III- 31. Temporal pattern of 0+ Chinook catches.

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).

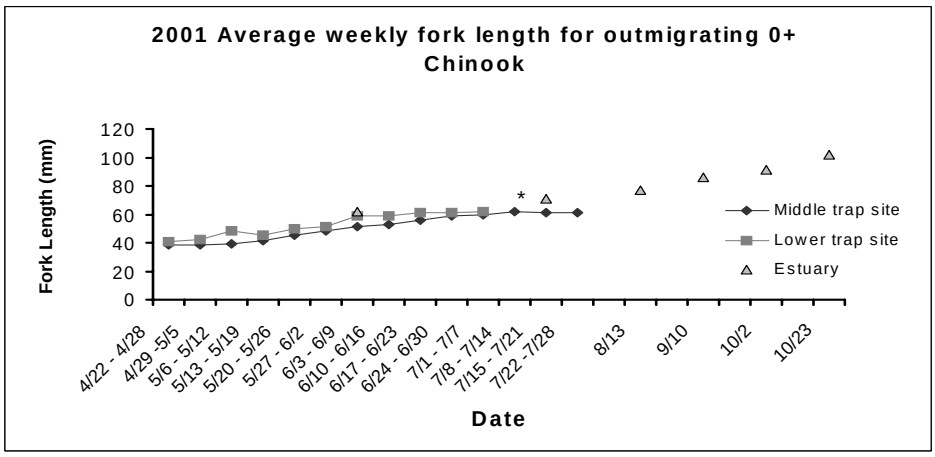

Figure III- 32. Average weekly fork lengths for 0+ Chinook.

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.

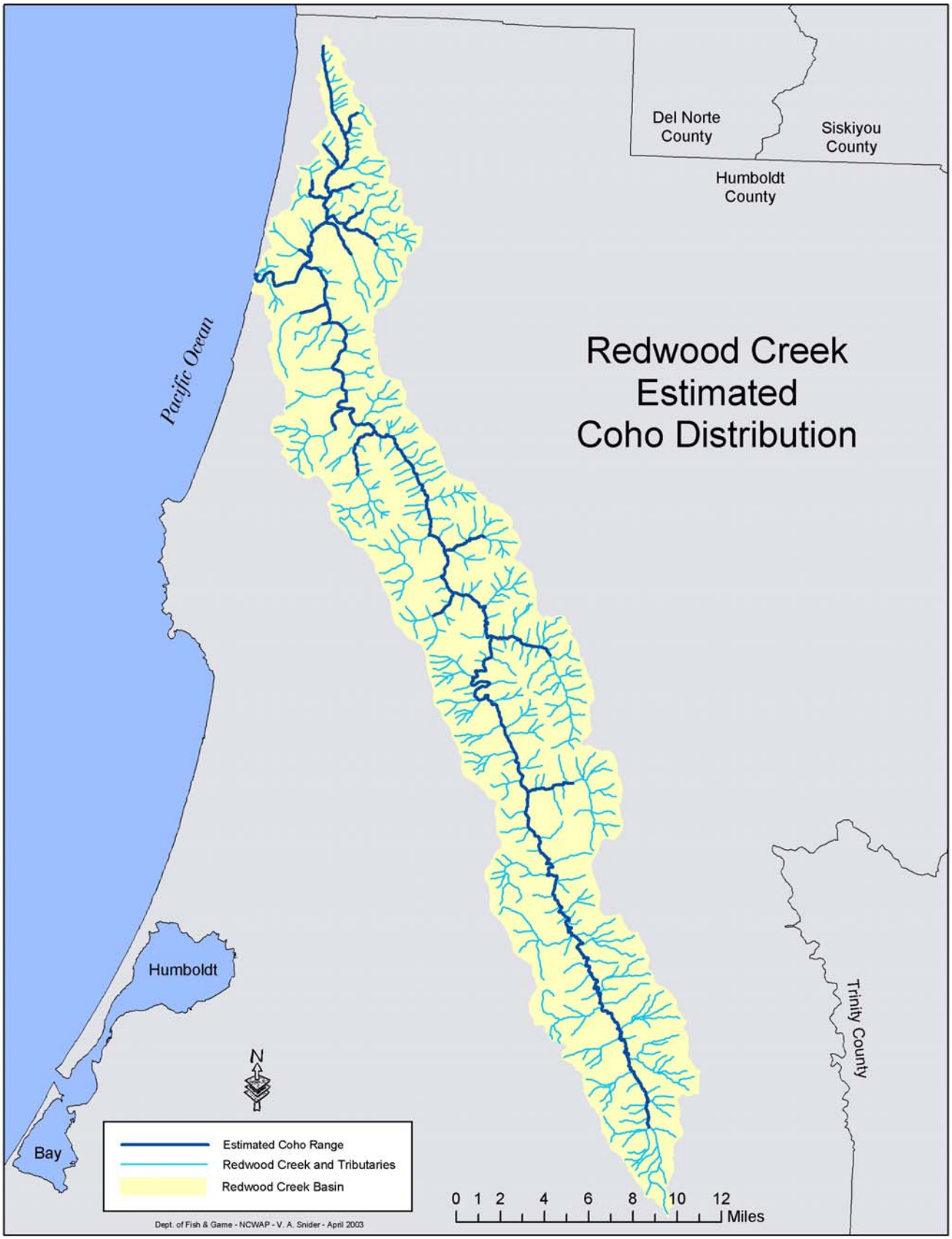

Figure III- 33. Estimated stream habitat used by coho salmon for migration routes, spawning and juvenile rearing in the Redwood Creek basin. Adapted from Cal EPA and RNSP.

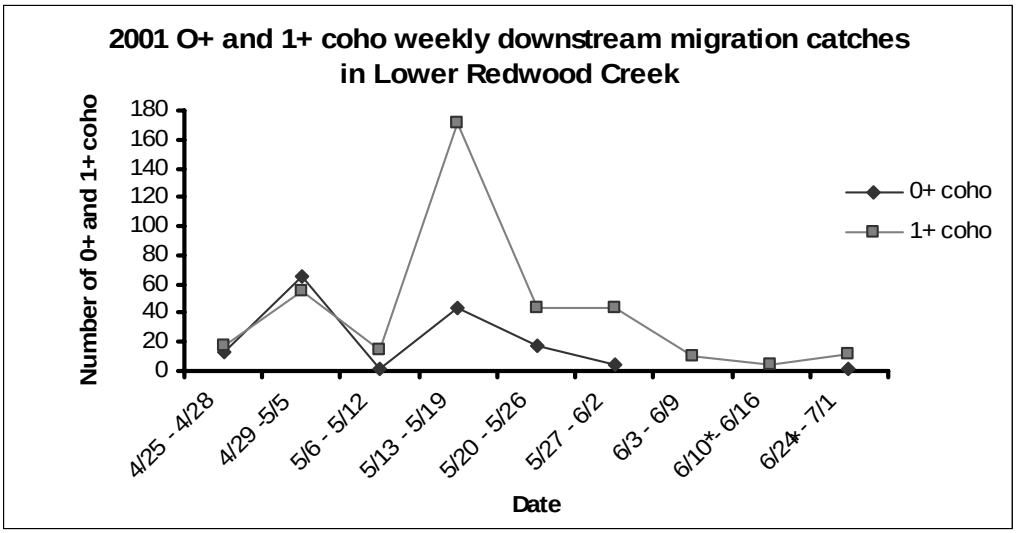

Figure III- 34. Weekly catches of 0+ and 1+ Coho in the lower Redwood Creek area, (Trap Located Just Downstream of Prairie Creek), 2001 (Wilzbach 2001).

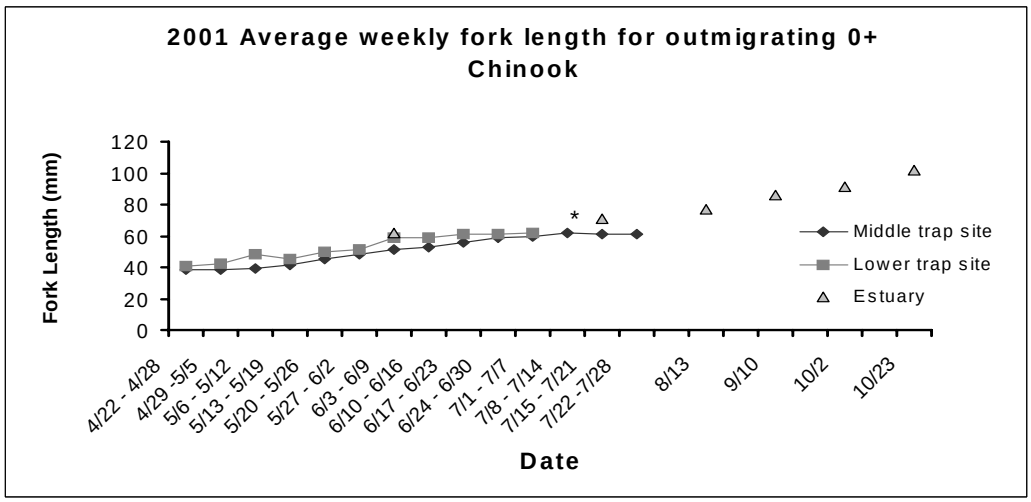

Figure III- 35. Average weekly fork lengths for age 0+ and 1 + Coho in the lower Redwood Creek area, (Trap Located Just Downstream of Prairie Creek), 2001 (Wilzbach 2001).

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.

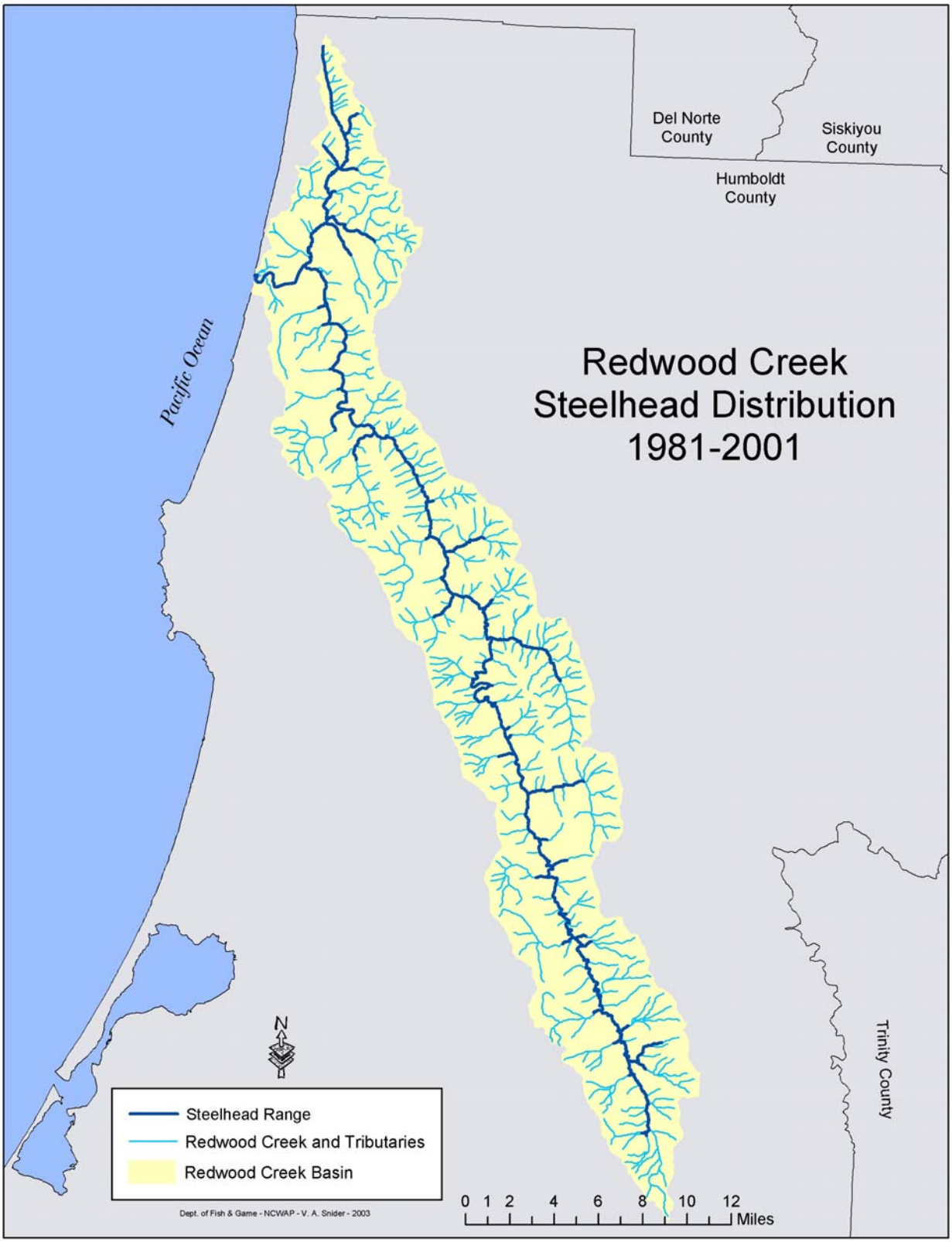

Figure III- 36. Stream habitat used by steelhead for migration routes, spawning and juvenile rearing in the Redwood Creek basin. Adapted from Cal EPA and RNSP.

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.

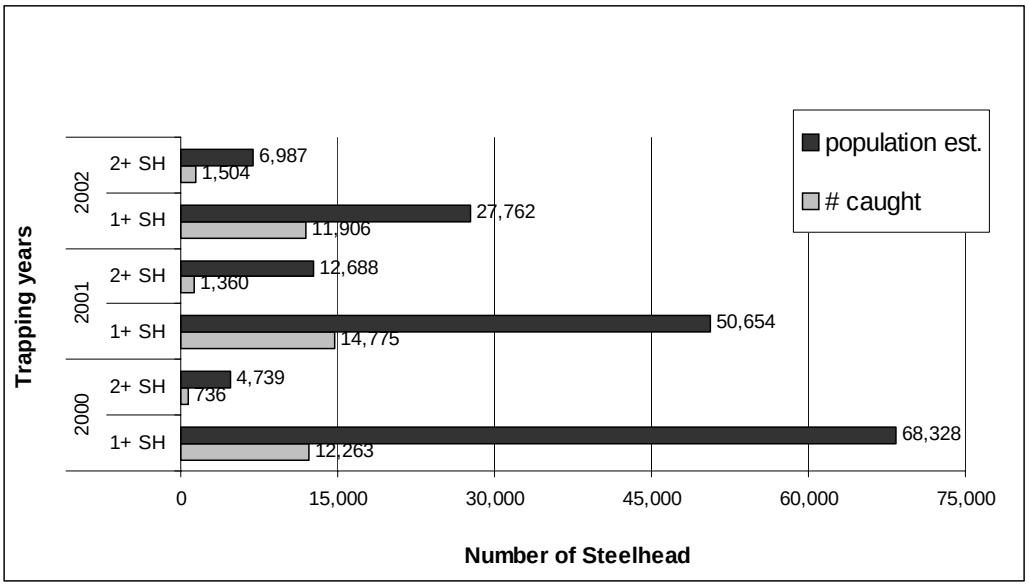

Figure III- 37. Yearly juvenile steelhead population estimates, 2000-2002. Adapted from trapping results on Redwood Creek (Sparkman 2000, 2001, and 2002).

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.

Steelhead population data Redwood Creek Estuary - Summer/Fall 2000			
Date	**Mouth**	**Population est.**	**Ave FL**
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.

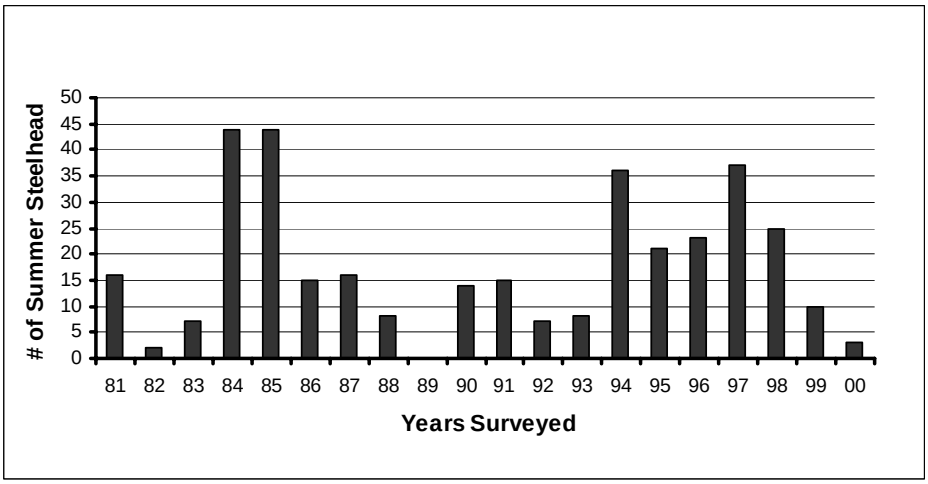

Figure III- 38. Summer steelhead dive counts on Redwood Creek, 1981-2000.

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.

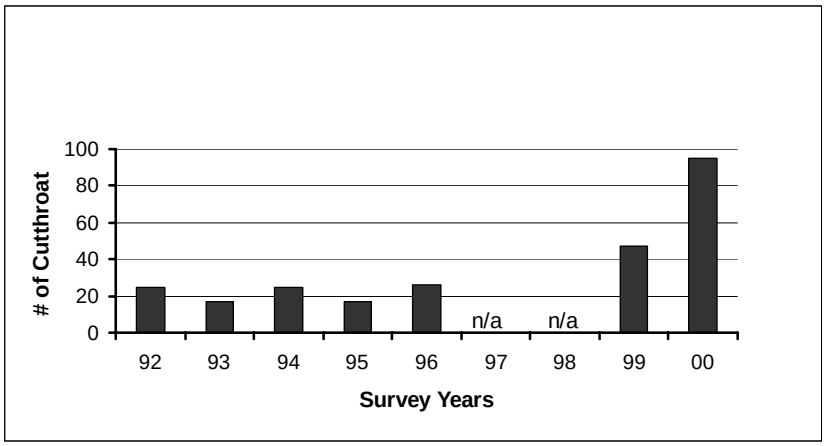

Figure III- 39. Number of coastal cutthroat trout observed during summer steelhead snorkel surveys on Redwood Creek mainstem, 1992-2000.

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

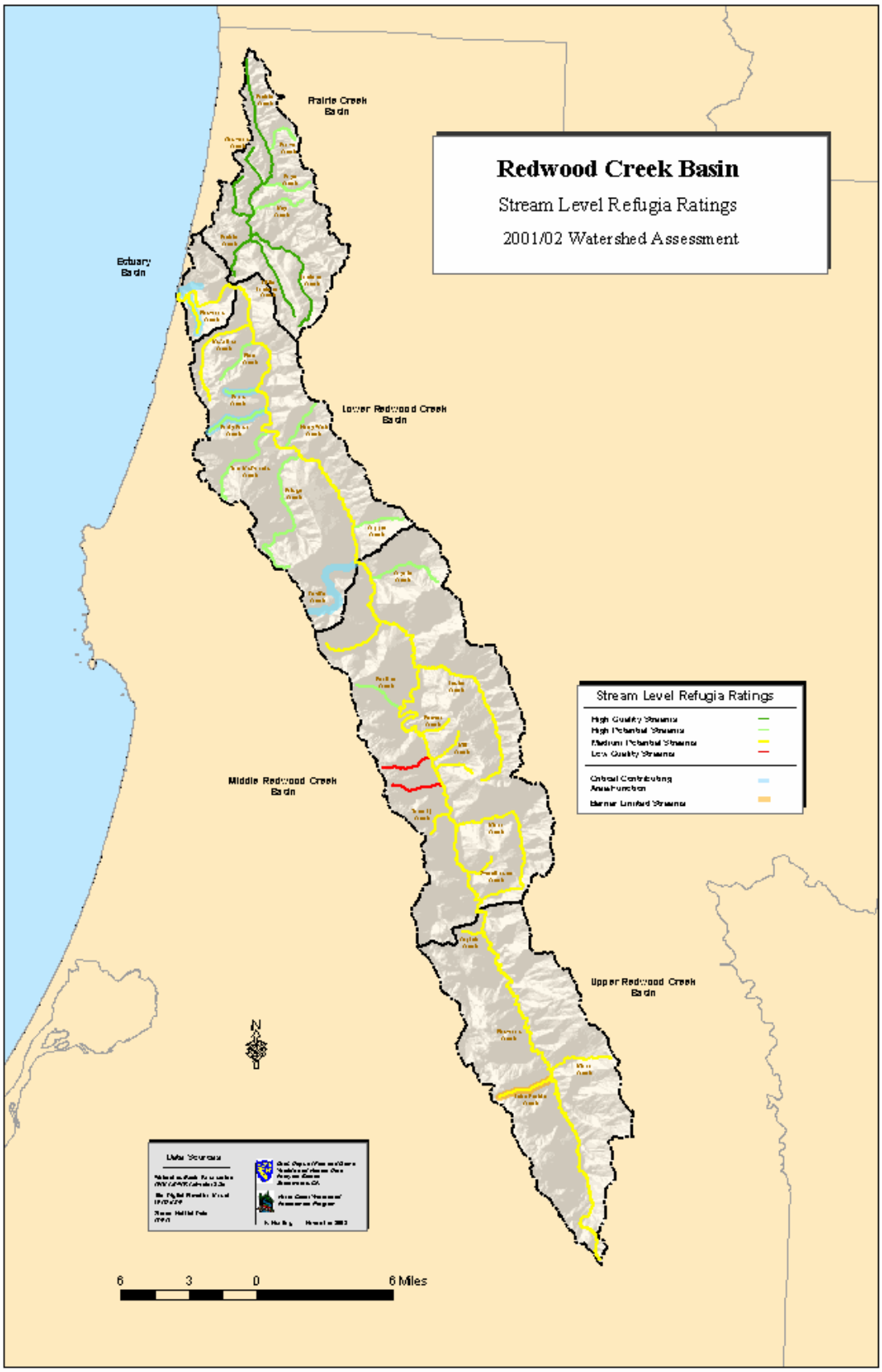

Figure III- 40. Refugia designations for select streams of the Redwood Creek basin.

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.