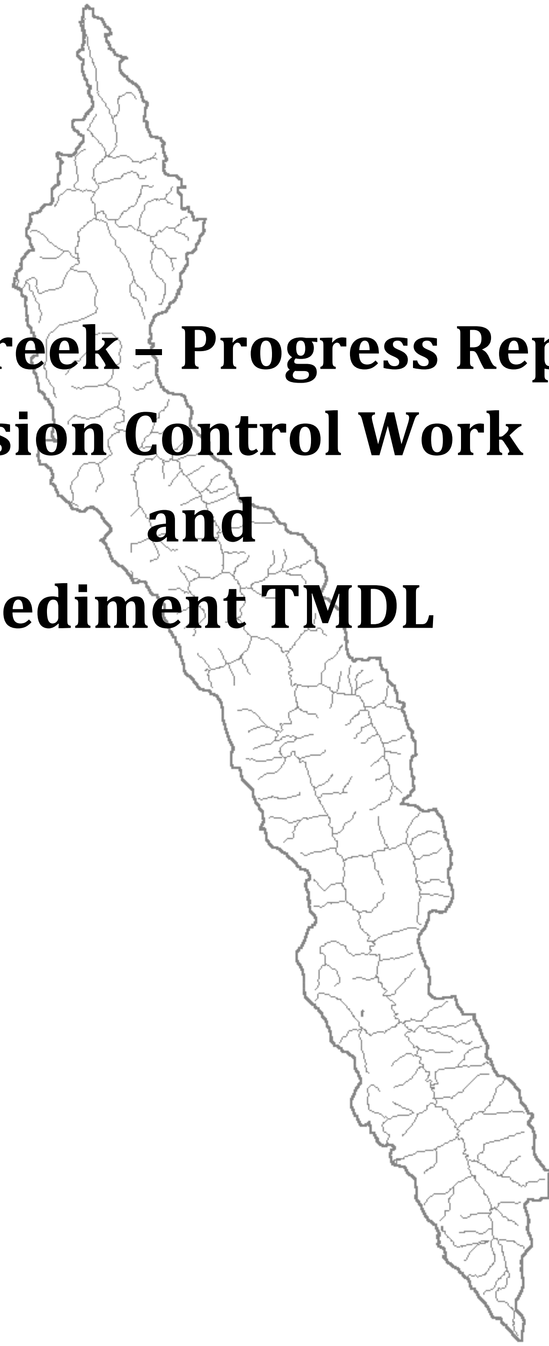

# Redwood Creek – Progress Report on Erosion Control Work and Sediment TMDL

Prepared for the participating landowners in the Redwood Creek watershed, the California Department of Fish and Game, and the Pacific Coast Fish, Wildlife and Wetlands Restoration Association

By Redwood National and State Parks.

June 20, 2011

NATIONAL PARK SERVICE
CALIFORNIA STATE PARKS
PACIFIC COAST FISH WILDLIFE & WETLANDS RESTORATION ASSOCIATION
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# Redwood Creek – Progress Report on Erosion Control Work and Sediment TMDL

Prepared by:
Greg Bundros
Darci Short

**June 20, 2011**

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Bundros, G.J. and Short, D. 2011. Redwood Creek – Progress Report on Erosion Control Work and Sediment TMDL. Redwood National and State Parks report to the Pacific Coast Fish, Wildlife and Wetlands Restoration Association, unpublished, 84 pp.

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# EXECUTIVE SUMMARY


The Redwood Creek watershed, in north coastal California, has unique characteristics that significantly increase the likelihood for successful watershed restoration and recovery. Redwood Creek is a moderate sized watershed that supports anadromous salmonid species. It has a National and State Park in the lower third of the watershed and the upper two-thirds is 90 percent owned by just eight landowners who manage lands for timber and ranching. Cooperative partnerships have formed to improve conditions throughout the watershed.

Cooperative efforts to control and prevent erosion from logging roads in the upper Redwood Creek watershed (areas upstream of the park) started in earnest in 1996. Detailed road assessments identified potential erosion sites, estimated sediment yields and recommended treatments. Subsequent road treatments have been completed through cooperative erosion control projects, separate landowner projects and timber harvest plan road work. About 120 miles have been upgraded and about 61 miles have been decommissioned. Total funding for all cooperative erosion control projects in the upper watershed through 2009 was about $5.8 million. Landowners have contributed about 33% of the funds.

Analysis of detailed volumetric data shows road treatments have reduced the potential sediment yield from logging roads in the upper watershed by about 531,000 cubic yards. This is about 30 percent of the potential sediment yield estimated at assessed sites or about 19 percent of the estimated total for the upper watershed.

Completed work has reduced potential sediment loading by about 36 percent of the TMDL's required 60 percent load reduction. However, 71 percent of the total reduction occurred in the lower watershed, on park lands, compared to a 29 percent reduction in the upper watershed, mostly private lands. While both represent significant reductions, more work is needed in the upper watershed to more fully distribute load reduction throughout the watershed. For watershed recovery, the work is necessary and achievable.

The analyses presented in this report prioritize erosion control and prevention treatments based on work completed through 2009. Each analysis works at a different scale and provides prioritizations that can be used individually or in combination appropriate to the scale and objective of the erosion prevention project.

A Watershed Improvement Plan is presented that identifies road management practices that can protect aquatic and riparian habitats, and move the watershed closer to recovery and meeting the objectives of the Redwood Creek TMDL.

# ACKNOWLEDGEMENTS

The road assessments and treatment projects in Redwood Creek would not have been possible without the generous funding by California Department of Fish and Game SB 271 grants, California Propositions 50 and 84, California State Water Resources Control Board, 319(h) grants, U.S. Fish and Wildlife Service, Bureau of Land Management, National Park Service, Resources Legacy Fund Foundation, and private landowners.

The project would also not have been possible without private landowner cooperation.  The private landowners in Redwood Creek are willing partners who have provided access to their lands, funding, opinions and perspectives, and an optimistic outlook for improved watershed conditions. It is our hope that the report information is used appropriately and private landowners in Redwood Creek are never penalized for their trusting cooperation.

This report was prepared for Mitch Farro of Pacific Coast Fish, Wildlife and Wetlands Restoration Association (PCFWWRA) by Redwood National and State Parks under a cooperative agreement.  We are grateful to Mr. Farro for his leadership role in Redwood Creek, as the project would not have occurred without his leadership.  Pacific Watershed Associates provided invaluable technical oversight, training and quality control during this work as a sub-contractor to PCFWWRA.  We are extremely grateful to Randy Lew who provided consistent quality control.  Most importantly, we acknowledge the field crews who worked so diligently under sometimes adverse field conditions. They are dedicated and highly skilled, and did an outstanding job.

Thanks to Randy Klein, Mary Ann Madej and Vicki Ozaki for synthesizing sediment load data for Redwood Creek and review of the TMDL discussion.  We also thank Judy Wartella for her expertise completing many of the GIS analyses contained in the report.

# TABLE OF CONTENTS

# Appendixes

## List of Figures

# List of Tables

# INTRODUCTION

The Redwood Creek watershed is unique from other north coastal California watersheds. It is relatively small (180,000 acres) and a national and state park occupies the lower-third of the watershed. Most of the land upstream of the park is used for forest products and ranching, and is owned by a relatively small number of large landowners which makes watershed-scale planning feasible. The Redwood Creek Watershed Group whose membership represents about 90 percent of the ownership and/or management of land in the watershed formed to improve water quality conditions throughout the watershed (RCWG, 2006). There are no major water diversions in the watershed, and the only developed municipality is the town of Orick, located along the lowermost reach of Redwood Creek. These attributes significantly increase the likelihood that recovery and restoration efforts in Redwood Creek can succeed.

Studies performed in Redwood Creek have documented that erosion and sedimentation from past floods impact the channel for decades (Madej and Ozaki, 2009) and affect many life cycles of anadromous salmonids. Erosion from logging roads has been identified as the largest controllable source of sediment in the watershed (RNSP, 1997; USEPA, 1998). The sediment TMDL for Redwood Creek (USEPA, 1998), the Recovery Strategy for California Coho Salmon (CDFG, 2004), the Redwood Creek Watershed Assessment Report (Cannata et al., 2006), the Redwood National and State Parks (RNSP) General Management Plan/General Plan (NPS-CDPR, 1999), and the Integrated Watershed Strategy for Redwood Creek (RCWG, 2006) all encourage completion of road assessments, and implementation of road decommission and upgrade projects to protect and restore aquatic and riparian habitat and water quality. In Redwood Creek, cooperative efforts to control and prevent erosion from logging roads on private lands started in 1996.

This report is an update to previous reports that summarized road assessment data collected in the upper Redwood Creek watershed and described treatment priorities based on analysis of the data. In this update, we: 1) describe the accomplishments of the erosion control work since cooperative efforts began and place the accomplishments in the context of the Redwood Creek sediment TMDL; 2) summarize the conditions of the remaining assessed roads in the upper watershed, and; 3) present updated treatment priorities for areas in the upper watershed based on work that has been completed through 2009. Similar to previous reports, a watershed improvement plan is also presented. The erosion control work described in this report includes projects completed through cooperative efforts, completed timber harvest plans and individual landowner projects for which we have data.

# BACKGROUND

## Watershed Description

Redwood Creek drains a 285 square mile watershed located in the Coast Range of northern California (Figure 1). The upstream two-thirds of the watershed is mostly private lands managed for timber production and ranching. Redwood National and State Parks occupies the lower-third of the watershed.

The watershed is steep and mountainous, and located within a tectonically active area with relatively rapid uplift. Weak, pervasively sheared rocks underlie the watershed. Mean annual watershed-wide precipitation averages about 80 inches. The combination of steep terrain, weak underlying geology and soils, and moderately high precipitation contribute to naturally high erosion rates and susceptibility to accelerated erosion.

The watershed is unusually long and narrow, and has a very large number of small tributary sub-watersheds. There are no major tributaries to Redwood Creek above Prairie Creek. Most tributaries are low-order and high gradient streams. Their channels are generally deeply incised, and steep hillslopes adjacent to channels are particularly landslide prone (Pitlick, 1982).

## Land Use

The primary land use in the watershed during the past 80 years has been timber production and ranching. Historically, roughly 82 percent of the Redwood Creek watershed supported old-growth coniferous forests. Harvesting of the coastal redwood forests in portions of the lower Redwood Creek watershed began in the latter half of the 1800s. Mechanized timber harvesting was established throughout the watershed by the late 1930s. Timber harvesting and associated road construction accelerated in the watershed in the late 1940s to 1950s in the Douglas-fir dominated upper watershed. During the 1960s timber harvest was concentrated more in the lower watershed, and logging continued steadily until expansion of Redwood National Park in 1978. By 1978, about 81 percent of the original forest in the watershed had been logged (Best, 1984).

## Roads

The earliest roads in the Redwood Creek watershed coincided with settlement in the mid-1800s. New roads were built as settlement and ranching expanded. A rapid rise in road construction occurred along with increased timber harvest in the mid-1900s. The road construction history for the Redwood Creek watershed was researched by RNSP and is described by Bundros et al. (2003).

The history of forest practice rules partly explains the legacy road conditions in the watershed today. State regulation of timber harvest activities began in 1945, but was not fully implemented until the passage of the Z'berg-Nejedly Forest Practice Act of 1973. The first substantive erosion

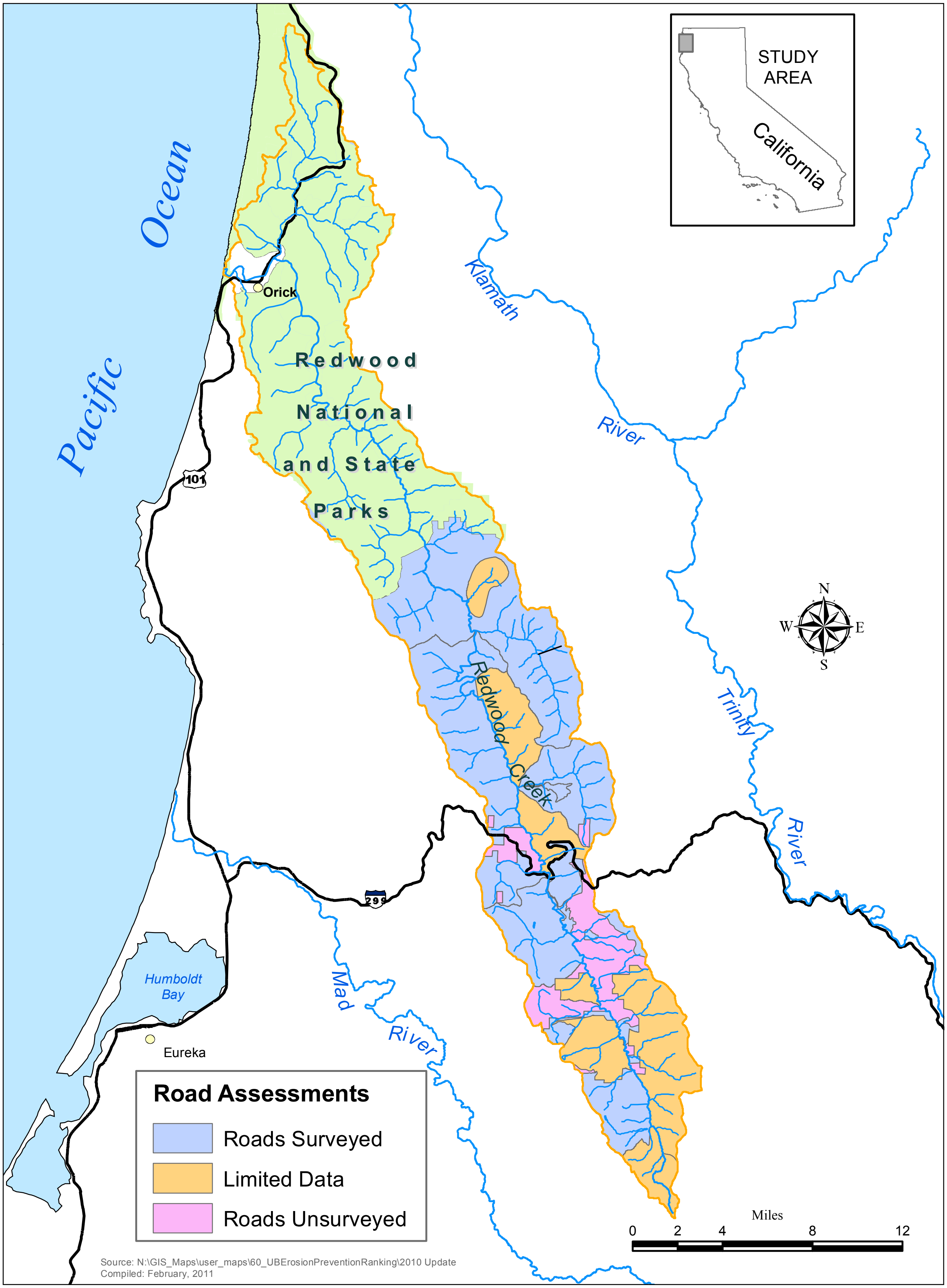


Figure 1. Location of the Redwood Creek watershed and road assessment areas.

control rules for logging roads appeared in 1983. By then, more than 1,000 miles of roads in the upper watershed had been built to inadequate standards. More than 88 percent of the roads in existence today were built before forest practice rules had been fully implemented. Today, there are about 1,040 miles of roads in the upper watershed of which about 907 miles are privately owned and managed. Road density averages 6.4 miles/mile$^2$ and ranges from 3.6 to 10.7 miles/mile$^2$ in tributary watersheds. The road density for all sub-watersheds is shown in Appendix A.

### Cooperative Erosion Control and Prevention Efforts

Cooperative efforts to control and prevent erosion from logging roads in upper Redwood Creek (areas upstream of the park) started in earnest in 1996. These efforts were built on trust. A small pilot project in 1995 was completed by RNSP and Green Diamond Resource Company (GDRCo - formerly Simpson Timber Company) in Coyote Creek. In 1996 and in cooperation with the Stover family, RNSP completed the first large assessment and implementation project in Garrett Creek. This was followed by a larger assessment completed by RNSP and multiple implementation projects on Sierra Pacific Industries lands. The success of these earlier projects led to a partnership between numerous landowners, RNSP and Pacific Coast Fish, Wildlife and Wetland Restoration Association (PCFWWRA) to advance cooperative erosion control efforts in the upper watershed.

The cooperative erosion control efforts in Redwood Creek would not have been possible without agency grants and landowner funding. The U.S. Fish and Wildlife Service, Jobs-in-the-Woods program, provided grant funds during the development of this cooperative program. The California Department of Fish and Game's (CDFG) Fisheries Restoration Grant program provided funding for subsequent assessments and implementation projects. Landowners have provided access, funding and support for all of the efforts described in this report.

Data from the initial road assessments completed in Redwood Creek were summarized in previous reports (Bundros et al., 2003; Bundros et al., 2004; Bundros and Short, 2009). Bundros et al. (2003) also contains detailed discussions on road construction history, road density, timber harvest in the inner gorges along Redwood Creek and landslide history, channel erosion and riparian conditions and restoration opportunities.

## ACCOMPLISHMENTS OF THE COOPERATIVE EROSION CONTROL PROGRAM 1996-2009

### Road Assessments

Road assessment projects were developed with willing landowners and implemented as funding became available. Eleven distinct assessment projects, shaped by watershed boundaries, willing landowners and grant opportunities have been implemented by four different investigators – RNSP, PCFWWRA, Natural Resources Management Corporation (NRM) and Five Counties Salmonid Conservation Program (SCP). Quality control for road assessments completed by PCFWWRA was provided by Pacific Watershed Associates and RNSP. Of the 1,100 miles of road existing in the upper watershed at the beginning of the program, about 773 miles (70 percent) have been assessed. The remaining 328 miles of roads are owned by landowners who have not participated in the cooperative erosion control efforts.

All road assessments included field work that identified potential erosion sites, estimated the volume of sediment that could deliver to a stream if erosion occurred, and prescribed corrective treatments. All sites assessed by PCFWWRA also included cost estimates for equipment and labor needs. Data were compiled on field forms (Appendix B) and sites located on airphoto mylar overlays. All field data were entered into a database and the location of each site was entered into GIS as a point coverage (Appendix C). Both database and GIS coverages are maintained by RNSP. Table 1 describes the road assessments in upper Redwood Creek.

Table 1. Road assessments in the upper Redwood Creek watershed.

| | Road Assessments (miles) | % of Beginning Length |
|---|---|---|
| PCFWWRA Assessed | 567 | 51% |
| RNSP Assessed | 93 | 8% |
| NRM Assessed | 88 | 8% |
| Five Counties SCP Assessed | 25 | 2% |
| Total Assessed | 773 | 70% |
| Not Assessed | 328 | 30% |
| Total Miles | 1,101 | 100% |

[1] Mileages shown differ from those reported in previous reports due to: Reassessment of Minor Creek by PCFWWRA 'replacing' the roads assessed by NRM, new road construction associated with THPs, assessment of roads subsequent to previous assessments and, to a lesser extent, clean-up/editing of minor GIS errors.
[2] Totals may differ slightly from those shown in other tables in this report due to rounding.

In all road assessments, investigators followed generally similar methods to collect and record information. However, subsequent data analysis revealed inconsistencies between some investigators which prevented the use of data collected by NRM and Five Counties SCP in most of the analyses in this report.

## Completed Road Treatments

Projects to control and prevent potential erosion identified by road assessments in the upper watershed have been implemented since 1996. As assessments were completed in specific areas, projects were implemented soon afterward to treat the obvious high priority roads and sites. Projects were implemented where assessments were completed while further assessments were occurring in other areas. After most of the assessments had been completed, treatment priorities for areas in the upper watershed were based on results from analyses reported by Bundros et al. (2003 and 2004).

Roads have been treated through cooperative erosion control projects, separate landowner projects and timber harvest plan (THP) road work. RNSP has reviewed all reports of cooperative projects completed from 1996 through 2009 and all CDF approved THPs within assessment areas through 2007. Most treated roads have been field reviewed by RNSP geologists to evaluate completed treatments. Some decommissioned roads were not field reviewed by RNSP, but were described in project completion reports prepared by Pacific Watershed Associates. BLM geologists provided similar reports and data for work completed in Lacks Creek.

Of the approximately 660 miles of roads assessed by PCFWWRA and RNSP, about 181 miles have been treated since 1996. About 120 miles have been upgraded and about 61 miles have been decommissioned. Total funding for all cooperative erosion control projects in the upper watershed through 2009 was about $5.8 million. Landowners provided about $1.9 million (33%) in funding with the remainder provided by various grant sources totaling about $3.8 million (67%). Costs associated with work completed independently by landowners and in association with THPs are not included. A list of projects and funding is included in Appendix D.

Table 2 shows selected statistics for sites that have been treated. Of the 4,955 sites assessed between 1996 and 2009, 1,090 sites (22 percent) have been treated. More than 13 percent of all assessed sites were decommissioned and about 9 percent of all assessed sites were upgraded. Combined, the sediment "saved" (the potential sediment yield prevented from entering a stream) by all treatments was over 531,000 yds$^3$. Figure 2 shows these data graphically.

Table 2. Sites treated and sediment saved for projects assessed by RNSP and PCFWWRA.

| | No. of Sites | Potential Sediment Yield (yds$^3$) | % Number of all Sites | % of Potential Sediment Yield |
|---|---|---|---|---|
| Sites in Initial Assessments (1996 – 2009) | 4,955 | 1,765,000 | 100% | 100% |
| Sediment Saved from Delivery | | | | |
| Decommissioned Sites | 660 | 414,000 | 13% | 23% |
| Upgraded Sites | 423 | 117,000 | 9% | 7% |
| Maintained Sites | 7 | 0 | 0% | 0% |
| Totals | 1,090 | 531,000 | 22% | 30% |
| | | | | |
| Sites Treated under THPs | 177 | 39,000 | 4% | 2% |
| Sites Treated under Cooperative Erosion Control Program | 913 | 492,000 | 18% | 28% |
| New Sites Treated, Not in Initial Road Assessments | 146 | Not avail. | 3% | Not applic. |
| Totals | 1,236 | 531,000 | 25% | 30% |

[1] All THPs filed through 2007, all cooperative projects through 2009.

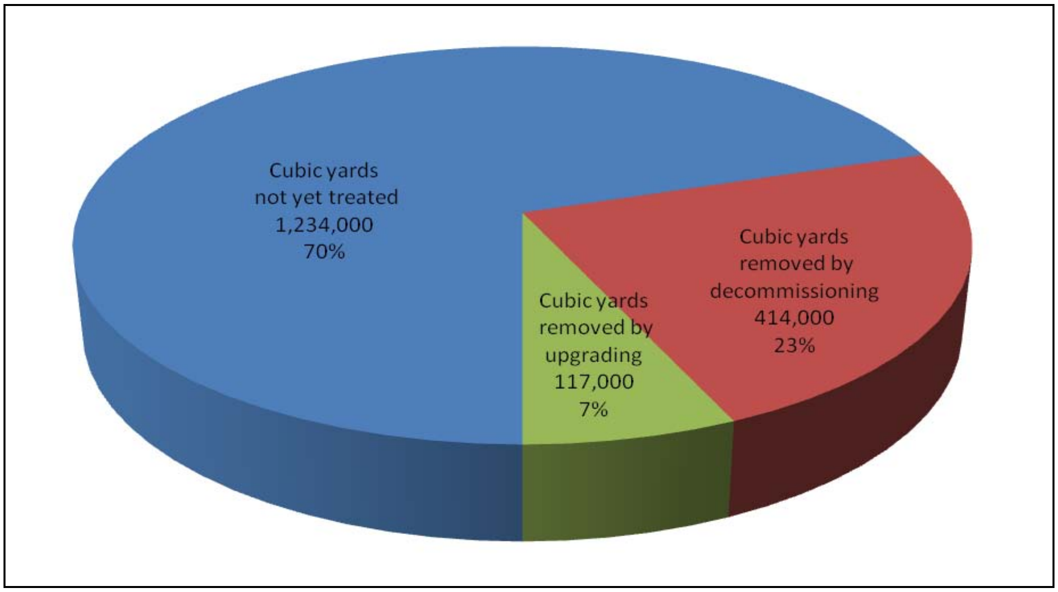


Figure 2. Reduction of potential sediment yield by decommission and upgrade treatments in upper Redwood Creek.

Further breakdown of the 1,090 treated sites show that about 76 percent of the sites were fluvial and about 24 percent were landslide sites. The fluvial sites accounted for about 48 percent of the volume 'saved' (prevented from delivery to a stream), while landslide sites accounted for 52 percent. Table 3 shows the sediment saved from fluvial and landslide sites that were in the initial road assessments.

Table 3: Sediment 'saved' from delivery from fluvial and landslide sites.
(Includes decommission and upgrade treatments.)

| Site type | Count | Sediment 'Saved' from Delivery | % of Count of all of Sites Treated | % of Potential Sediment Yield 'Saved' |
|---|---|---|---|---|
| All Sites Treated and in Initial Road Assessments | 1,090 | 531,000 | 100% | 100% |
| Fluvial Sites | 833 | 257,000 | 76% | 48% |
| Stream Crossings | 542 | 237,000 | 50% | 45% |
| Other Fluvial Sites | 291 | 20,000 | 27% | 4% |
| Landslide Sites | 257 | 274,000 | 24% | 52% |

The initial assessments by RNSP and PCFWWRA included 2,540 stream crossing. Of those, 1,590 (63%) had a diversion potential. Of all stream crossings, 464 (18%) were 'critical' crossings (stream crossings with an undersized culvert, diversion potential and at least a medium plug potential). Treatments, either decommission or upgrade, have corrected 340 diversion potentials and 110 critical crossings. These statistics are summarized in Table 4.

Table 4. Summary of stream crossings, crossings with diversion potential and critical crossings.

| Type of Stream Crossing | Number of Sites in Initial Assessments | % of all Sites | Number of Sites Treated | % of Type Treated |
|---|---|---|---|---|
| Stream Crossings | 2,540 | 100% | 540 | 21% |
| w/ Diversion Potential | 1,590 | 63% | 340 | 21% |
| Critical Crossings | 464 | 18% | 110 | 24% |

Another way to look at treatment accomplishments is spatially. Figure 3 shows the treatment priorities reported by Bundros et al. in 2004 that assigned treatment priorities to the sub-watersheds in upper Redwood Creek. Priorities were based on a risk analysis that considered sediment, as the resource threat, and salmonids, as the resource at risk. Figure 4 shows that the greatest reduction of potential sediment yield has occurred in the areas where the treatment priorities were the highest in that analysis.

## Accomplishments and the Total Maximum Daily Load for Redwood Creek

This section places the erosion control and prevention work completed between 1998 and 2009 in the Redwood Creek watershed in context with the Total Maximum Daily Load (TMDL) for Redwood Creek. We attempt to answer the question, "To what extent has the road work completed throughout the watershed in the past 12 years met the objectives identified by the TMDL?" RNSP started decommissioning roads in the lower watershed in 1978 and cooperative erosion control and prevention work in the upper watershed (areas upstream of the park) started in 1996, before TMDL discussions began.

### *TMDL for Redwood Creek*

The sediment TMDL for the Redwood Creek watershed was developed primarily to promote activities that protect aquatic and riparian habitats and water quality from sedimentation associated with land use. Accelerated erosion from the combined effects of past land use practices and large storms impacted the migration, spawning, reproduction, and early development of anadromous fish such as coho salmon, Chinook salmon, and steelhead trout (EPA, 1998). The TMDL identified logging roads as the major source of controllable sediment.

Based on long-term annual sediment load records for Redwood Creek, the TMDL estimated the total annual sediment loading at about 4,750 tons per square mile per year. The total allowable sediment load, or TMDL, was estimated at 1,900 tons per square mile per year, a 60 percent reduction in total sediment loading. To allow for temporal variation, the allowable load was expressed as a 10-year rolling annual average.

The TMDL identifies both instream and hillslope numeric targets. Instream targets are meant to provide a measure of the quality of aquatic habitat and whether or not streams are recovering from sediment impacts associated with management activities. The TMDL envisions a monitoring program that would evaluate the instream targets through time. To our knowledge, such a monitoring program does not exist. In contrast, hillslope targets describe the desired condition for the watershed with respect to management activities that can affect sedimentation and water

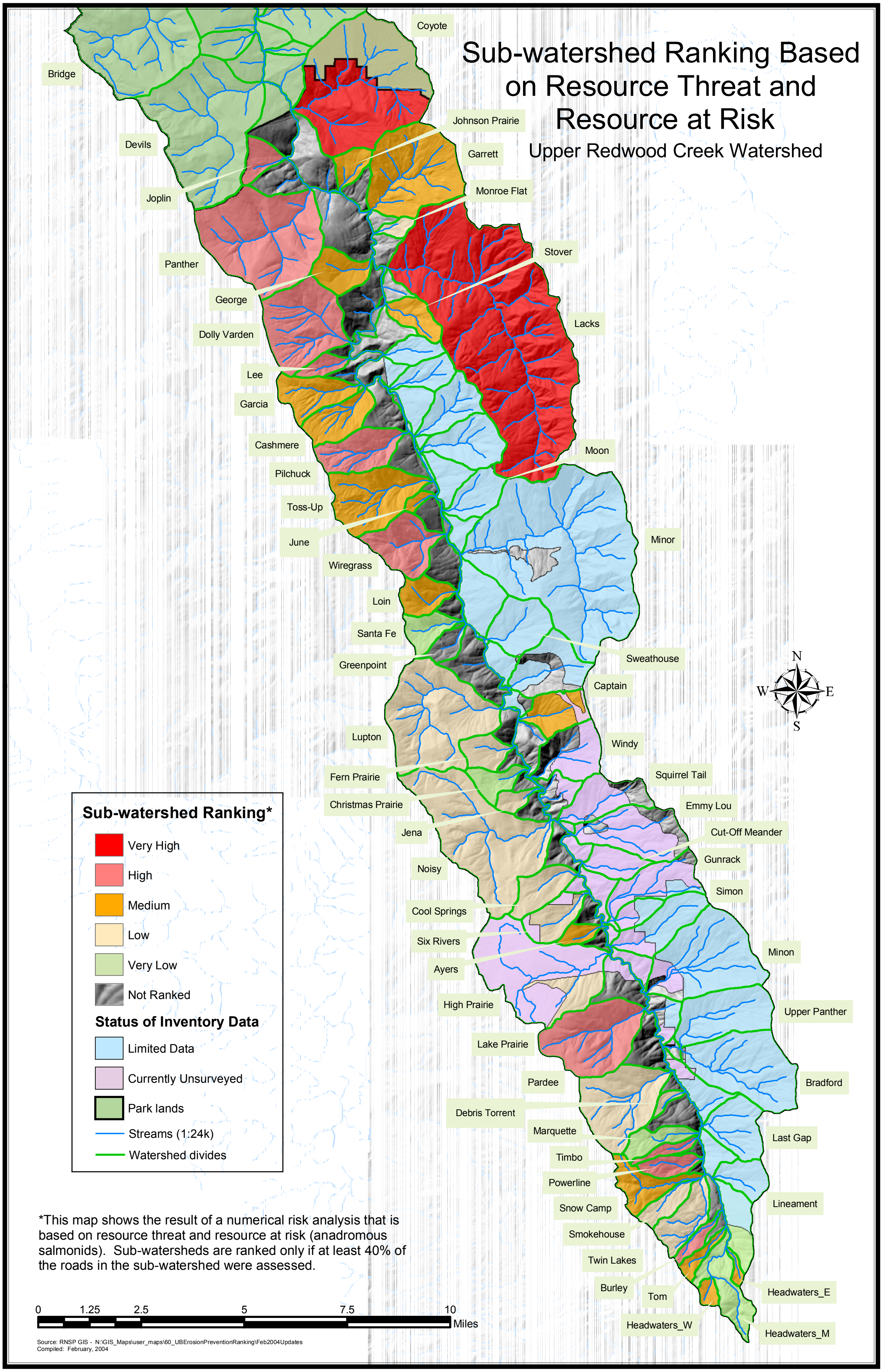


Figure 3. Treatment priorities based on threat and resource at risk, 2004.

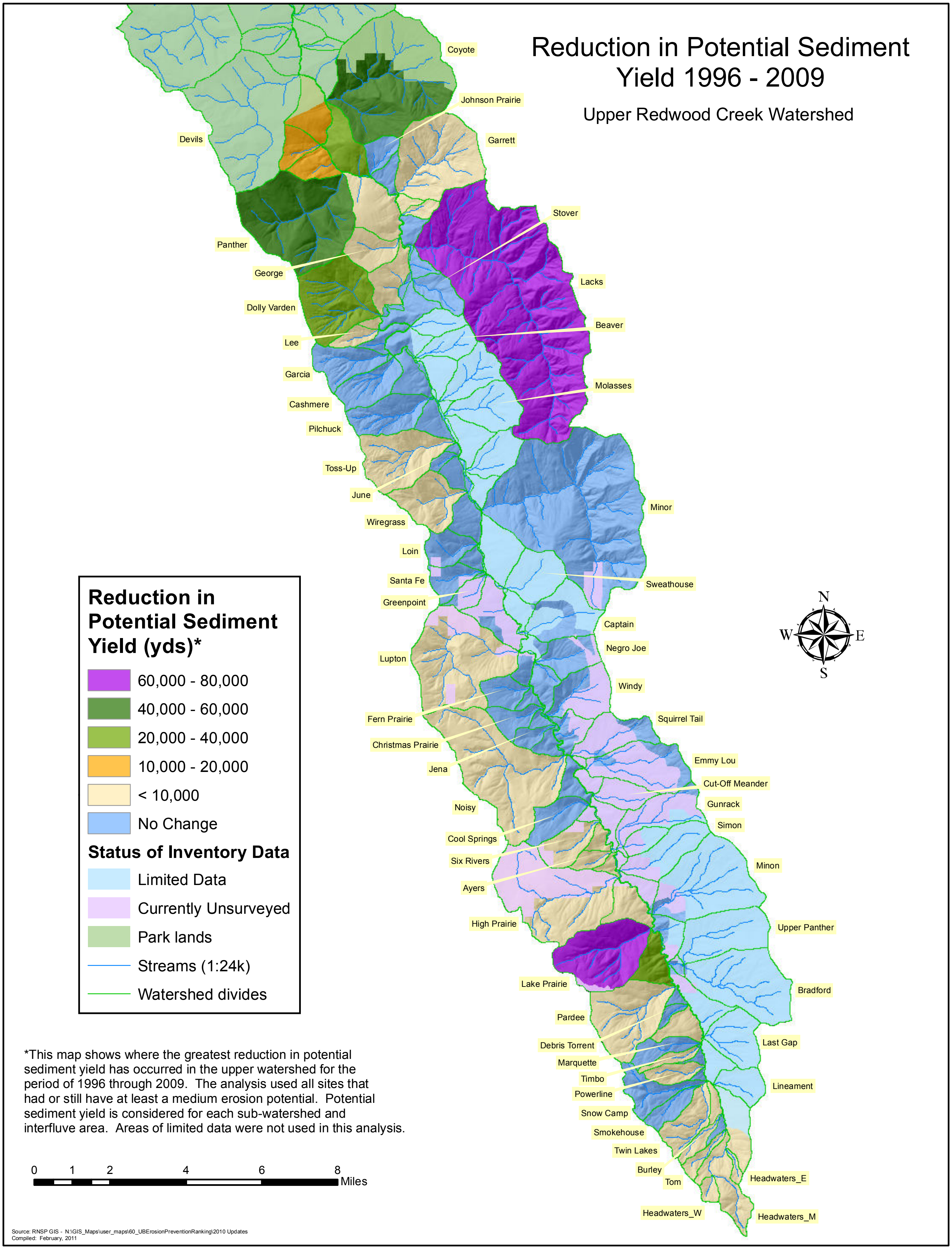


Figure 4. Reduction in potential sediment yield, 2009.

quality. Hillslope targets address the disconnect between the timing of improved hillslope conditions and channel recovery, and separate legacy channel effects from current hillslope conditions. Hillslope targets are also measureable and their improvements are immediate. The EPA believed that meeting hillslope targets would allow watershed recovery and attainment of instream targets through time.

The following discussion focuses on the hillslope numeric targets because they relate directly to the erosion control and prevention work performed in the Redwood Creek watershed. Because many of the roads in the lower watershed, on park lands, had already been treated by 1998, the primary focus of the discussion will be on the work completed in the upper watershed, mostly private lands and for which we have data. Additional information about the Redwood Creek TMDL can be found in Appendix E.

### *Hillslope Numeric Targets and Progress Made Attaining the Targets*

The hillslope numeric targets in the TMDL describe the desired conditions with respect to road design, location, inspection and maintenance, and timber harvest practices in sensitive streamside areas. The following describes to what extent the hillslope targets have been met in the upper watershed through cooperative erosion control and prevention work, independent landowner projects or through completed timber harvest plans. The hillslope targets are listed individually, followed by a description of the accomplishments and a brief discussion that integrates the targets and accomplishments:

> Target: *No crossings have a diversion potential (i.e., crossings are reconfigured permanently to prevent stream diversion).*

Accomplishments: The number of stream crossings with diversion potential has been reduced by 21 percent on assessed roads. Initial assessments identified about 2,540 stream crossings of which about 1,590 (63%) had a diversion potential. Subsequently, about 340 have been either decommissioned or upgraded. Because 270 stream crossings were decommissioned, there are now about 2,270 crossings remaining in the assessment areas, of which 1,250 (56%) have a diversion potential.

These results can be extended to the unassessed roads in the upper watershed. The initial assessments identified about 2.4 crossings with diversion potential per mile of road. By applying this average density to all unassessed roads, we estimate there were about 2,650 stream crossings with diversion potential in the entire upper watershed prior to treatments. When the 340 treated crossings are considered, the number of stream crossings with diversion potential in the upper watershed has been reduced by about 13 percent since cooperative erosion control began in 1996.

Discussion: Progress has been made preventing stream diversions, but more work needs to be done. Language that acknowledges the sediment threat to water quality from stream diversion erosion has been in the state forest practice rules since 1983. The rules, however, have often relied on the *maintenance* of structures, such as waterbars, to prevent diversions rather than requiring construction of more permanent, maintenance-free structures such as dips. Since maintenance requirements expire one to three years after completion of a timber harvest plan, temporary structures eventually break down and become ineffective. Rules and enforcement of measures that prevent stream diversions have improved in recent years. New road rules under consideration at the time of this writing may finally address this critical issue (CDF, 2011).

> Target: *All culverts and crossings are sized to pass the 50-year flood and associated sediment and debris. Crossings and culverts in the snow zone (generally, upstream of Highway 299) are sized large enough to accommodate flows and associated sediment and debris caused by rainfall and snow melt runoff.*

Accomplishments: The number of crossings capable of passing a 50-year flood in the assessment areas increased by about 22 percent. The improvement occurred by decommissioning and upgrading roads. Of the remaining crossings in the assessment areas, 43 percent of the culverted crossings will pass a 50-year flood, meeting the TMDL hillslope target, and 37 percent will pass a 100-year flood, the current sizing standard in state forest practice rules.

Discussion: Stream crossing culvert sizing requirements and methods have markedly improved. State forest practice rules changed culvert sizing requirements for stream crossings from a 50-year flood to a 100-year flood in 2001 (CDF, 2001). Guidance documents prepared by the California Department of Forestry and Fire Protection describe proper culvert sizing methods and considerations for passage of flood flows, including sediment and debris (Cafferata et al., 2004).

> Target: *All landings and road fills on slopes >50% which could potentially deliver sediment to a stream are pulled back and stabilized*.

Accomplishments: Based on GIS analysis of assessed sites with at least a medium treatment urgency, 43 percent of the sites on slopes greater than 50 percent were treated. When relationships from assessed roads that consider the number of sites per mile of road and the percentage of sites that occupy various slope categories are applied to the miles of unassessed roads, about 31 percent of the sites on slopes greater than 50 percent were treated throughout the upper watershed.

Table 5 below classifies the road miles that have been treated by hillslope position. Hillslope position is based on an equal division of the hillslope area above a stream channel and is divided into three positions, including the upper-third, middle-third and lower-third.

Table 5. Treated roads and hillslope position.

| Road Treatment | Miles | % of Road Miles Treated Based on Hillslope Position | | |
|---|---|---|---|---|
| | | Lower | Middle | Upper |
| Decommissioned | 61 | 50% | 38% | 12% |
| Upgraded | 123 | 28% | 38% | 34% |

Discussion: Significant progress has been made treating landings, road fills and crossings on the steeper hillslope areas. Erosion control and prevention work in upper Redwood Creek has been guided by treatment priorities established through analyses of road assessment data (Bundros et al., 2003 and 2004). The treatment priorities considered, among other things, the proximity of roads to a stream channel and the likelihood of failure and sediment delivery. Generally, the steepest hillslope areas are found along streams and in the lowermost hillslope position. Results in Table 5 (above) are consistent with the GIS analysis of treated sites and slope steepness. The table shows that most of the decommissioned roads occupied lower hillslope positioned areas. In contrast, roads that have been upgraded tended to occupy the more gentle, mid- to upper- hillslope positions. Roads on gentler slopes are commonly used to access and treat the roads on steeper slopes, and they are nearly always treated too.

> Target: *All roads have surfacing and drainage facilities or structures which are appropriate to their patterns and intensity of use*.

Accomplishments: The analysis of road assessment data cannot determine the degree to which this target is being met.

Discussion: This target is affected primarily by land use regulations and, in general, we believe progress has been made in attaining this target. Provisions that address road surfacing, timing of road use and drainage facilities are found in multiple sections of the state forest practice rules. These measures were greatly improved with the implementation of the Threatened or Impaired Watershed rules in 2001 (CDF, 2001) and the Anadromous Salmonid Protection Rules (CDF, 2009). A good example of improved road management is Green Diamond Resource Company's Aquatic Habitat Conservation Plan (GDRCo, 2006) which contains standards for road surfacing, timing of road use and drainage structures.

> Target: *All roads are inspected and maintained annually or decommissioned. Decommissioned roads are maintenance-free.*

Accomplishments: Excluding roads that have been decommissioned, about 44 percent of all roads assessed are being maintained. About 10 percent of the roads assessed have been decommissioned and are maintenance-free. Including the decommissioned roads, about 54 percent of all roads assessed are being maintained or are maintenance-free, leaving 46 percent of the assessed roads unmaintained.

Discussion: In 2004, we reported that 32 percent of all roads assessed were being maintained (Bundros et al., 2004). The fact that 54 percent of the assessed roads are now being maintained (or are maintenance-free) is a substantial step towards reaching the TMDL target. It is possible that more roads are being maintained than we know about because work can occur without our knowledge. Road inspection and maintenance are affected more by land use regulations than by our cooperative erosion control and prevention program, but there are no regulations that require long-term annual road inspection and maintenance. Green Diamond Resource Company's Aquatic Habitat Conservation Plan (GDRCo, 2006) contains explicit road inspection and maintenance standards for the 50-year life of the permit. Green Diamond Resource Company manages about 33 percent of all roads in the upper watershed. The TMDL target would more likely be met if similar commitments were adopted throughout the watershed. Given the extensive road network in the upper watershed, it is unlikely the target will ever be met without significant incentives and effort.

The enormous maintenance responsibilities for the roads in the upper watershed points to the need to: 1) decommission more roads in the upper watershed, and 2) make roads as maintenance-free as possible when they are in use and especially before THP inspection and maintenance requirements expire.

> Target: *Roads are not located in steep inner gorge or unstable headwall areas except where alternative road locations are unavailable.*

Accomplishments: About 15 miles of roads have been decommissioned and 5 miles have been upgraded in the inner gorges of the upper watershed. Based on GIS analysis and excluding county and state roads, about 91 miles of inner gorge roads remain in the upper watershed. About 66 miles of the remaining inner gorge roads have been assessed. Of these roads, about 20 miles (30%) are drivable and/or maintained; the balance are not drivable and/or maintained. We have no information on roads in unstable headwall areas.

Discussion: The vast majority of inner gorge roads were built before 1962. Current forest practice rules strongly discourage the construction or reconstruction of inner gorge roads. Based on the review of timber harvest plans submitted for Redwood Creek, no new inner gorge roads have been proposed for more than a decade. Residential subdivision and associated road construction may spawn construction of inner gorge roads without strong County oversight.

> Target: *Clearcut and/or tractor yarding are not used in steep, unstable streamside areas unless a detailed geological assessment is performed which shows there is no potential for increased sediment delivery as a result of using these methods*.

Accomplishments: The analysis of road assessment data cannot determine the degree to which this target is being met. We have no information to address the metric requiring "*<u>no</u>* [emphasis added] *potential for increased sediment*".

Discussion: Improved forest practices have contributed significantly to attaining this TMDL target, because the rules now acknowledge the sensitivity of streamside areas to ground disturbance. The *Report of the Scientific Review Panel on California Forest Practice Rules and Salmonid Habitat* (Ligon et al., 1999) was a landmark study that, among other things, stressed the need for greater evaluation of steep streamside areas. As a result of this study and since 2001, state forest practice rules have required a detailed geologic assessment of proposed timber harvest operations on steep streamside areas, greater conifer retention in streamside areas and have discouraged tractor use in these areas (CDF, 2001). When harvest activities are proposed in potentially unstable streamside areas, findings from detailed geologic reports are reviewed during pre-harvest inspections by geologists from the California Geological Survey, the North Coast Regional Water Quality Control Board, and Redwood National and State Parks. The metric requiring "*<u>no</u>* [emphasis added] *potential for increased sediment"* is unlikely met by any ground disturbing activity.

### *Sediment Load Reduction 1998-2009*

The TMDL estimated that a 60 percent reduction in the long-term annual sediment load for Redwood Creek (4,750 tons/square mile/year) was needed for watershed recovery. Load reduction would be accomplished by treating controllable sources of sediment from roads as identified by the TMDL hillslope numeric targets. This section looks at how much of the controllable sediment load has been reduced throughout the watershed since 1998.

Controllable loads have been reduced by road decommissioning and upgrading projects. In the lower watershed, primarily park lands, an aggressive road decommissioning program has been underway since 1980. In the upper watershed, primarily private lands, roads have been decommissioned and upgraded through cooperative efforts, landowner projects and timber harvest activities since 1996. Properly decommissioned roads are maintenance-free and sediment sources are removed. In contrast, upgraded roads still contain potential sediment because the road is still in place, but the likelihood of failure during a large storm is low.

In estimating the controllable load reductions (or sediment 'saved'; i.e., the amount of sediment prevented from entering a stream by treating the road), the total volume of sediment treated through upgrades was also included, providing the corrective work met established standards, and the likelihood of site failure was low following treatment. Based on road assessment data for the upper watershed and records from the parks' Watershed Restoration Program, Table 6 shows the reductions of controllable loads in the watershed since 1998.

Table 6. Controllable loads and reductions, Redwood Creek, 1998-2009
(rounded to 1,000s).

| | Controllable Loads (tons) | | Load Reduction (sediment 'saved') | | | |
|---|---|---|---|---|---|---|
| Sub-Watershed | 1998 | 2009 | Tons | % by Sub-Wshd | % of 1998-2009 Total Reduction | % of Total 1998 Controllable Load |
| Lower Watershed | 3,358,000 | 1,417,000 | 1,941,000 | 58% | 71% | 25% |
| Upper Watershed | 4,289,000 | 3,511,000 | 796,000 | 19% | 29% | 10% |
| Totals | 7,647,000 | 4,928,000 | 2,737,000 | NA | 100% | 36% |

Overall, controllable sources of sediment have been reduced by about 36 percent in the entire watershed, more than half the 60 percent reduction required by the TMDL. Most of the load reduction (71%) has occurred within the lower watershed where work has been reliably funded for a longer time. In the lower watershed, road decommissioning on park lands has treated about 58 percent of the controllable loads in the lower watershed. In the upper watershed, road decommissioning and upgrade work has reduced watershed-wide controllable loads by about 29 percent, or about 19 percent of the controllable loads in the upper watershed. Work on private lands has been funded by competitive grants and the landowners. Methods used to estimate load reductions are described in Appendix E

### *Long-Term Average Annual Sediment Loads and 10-Year Rolling Annual Average*

The USGS operates a stream gaging station at Orick, about three miles upstream from the mouth of Redwood Creek. Stream discharge has been measured since 1954 and the total sediment load (suspended and bed load) has been measured since 1972. The more than six decade-long continuous record captures the variation in hydrologic conditions as well as the watershed's response to land use and changing watershed conditions. Table 7 lists the average annual total sediment loads for Redwood Creek measured at Orick for selected time periods. The time periods were selected to show how the length of period considered and low to moderate flows can affect average annual sediment loads.

Table 7. Average annual sediment loads at Orick gage for selected time periods.

| Period | Years | Average Annual Loads (tons/sqmi/yr) | Comments |
|---|---|---|---|
| 1954-2009 | 56 | 4,100 | complete record (1954-1971 are synthesized data) |
| 1954-1997 | 44 | 4,700 | includes large storms; pre-TMDL |
| 1990-2009 | 20 | 2,000 | includes 1990s low flows and 1996-97 storms |
| 1987-1993 | 7 | 870 | low flow period |
| 1998-2009 | 12 | 1,800 | moderate flows during TMDL period |

The EPA established the TMDL (allowable sediment load allocation) for Redwood Creek at 1,900 tons/square mile/year expressed as a 10-year rolling annual average. The rolling average was meant to allow for variations in rainfall and runoff through time. Figure 5 shows the 10-year rolling annual sediment average for Redwood Creek from 1960 to 2009.

The total annual sediment load peaked in Redwood Creek by the early-1970s following periods of widespread sedimentation from the combined effects of early land use and large storms. Annual average sediment loads and the 10-year rolling average (plotted as the last year in a 10-year period) declined steadily for the next 20 years during a period of mostly low to moderate flows. During a period of low flows from 1987-1994, the 10-year rolling average fell below the TMDL target of 1,900 tons/square mile/year for the first time. The declining trend in the 10-year rolling average reversed following the storms in 1996 and 1997. Since 2007, the 10-year rolling average has once again dropped below the TMDL during a period of moderate flows.

### *Discussion*

Since the EPA established the TMDL in 1998, potential sediment loads have been reduced by about half of the required 60 percent load reduction at the watershed scale. But, the reduction has occurred to a greater extent by work completed in the lower watershed within park areas. Further reductions in controllable loads in the upper watershed are needed to more fully distribute load reduction efforts throughout the watershed. The 29 percent load reduction in the upper watershed was achieved by decommissioning and upgrading roads. Because upgraded roads are not maintenance-free, long-term maintenance of those roads will be critical to fully realize the benefits from the investments to reduce the potential for future road failures.

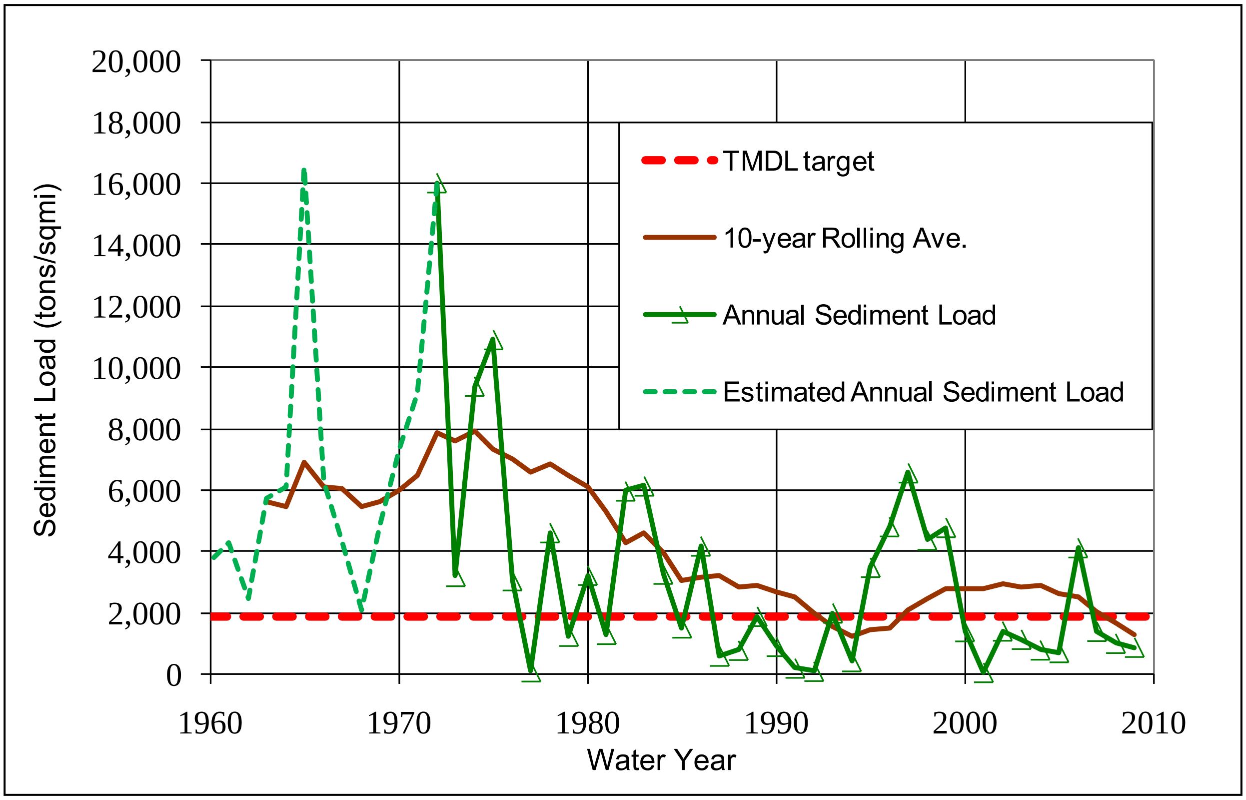


Figure 5. Total annual sediment loads for Redwood Creek, 10-year rolling annual average and TMDL target.

The fact that the 10-year rolling annual average for sediment loads in Redwood Creek can fall below the TMDL target (1,900 tons/square mile/year) is very encouraging. We believe it shows the cumulative benefits and returns from erosion control and prevention efforts and improved land management practices. However, the 1996 and 1997 storms serve as reminders that more work needs to be done. Curry (HSU, 2007) reported that, in Redwood Creek and at the watershed scale, the storms were relatively moderate storms (12-year recurrence interval), but they triggered about 250 landslides throughout the watershed that eroded more than 745,000 yds$^3$ of material and reversed the declining trend of the 10-year rolling average curve. About 63 percent of the landslides were associated with roads (HSU, 2007). If large sediment inputs to Redwood Creek can be prevented during future large storms, sediment loads will drop as legacy sediment stored in the channel moves out of the system. Combined with cooperative efforts that decommission more roads, especially those in sensitive geomorphic settings, and upgrade and maintain the remaining road network, we believe the annual sediment loads will drop below the TMDL target and will be sustainable through the infrequent large storms.

There are about 1,040 miles of road in the upper Redwood Creek watershed and about 280 miles of road in the lower watershed. Road density in the upper watershed has fallen from about 7.2 miles/square mile in 2004 to about 6.4 miles/square mile as of 2009. Road density in the lower watershed has fallen from about 4.9 miles/square mile in 1978 to about 2.4 miles/square mile. Both reductions are improvements, but we believe the road density in the upper watershed is still too high. At 6.4 miles/square mile, the road density in the upper watershed approximates the drainage density (7.5 miles/square mile) for *all* streams in the watershed. Thus, more roads need to be decommissioned in the upper watershed to reduce the sediment threats associated with roads.

When considering all work completed in the lower and upper watershed, the total amount of sediment 'saved' from 1998 to 2009 is approximately 2,737,000 tons, or about 9,900 tons per square mile of watershed area. This represents about 227,000 tons/year or 820 tons/square mile/year. To put the sediment savings into perspective, the total sediment load for the same period in Redwood Creek was about 6,100,000 tons, or 22,000 tons/square mile, or 1,800 tons/square mile/year. Because the amount of sediment reduction from erosion control efforts is not 'realized' in the same way as the annual sediment loads for Redwood Creek, it is difficult to make a direct comparison between the two. But, the fact that sediment reduction is about 46 percent of the average annual load places a certain significance on the work accomplished. It will take large storms to test the effectiveness of the hillslope work and be able to observe the benefits from the completed work.

Figure 6 shows the annual sediment 'savings' from work completed in the watershed from 1998 to 2009. Also shown is the average annual sediment load for Redwood Creek for this same time period and the TMDL 10-year rolling average. While a direct comparison of sediment 'saved' to annual sediment transport rates is not possible because of the time delay in realizing the benefits of the work, showing this information together helps put the sediment 'savings' in perspective. As would be expected, the rate of work in the upper and lower watersheds varied, and years with no or minimal work coincided with a lack of project funding. Of the total sediment 'saved', about 29 percent was saved from the upper watershed and 71 percent was saved from the lower watershed.

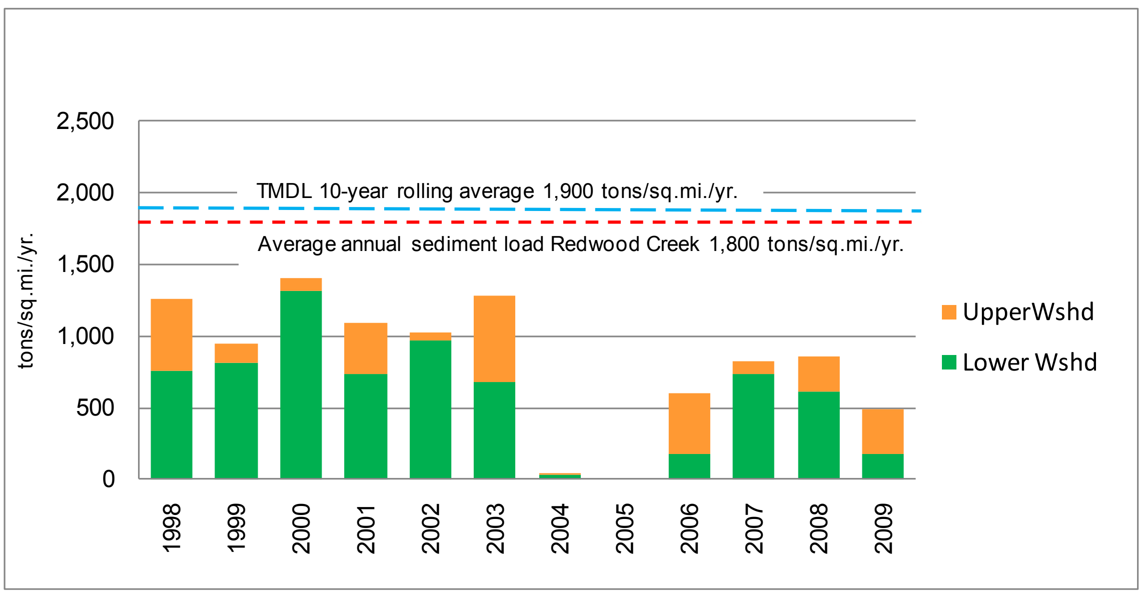


Figure 6. Annual sediment 'savings', TMDL target, and average annual sediment load in Redwood Creek 1998-2009.

Figure 7 is another way to consider the benefits from the sediment savings from 1998 to 2009. It shows the cumulative annual sediment load for Redwood Creek measured at Orick and the savings from erosion control and prevention work. Sediment savings are shown along with both measured sediment loads and what the theoretical sediment loads might have been without these efforts. The plot shows that cumulative sediment loads would have increased by about 30 percent without completed erosion control and prevention treatments. The plot assumes the sediment 'savings' are immediate, which we know is unlikely.

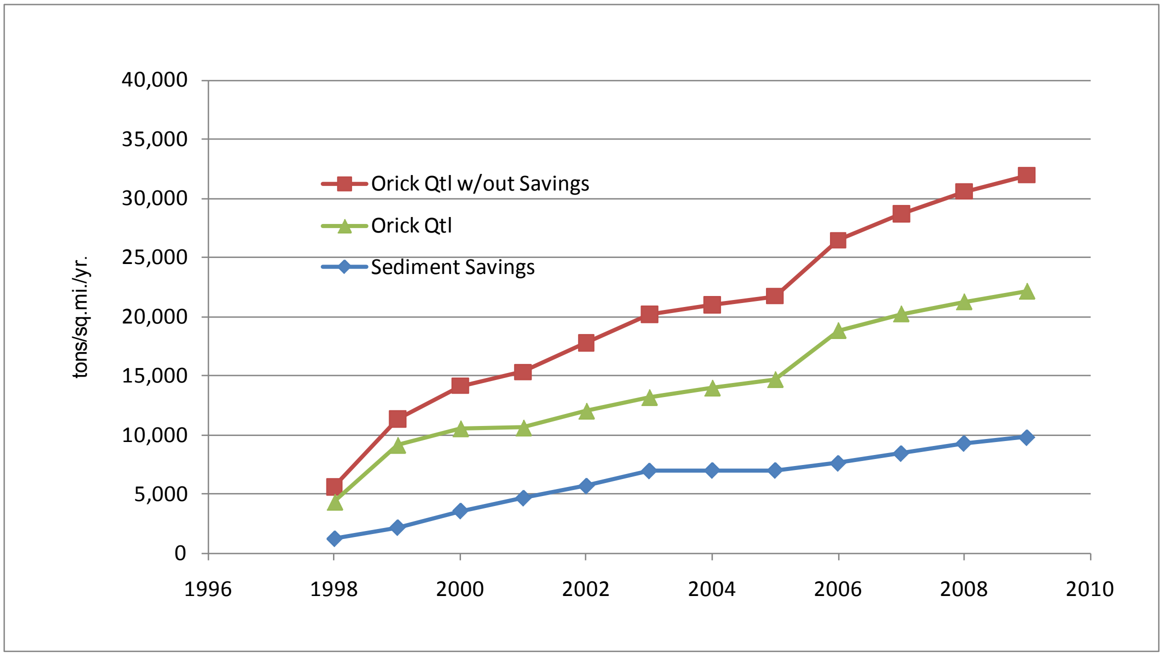


Figure 7. Cumulative annual sediment load (Qtl) at Orick with and without 'savings' from erosion control and prevention efforts 1998-2009.

The results presented in this section represent the minimum benefits from the completed work. In other words, it is important to remember that, through time, the sediment savings provide returns just like any investment: interest and dividends accrue and compound annually. And, as with investments, small increases in principle amounts add up to large returns through time. Water quality and salmonid habitat will likely improve at the sub-watershed level before the cumulative benefits combine to improve conditions in the main channel of Redwood Creek. Sediment reduction from erosion control and prevention efforts will create benefits such as clean water, increased pool depth and frequency, and stable riparian areas that support conifer growth for large woody debris recruitment and improved stream water temperatures. A less tangible but significant return on these investments are the offsite cumulative impacts that will be prevented by the competed work.

Significant progress has been made toward attaining the TMDL hillslope targets in Redwood Creek, but more work needs to be done. Further reductions in controllable loads in the upper watershed are needed to more fully distribute load reduction efforts throughout the watershed. The rate of future work will depend on funding opportunities and global economic trends which affect the demand for lumber products. A more consistent and well-funded watershed-wide program would speed attainment of the TMDL targets and watershed recovery. The Park is committed to seeking funding opportunities in partnership with cooperators primarily to decommission roads.

# CURRENT ROAD CONDITIONS

This section describes the current condition of the remaining assessed roads in upper Redwood Creek. Results are based on road assessment data which have been updated for each site and road that has been treated through either cooperative erosion control projects, separate landowner projects or THP road work

Throughout this discussion we use project data that are reliable for the specific summary statistic or analysis. During each assessment, some investigators recorded all data used in all tables and analyses in this report. Others did not record estimated treatment costs or used volumetric surveys that were inconsistent with most other assessments in the watershed. Table 8 shows the assessment projects, the total road miles for those projects and which data are used in summary statistics and analyses.

Table 8. Projects and data used in summary statistics and analysis for remaining (not decommissioned) roads.

| Projects with Reliable Data | Summary Statistic or Data Analysis | Total Road Miles Assessed | % of Remaining Roads in Upper Redwood Creek |
|---|---|---|---|
| PCFWWRA | All cost tables and prioritizing roads | 518 | 50% |
| PCFWWRA and RNSP | Sediment yield and prioritizing roads and areas | 601 | 58% |
| PCFWWRA, RNSP, NRM and County | Drivability and maintenance status | 712 | 68% |
| Not Assessed | | 328 | 32% |
| Total all Remaining Roads | | 1040 | |

## DRIVABILITY AND MAINTENANCE STATUS

Drivability and road maintenance status were documented during each assessment. The data were updated after completion of subsequent road treatments. Roads were described as drivable, not drivable, maintained, unmaintained, or decommissioned. Of the remaining (not decommissioned) 712 miles of assessed roads, about 400 miles are considered drivable by a standard 4WD vehicle and about 257 miles are considered not drivable. Drivability was not documented for about 55 miles of roads. Drivability is summarized in Table 9.

Table 9. Drivability of all assessed roads through 2009.

| Drivability | Miles | % of Total Assessed Miles |
|---|---|---|
| Drivable | 400 | 56% |
| Not Drivable | 257 | 36% |
| Not Documented | 55 | 8% |
| Total Assessed Roads Remaining | 712 | 100% |

Maintained roads show signs of recent maintenance, such as cleaning of culvert inlets, trash racks, and inboard ditches; grading; rolling dip or water bar reconstruction; brushing; culvert replacement; or fill reconstruction. Unmaintained roads lack obvious maintenance to culverts and ditches, and vegetation encroaches on the road and road surface. The road may or may not be drivable. There are presently about 310 miles of maintained roads and about 330 miles of unmaintained roads. The status was not documented for about 72 miles of road. Table 10 summarizes these data.

Table 10. Maintenance status of all assessed roads through 2009.

| Maintenance Status | Miles | % of Total Assessed Miles |
|---|---|---|
| Maintained | 310 | 44% |
| Unmaintained | 330 | 46% |
| Unknown Status | 72 | 10% |
| Total Assessed Roads Remaining | 712 | 100% |

## POTENTIAL SEDIMENT YIELD

Potential sediment yield is the volume of sediment that can potentially erode and be delivered to a stream during a large storm. The volume is an estimate calculated from field measurements made of the void that would erode if a potential erosion site failed. In this report, *potential sediment yield* is always the larger of *site potential yi*eld or the *extreme potential yield* (refer to the glossary for definitions) for each site (if one exists).

Initial road assessments by PCFWWRA and RNSP identified 4,955 sites as reported in Table 2. During subsequent road treatment projects, additional erosion sites were identified and assessed. The values reported below reflect all data from the initial road assessments and data from 129 additional sites assessed during treatment projects.

A total of 5,084 sites were evaluated in the field since 1996 by PCFWWRA and RNSP. Of these, 737 have been decommissioned and subsequently have negligible potential sediment yield. Of the remaining 4,347 sites, there are 3,528 fluvial erosion sites and 819 landslide sites. Potential sediment yield is summarized in Table 11.

Table 11. Potential sediment yield for remaining (not decommissioned) sites assessed by PCFWWRA and RNSP with proposed treatments.

| | No. of Sites | Erosion Volume (yds$^3$) [2] | Site Potential Yield (yds$^3$) | Extreme Potential Yield [3] (yds$^3$) | Potential Sediment Yield [4] (yds$^3$) | % of No. of Sites | % of Potential Sediment Yield |
|---|---|---|---|---|---|---|---|
| Sites Assessed and Remaining [1] | 4,347 | 1,697,600 | 985,000 | 468,800 | 1,270,000 | 100% | 100% |
| | | | | | | | |
| All Sites with No Yield | 569 | 8,600 | 0 | 0 | 0 | 13% | 0% |
| All Sites, Yield >0 | 3,778 | 1,689,000 | 985,000 | 468,800 | 1,269,900 | 87% | 100% |
| M-H Sites, Yield >0 | 1,942 | 1,015,800 | 637,900 | 366,000 | 865,400 | 45% | 68% |
| | | | | | | | |
| All Fluvial Sites | 3,528 | 712,300 | 708,100 | 112,000 | 768,000 | 81% | 60% |
| All Landslide Sites | 819 | 985,200 | 276,900 | 356,800 | 501,900 | 19% | 40% |
| | | | | | | | |
| Field Call for Treatment | | | | | | | |
| Decommission | 1,405 | 861,200 | 384,100 | 264,800 | 547,200 | 32% | 43% |
| Upgrade | 2,016 | 759,500 | 528,600 | 175,000 | 627,100 | 46% | 49% |
| Maintain | 895 | 74,800 | 70,600 | 25,000 | 90,600 | 21% | 7% |
| None | 31 | 2,100 | 1,700 | 4,000 | 5,100 | 1% | 0% |
| Totals all Sites[4] | 4,347 | 1,697,600 | 985,000 | 468,800 | 1,270,000 | 100% | 100% |

Table notes:
[1] Number of sites differs from value shown in Table 2, because this table includes 129 additional sites assessed during treatment projects.
[2] Erosion Volume is that amount of sediment that can potentially erode from a site.
[3] 329 out of 4,327 sites had an extreme potential yield.
[4] Potential Sediment Yield is the greater of the site potential yield and the extreme potential yield for each site then summed for all sites. It is not the sum of the two columns "Site Potential Yield" and "Extreme Potential Yield".
[5] Small differences in sums or with other tables are due to rounding.

### *Fluvial Erosion Sites*

Of the remaining sites, not decommissioned, there are 3,528 fluvial erosion sites. Of those, 2,301 are haul road stream crossings. Of these, 1,218 have treatment urgencies of medium or higher with the potential to yield about 465,600 yds$^3$ of sediment to streams. This is about 63 percent of the potential sediment yield of all medium and higher urgency fluvial erosion sites. Skid trail crossings account for the next largest volume of potential sediment yield with an estimated 14,200 yds$^3$ possible sediment delivery from 78 sites with medium or higher treatment urgency. Selected data for fluvial erosion sites are shown in Table 12.

Table 12. Selected information for fluvial erosion sites.

| Fluvial Features | All Urgency Sites | | Medium to High Urgency Sites | | | |
|---|---|---|---|---|---|---|
| | No. of Sites | Potential Sediment Yield | No. of Sites | Potential Sediment Yield | % of No. of Medium+ Sites | % of Pot. Sediment Yield |
| Haul road stream crossings | 2,301 | 723,800 | 1,218 | 465,600 | 83% | 61% |
| DRC[1] with sediment delivery | 358 | 10,400 | 111 | 5,100 | 8% | 1% |
| DRC, no sediment delivery | 463 | 0 | 0 | 0 | 0.0% | 0.0% |
| DRC, road reaches | 5 | 100 | 0 | 0 | 0.0% | 0.0% |
| Road reach | 142 | 5,700 | 53 | 3,300 | 4% | 0% |
| Skid trail crossings | 147 | 25,000 | 78 | 14,200 | 5% | 2% |
| Swales | 112 | 3,000 | 6 | 800 | 0% | 0% |
| Totals | 3,528 | 768,000 | 1,467 | 489,000 | 100% | 64% |

[1] DRC – Ditch Relief Culvert

### Fish passage at stream crossings –

There were 21 Class I stream crossings identified during road assessments. Subsequent to initial assessments, four sites were decommissioned, one upgraded and one found not treatable as part of an adjacent road decommissioning project. Of the 17 remaining sites, four sites have treatment urgencies of medium or higher. Table 13 shows the current status of these four Class I streams. One of the crossings shown is identified as a possible barrier to fish.

There are additional Class I stream crossings in Redwood Creek along roads managed by Humboldt County and Caltrans that are not reported here. Areas not assessed as part of the cooperative erosion control program are also not included in Table 13.

Table 13. Class I stream crossings with medium or higher urgency.

| Site ID | Road Name | Location | Type | Urgency | Comment |
|---|---|---|---|---|---|
| 2064050 | LC4000 | Mainstem Lacks | Washed out | MED | "King's Crossing" mostly washed-out. About 100 yds$^3$ remain within mainstem. |
| 4037223 | Dolly Varden | Cashmere | Old log bridge | MED-HIGH | Failing -bridge may be barrier. Need to replace or remove. |
| 5038016 | UPR-10 | Mainstem Windy | Bridge | MED-HIGH | Bridge seriously constricting channel. Need to replace.~400 yards of pot. yield. |
| 5044018 | L2000-CN | Noisy | Bridge | MED | Bridge condition is OK. Road drainage treatments are medium urgency. |

### *LANDSLIDE SITES*

Of the remaining sites, not decommissioned, there are 819 assessed landslide sites. Of these, 477 sites have medium or higher treatment urgencies and potential sediment yield of about 376,400 yds$^3$. This is about 75 percent of total potential sediment yield from all landslide sites. Selected information for landslide sites is shown in Table 14.

Table 14. Selected information for landslide sites.

| Landslide Features | All Urgency Sites | | Medium to High Urgency Sites | | | |
|---|---|---|---|---|---|---|
| | No. of Sites | Potential Sediment Yield | No. of Sites | Potential Sediment Yield | % of No. of Medium + Sites | % of Pot. Sediment Yield |
| Road | 589 | 245,000 | 336 | 188,600 | 71% | 38% |
| Landing | 86 | 43,400 | 49 | 40,900 | 10% | 8% |
| Hillslope | 10 | 22,100 | 4 | 4,700 | 1% | 1% |
| Road, Hillslope | 64 | 114,300 | 35 | 76,800 | 5% | 15% |
| Road, Landing | 36 | 34,400 | 26 | 31,600 | 6% | 6% |
| Road, Swale | 25 | 23,500 | 21 | 21,100 | 7% | 4% |
| Landing, Hillslope, Swale | 9 | 19,200 | 4 | 12,700 | 0% | 3% |
| Totals | 819 | 501,900 | 477 | 376,400 | 100% | 75% |

## Estimated Costs for Treating Remaining Roads

Costs for treating all assessed sites and roads have been reported in past reports (Bundros et al., 2003 and 2004; Bundros and Short, 2009) that estimated costs based on site specific information for equipment, material and labor needs using costs and rates in effect at the time of the reports. For this report, we used average treatment costs ($/mile of road to be treated) calculated in 2009 from assessment data and applied those values to the remaining untreated roads in the upper watershed. We used this simplified method because the schedule for project implementation is uncertain and we know that costs, especially fuel costs, can vary significantly with time. Thus, the cost estimates presented in this report are intended to provide only a general scale of funding needed to treat the remaining roads in the upper Redwood Creek watershed.

Table 15 lists the type of treatments prescribed by field crews, unit treatment costs and estimates to treat the remaining roads in the upper watershed. For the remaining assessed roads, cost estimates assume that all sites prescribed for decommission would be treated and only the upgrade sites with urgency equal to or greater than medium would be treated. The final column in Table 15 extends the cost estimates to include all roads (not state or county owned) in the upper watershed based on the per mile treatment cost for assessed roads and with the same ratio of decommissioned to upgraded roads.

The estimated cost to treat the remaining 518 miles of assessed roads is about $24 million. When estimates are extended to include unassessed roads, the estimated total cost to treat all remaining untreated roads in the upper watershed is about $44 million.

Table 15. Estimated treatment costs for roads not yet treated and extended to all roads.

| Miles prescribed for treatment type: | Assessed roads | | | | Costs extended to include all unassessed roads |
|---|---|---|---|---|---|
| | Data from previous reports | | | | |
| | 2003 | 2004 | 2009 | 2011 | 2011 |
| Decommission (mi) | 144 | 167 | 152 | 154 | 275 |
| Upgrade (mi) | 207 | 226 | 235 | 222 | 397 |
| Maintain (mi) | 83 | 95 | 76 | 142 | 151 |
| Total (mi) | 434 | 488 | 463 | 518 | 823 |
| | | | | | |
| Average Cost per Mile Decommission | $43,700 | $42,800[1] | $72,700 | $72,700[2] | $72,700 |
| Average Cost per Mile Upgrade | $36,300 | $36,900[1] | $59,400 | $59,400[2] | $59,400 |
| Average Cost per Mile Maintain | not avail | not avail | not avail | not avail | not avail |
| Total Cost to Treat Roads with Costs Assigned: | $13,815,000 | $15,485,000 | $24,950,000 | $24,362,000 | $43,588,000 |
| Overall Average Cost per Mile | $31,800 | $31,800 | $64,600 | $53,000 | $61,680 |

[1] Fuel costs rose significantly between 2004 and 2009 affecting all costs.
[2] Cost per mile for 2011 estimate based upon costs calculated in 2009.

# TREATMENT PRIORITIES

This section presents examples of analyses that can be used to establish treatment priorities based on road assessment data. Each example analyzes road assessment data differently and at a different scale. Establishing priorities helps determine where the greatest benefits can be achieved and ensures limited funds are spent wisely.

The analyses in this section have been presented in our previous summary reports (Bundros et al., 2003 and 2004). Here, we repeat those analyses with consideration of all road treatments completed since cooperative erosion control efforts began. The results presented in this section reflect the new treatment priorities for the remaining assessed roads in the upper watershed.

## PRIORITIZING ROADS AND SUB-WATERSHEDS USING DATABASE QUERIES

This analysis relies on database queries that characterize individual roads and sub-watersheds so that treatment priorities can be established. Unlike other analyses described in this section, database queries are based on *treatment urgency* instead of *erosion potential*.

### *ROADS*

This analysis establishes a treatment priority for individual *roads* using database queries and data for sites assessed by PCFWWRA, and not decommissioned. Sites assessed by others were omitted because field crews did not prescribe detailed treatments nor estimate treatment costs. Roads that contained sites with medium to high treatment urgencies were ranked based on three criteria: 1) potential yield (volume of sediment that can enter a stream) from the entire road; 2) potential yield per mile of road evaluated, and; 3) treatment cost-effectiveness (the cost per cubic yard to prevent sediment from entering a stream). Road treatment priority was based on the ranking of each criterion for each road. Of the nearly 580 roads originally assessed, Table 16 lists, in alphabetical order, the 20 roads that have the highest treatment priority based on potential sediment yield, potential yield per mile of road and/or treatment cost-effectiveness when the top 30 roads (5%) of each criterion was considered. Tables F-1, F-2, and E-3 (Appendix F) show how each road ranked for each criterion.

Table 16. Treatment priority for roads based on potential sediment yield, yield per mile and/or treatment cost-effectiveness. (The four roads with bolded names rank high in all three criteria.)

| Road Name | Length (mi) | Total no. of sites | Total no. M to H sites | Potential Sediment Yield all sites (yds$^3$) | For Medium to High Urgency Sites | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Potential Sediment Yield (yds$^3$) | Potential Sediment Yield per mile (yds$^3$ / mi) | Cost/yard "saved" | Total Cost |
| 809 | 1.8 | 15 | 13 | 16,032 | 12,510 | 7,032 | $12.53 | $156,745 |
| 831 | 2.1 | 13 | 7 | 7,699 | 7,338 | 3,578 | $2.02 | $14,821 |
| 1140 | 0.8 | 15 | 7 | 12,616 | 7,144 | 9,516 | $3.34 | $23,856 |
| 1410 | 1.9 | 23 | 12 | 8,125 | 7,602 | 3,994 | $4.43 | $33,660 |
| 1431 | 1.7 | 29 | 22 | 9,479 | 9,375 | 5,626 | $10.24 | $95,960 |
| 1433 | 0.5 | 7 | 7 | 3,978 | 3,978 | 7,835 | $3.04 | $12,109 |
| 1440 | 1.5 | 18 | 15 | 15,155 | 14,588 | 9,657 | $2.15 | $31,314 |
| 800G | 0.3 | 2 | 2 | 3,726 | 3,726 | 12,298 | $3.28 | $12,236 |
| Dolly Varden | 11.8 | 155 | 114 | 109,890 | 103,954 | 8,793 | $11.87 | $1,234,068 |
| DVA | 1.3 | 18 | 15 | 7,480 | 7,292 | 5,640 | $15.49 | $112,964 |
| LC5000 | 2.3 | 26 | 21 | 23,659 | 23,089 | 10,176 | $2.57 | $59,360 |
| N500A | 0.2 | 3 | 3 | 1,697 | 1,697 | 7,318 | $4.92 | $8,348 |
| Old Hwy 299 | 2.5 | 52 | 39 | 16,040 | 15,064 | 6,074 | $15.52 | $233,836 |
| PR1106 | 0.6 | 5 | 5 | 10,417 | 10,417 | 17,639 | $3.02 | $31,477 |
| R1000 | 2.1 | 21 | 13 | 8,914 | 8,775 | 4,164 | $3.84 | $33,653 |
| R2100 | 0.2 | 2 | 2 | 1,557 | 1,557 | 7,402 | $3.05 | $4,746 |
| R3351 | 0.1 | 1 | 1 | 750 | 750 | 6,544 | $1.36 | $1,017 |
| R3800 | 0.9 | 11 | 10 | 9,796 | 9,774 | 11,364 | $5.89 | $57,576 |
| R3810 | 0.1 | 2 | 1 | 5,000 | 3,500 | 43,126 | $2.90 | $10,165 |
| RC-2 | 1.5 | 25 | 14 | 10,122 | 9,120 | 6,168 | $14.77 | $134,682 |

Table note:
Costs above include only heavy equipment costs for site specific treatments and laborers for culvert installations. Costs do not include equipment mobilization, road opening, heavy equipment requirements for road drainage treatments, culvert materials costs, mulch and seeding costs, project layout, coordination, oversight, report preparation, or overhead.

The 1140, 1440, LC5000 and PR1106 roads have the highest treatment priority because each road appeared in the top 30 roads and in all three criteria. These roads have relatively high potential sediment yield, high yield per mile of road, and high treatment cost-effectiveness. The other roads listed in Table 16 ranked high in at least two of the three criteria.

### *SUB-WATERSHEDS*

This analysis establishes a treatment priority for individual *sub-watersheds* using database queries and data for sites assessed by PCFWWRA and RNSP, and not decommissioned. Sites assessed by others were omitted because we determined the volume estimates are inaccurate (Bundros and Short, 2009). The analysis presents basic information for each sub-watershed, and computes the total potential sediment yield per mile of road (yds$^3$/mile) for each sub-watershed. The query evaluates sites with medium to high erosion potentials in sub-watersheds where at least 40 percent of the road miles had been evaluated. The results were sorted by the potential sediment yield per mile of road and assigned a priority ranging from very low to very high. The priority for each sub-watershed was assigned by comparing its yield per mile to the highest yield per mile value of the sub-watersheds considered. The very low priority sub-watersheds would yield 0-20 percent of the yield per mile for the sub-watershed with the highest value, and the very high priority sub-watershed would yield 80-100 percent of the highest yielding sub-watershed.

Table 17 shows the query results and establishes a treatment priority for each sub-watershed by the total potential sediment yield per mile of road. Potential sediment yield per mile ranged from about 52 yds$^3$/mile in Six Rivers Creek to 5,745 yds$^3$/mile of road in Lee Creek. Lee Creek was considered an outlier in this analysis because its yield was nearly twice the value of the next highest sub-watershed. Potential sediment yield averaged about 1,140 yds$^3$/mile.

Also from the Table 17, Lacks Creek has the highest potential sediment yield, equal to about 142,000 yds$^3$. Lacks Creek is more than twice the size of the next largest sub-watershed, so the fact that it has the highest total potential yield is no surprise. Of the 42 sub-watersheds considered, 14 sub-watersheds can potentially yield more than 10,000 yds$^3$ of sediment per square mile.

Table 17. Sub-watershed treatment priority based on potential sediment yield per mile of road.

| Sub-Watershed | Acres | Roads | | | Potential Sediment Yield | | | Sub-Watershed Priority |
|---|---|---|---|---|---|---|---|---|
| | | Total (mi) | Evaluated (%) | Density ($mi/mi^2$) | Total ($yds^3$) | Yield/mile$^2$ ($yds^3/mi^2$) | Yield/Mile ($yds^3/mi$) | |
| Lee | 292 | 3.1 | 100% | 6.7 | 17,546 | 38,493 | 5,745 | Very High |
| Wiregrass | 1,153 | 9.5 | 92% | 5.3 | 34,515 | 19,152 | 3,635 | Very High |
| Johnson Prairie | 386 | 2.2 | 87% | 3.6 | 7,338 | 12,179 | 3,371 | Very High |
| Toss-Up | 1,709 | 15.7 | 97% | 5.9 | 43,662 | 16,355 | 2,778 | High |
| Pilchuck | 1,086 | 8.8 | 92% | 5.2 | 24,398 | 14,381 | 2,773 | High |
| Loin | 601 | 5.0 | 81% | 5.3 | 12,515 | 13,328 | 2,517 | High |
| Timbo | 229 | 3.8 | 94% | 10.7 | 8,769 | 24,479 | 2,295 | High |
| Headwaters_W | 179 | 1.7 | 52% | 6.0 | 3,740 | 13,360 | 2,235 | High |
| Stover | 544 | 4.8 | 56% | 5.7 | 9,885 | 11,621 | 2,052 | Medium |
| Garcia | 905 | 10.1 | 90% | 7.1 | 20,627 | 14,581 | 2,049 | Medium |
| Powerline | 408 | 4.3 | 94% | 6.8 | 8,874 | 13,916 | 2,048 | Medium |
| Dolly Varden | 2,151 | 23.5 | 92% | 7.0 | 44,327 | 13,191 | 1,883 | Medium |
| Tom | 259 | 2.2 | 93% | 5.4 | 4,067 | 10,045 | 1,853 | Medium |
| Coyote | 5,043 | 16.5 | 57% | 2.1 | 30,159 | 3,827 | 1,829 | Medium |
| June | 125 | 0.9 | 100% | 4.8 | 1,694 | 8,701 | 1,804 | Medium |
| Lacks | 10,977 | 82.5 | 85% | 4.8 | 142,333 | 8,298 | 1,724 | Medium |
| Smokehouse | 426 | 5.8 | 74% | 8.7 | 9,210 | 13,850 | 1,594 | Medium |
| Negro Joe | 806 | 9.5 | 72% | 7.6 | 12,380 | 9,830 | 1,301 | Low |
| George | 699 | 6.4 | 100% | 5.8 | 8,145 | 7,461 | 1,282 | Low |
| Twin Lakes | 811 | 9.8 | 90% | 7.8 | 11,875 | 9,369 | 1,206 | Low |
| Fern Prairie | 509 | 6.5 | 73% | 8.2 | 7,310 | 9,194 | 1,124 | Low |
| Garrett | 2,643 | 21.1 | 62% | 5.1 | 18,688 | 4,525 | 886 | Low |
| Minor | 8,248 | 84.6 | 87% | 6.6 | 73,535 | 5,706 | 869 | Low |
| Burley | 255 | 3.0 | 91% | 7.4 | 2,564 | 6,444 | 866 | Low |
| Lupton | 3,329 | 41.1 | 62% | 7.9 | 35,637 | 6,852 | 866 | Low |
| Headwaters_M | 1,688 | 15.4 | 72% | 5.8 | 12,352 | 4,684 | 802 | Low |
| Snow Camp | 773 | 8.2 | 66% | 6.8 | 6,262 | 5,182 | 767 | Low |
| Lake Prairie | 2,144 | 18.8 | 82% | 5.6 | 14,035 | 4,190 | 746 | Low |
| Panther | 3,800 | 30.7 | 95% | 5.2 | 21,767 | 3,666 | 708 | Very Low |
| Jena | 246 | 4.1 | 47% | 10.7 | 2,715 | 7,061 | 660 | Very Low |
| Cashmere | 861 | 9.3 | 80% | 6.9 | 5,554 | 4,130 | 595 | Very Low |
| Pardee | 1,985 | 23.6 | 68% | 7.6 | 11,280 | 3,638 | 478 | Very Low |
| Christmas Prairie | 455 | 6.9 | 73% | 9.8 | 3,033 | 4,267 | 437 | Very Low |
| Noisy | 4,030 | 46.8 | 73% | 7.4 | 19,326 | 3,069 | 413 | Very Low |
| Marquette | 492 | 6.7 | 91% | 8.7 | 2,747 | 3,572 | 410 | Very Low |
| Cool Springs | 737 | 9.5 | 45% | 8.3 | 3,592 | 3,118 | 377 | Very Low |
| Santa Fe | 530 | 8.7 | 65% | 10.5 | 3,003 | 3,625 | 344 | Very Low |
| Debris Torrent | 129 | 2.0 | 91% | 9.8 | 559 | 2,770 | 283 | Very Low |
| High Prairie | 3,476 | 40.1 | 50% | 7.4 | 8,011 | 1,475 | 200 | Very Low |
| Joplin | 441 | 3.7 | 90% | 5.4 | 657 | 954 | 176 | Very Low |
| Ayers | 242 | 3.6 | 97% | 9.5 | 511 | 1,350 | 143 | Very Low |
| Six Rivers | 741 | 9.2 | 57% | 8.0 | 479 | 414 | 52 | Very Low |

## Prioritizing Areas within the Watershed Using a GIS Spatial Analysis

This analysis establishes a treatment priority for *areas* in the upper watershed using a GIS spatial analysis and data from sites assessed by PCFWWRA and RNSP, and not decommissioned. Data from sites assessed by others were not used. Rather than focusing on a specific road or sub-watershed, this method analyzes potential sediment yield throughout the upper watershed and highlights discrete areas by the concentration or *density* of potential sediment yield. The spatial analysis ignores sub-watershed boundaries.

The analysis uses both numeric and spatial data. Numeric data are the potential sediment yield values for sites as estimated by the field crews, and the spatial data comes from GIS point coverage for each site evaluated during the assessment. Because each point represents the location of a site, the analysis can evaluate the potential sediment yield of one site in relation to the potential sediment yield of sites that surround it.

Using GIS and the data sources described above, the density or "hot spots" (potential sediment yield per square mile) throughout the upper Redwood Creek watershed was computed. Simply stated, an analysis tool found in GIS software can scan and analyze a contiguous area using a moving one square mile circular "window." As the window sweeps across the landscape, it notes the potential sediment yield at each site location and adds to it the yield associated to neighboring sites if they are within one square mile of the site being evaluated. The results of this analysis are shown in Figure 8. The darkest colors represent the areas that contain the highest density of potential sediment yield, suggesting another possible treatment priority.

## Prioritizing Sub-Watersheds Using Risk Analyses

This analysis establishes treatment priorities using a numeric risk analysis and data from sites assessed by PCFWWRA and RNSP, and not decommissioned. Rather than analyzing a specific road or broad contiguous area, this method prioritizes each *sub-watershed* based on specific criteria. Similar to other analyses, at least 40 percent of the road length in each sub-watershed must have been assessed to be considered, and only sites with medium or higher erosion potential are included in the analysis. The analysis is performed twice. First, evaluates sub-watersheds based on the likelihood for and magnitude of potential erosion which we call *resource threat*. Then, anadromous salmonids are added to the analysis that considers salmonids as the *resource at risk*.

### *Resource Threat*

This risk analysis establishes a sub-watershed treatment priority based on resource threat, or the likelihood for and magnitude of erosion in each sub-watershed. The resource threat for each sub-watershed considers three criteria: 1) potential sediment yield; 2) critical crossings, and; 3) Shalstab. Resource threat was computed as follows:

Resource Threat = Yield + CXing + Shalstab

where, for each sub-watershed:

*Yield* is the total potential sediment yield for the sub-watershed,
*CXing* is the number of critical crossings in the sub-watershed, and

*Shalstab* is the number of Shalstab sites in the sub-watershed.

Weighted values were assigned to each criterion (Appendix G) based on the actual range of values for each criterion. The weighted values were then summed to create a final score for each sub-watershed. The final scores were sorted from high to low values and a sub-watershed treatment priority assigned based on 20% breaks in cumulative total scores. The results are shown in Figure 9 and Table 18 and suggest that Lacks, Minor and Dolly Varden creeks have the highest treatment priority based on potential resource threat, followed by Toss-Up, Lupton and Wiregrass creeks. The results are in general agreement with the spatial analysis for potential sediment yield density (Figure 8).

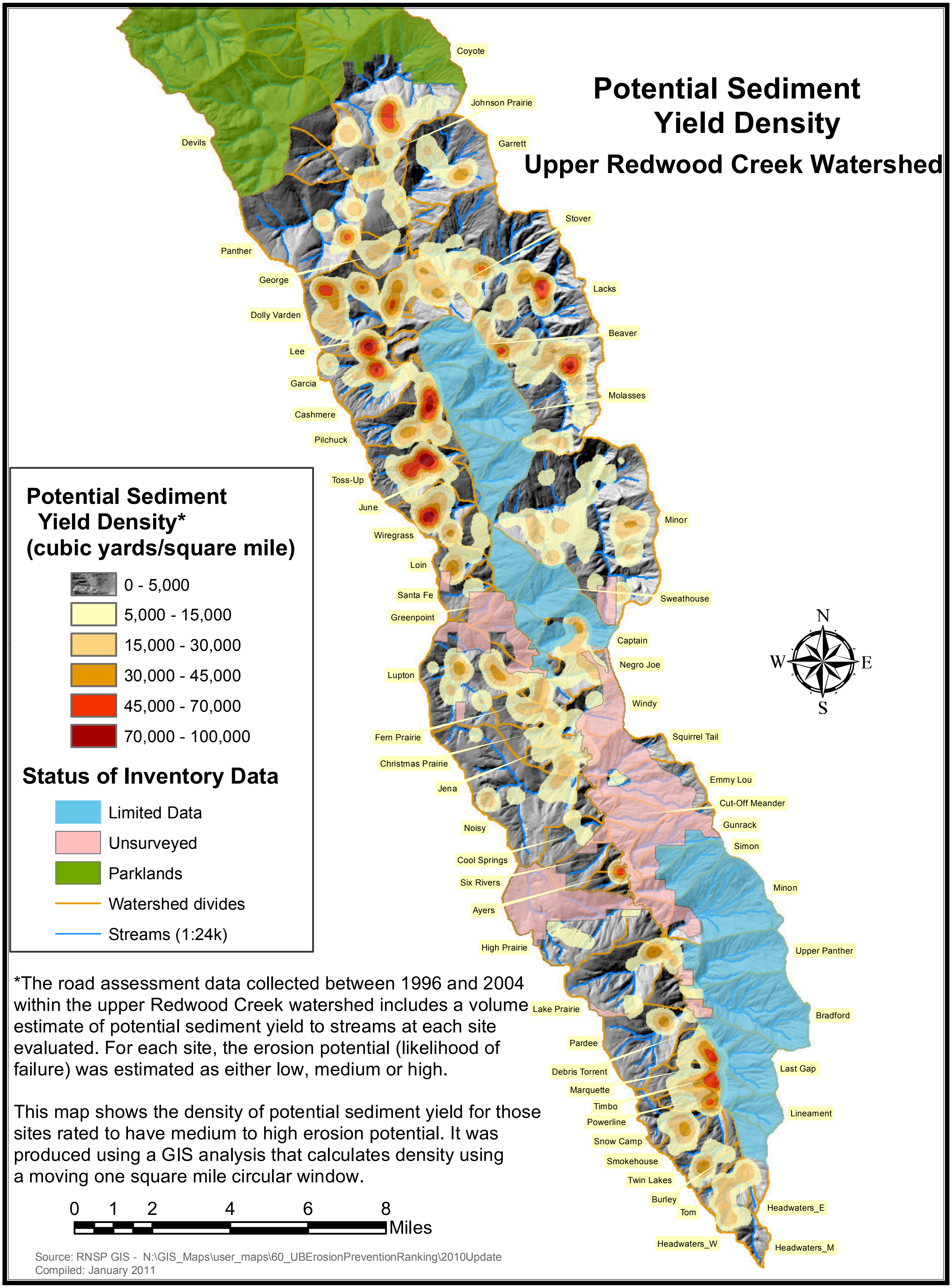


Figure 8. Potential sediment yield density.

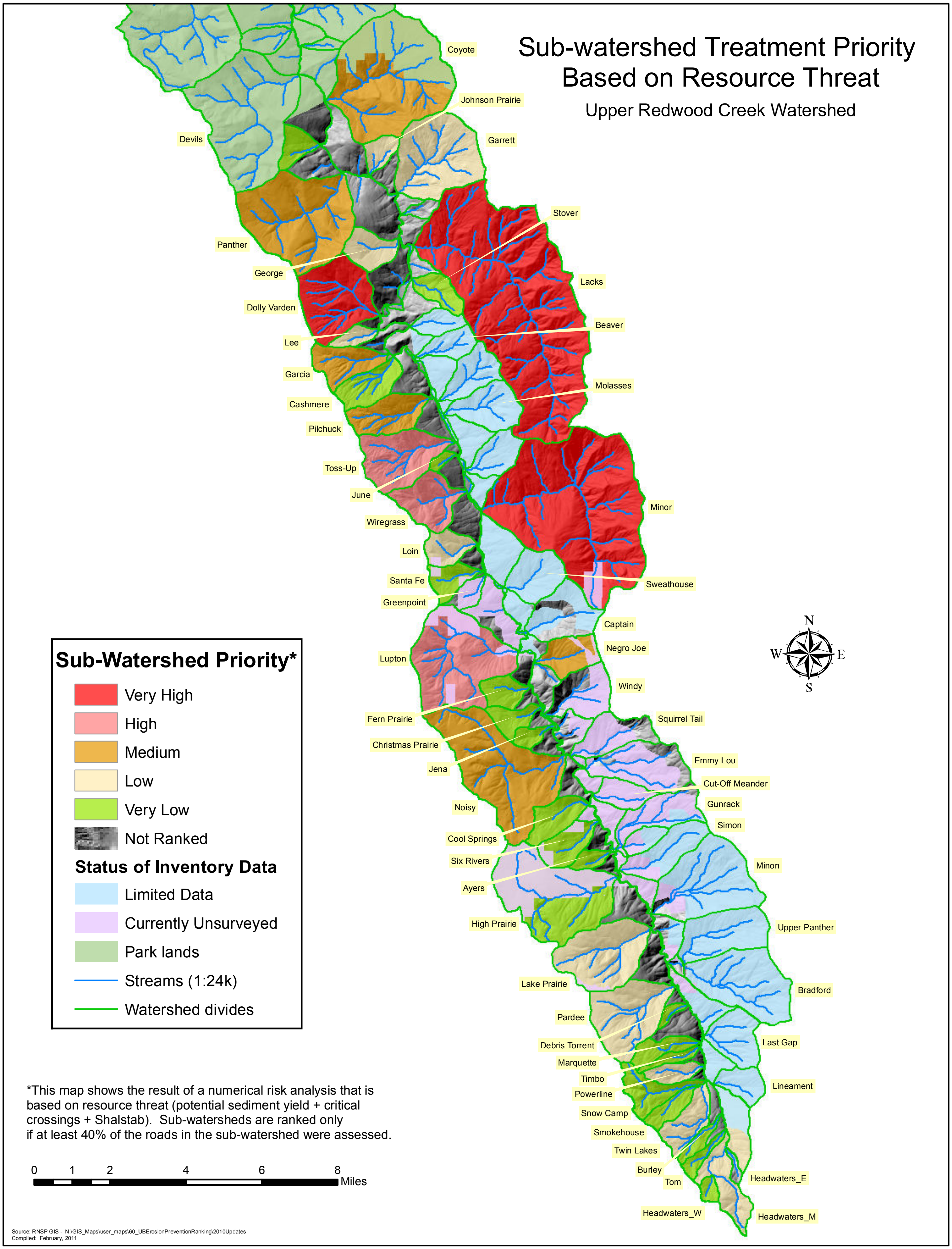


Figure 9. Sub-watershed ranking based on threat.

Table 18. Sub-watershed treatment priority based on resource threat.

| Sub-Watershed | Area (ac) | Weighting Values for: Potential Sediment Yield | Critical Crossings | Shalstab | Total Score | Sub-Watershed Priority |
|---|---|---|---|---|---|---|
| Lacks | 10,977 | 9 | 9 | 9 | 27 | Very High |
| Minor | 8,248 | 9 | 9 | 9 | 27 | Very High |
| Dolly Varden | 2,151 | 9 | 7 | 3 | 19 | Very High |
| Toss-Up | 1,709 | 7 | 3 | 7 | 17 | High |
| Lupton | 3,329 | 7 | 3 | 5 | 15 | High |
| Wiregrass | 1,153 | 7 | 3 | 5 | 15 | High |
| Coyote | 5,043 | 5 | 5 | 3 | 13 | Medium |
| Negro Joe | 806 | 3 | 7 | 3 | 13 | Medium |
| Garcia | 905 | 5 | 3 | 3 | 11 | Medium |
| Noisy | 4,030 | 5 | 5 | 1 | 11 | Medium |
| Panther | 3,800 | 5 | 3 | 3 | 11 | Medium |
| Pilchuck | 1,086 | 5 | 1 | 5 | 11 | Medium |
| Garrett | 2,643 | 3 | 5 | 1 | 9 | Low |
| Pardee | 1,985 | 3 | 3 | 3 | 9 | Low |
| Lake Prairie | 2,144 | 3 | 1 | 3 | 7 | Low |
| Johnson Prairie | 386 | 1 | 5 | 0 | 6 | Low |
| George | 699 | 1 | 3 | 1 | 5 | Low |
| Headwaters_M | 1,688 | 3 | 1 | 1 | 5 | Low |
| Lee | 292 | 3 | 1 | 1 | 5 | Low |
| Loin | 601 | 3 | 1 | 1 | 5 | Low |
| Powerline | 408 | 1 | 3 | 1 | 5 | Low |
| Twin Lakes | 811 | 3 | 1 | 1 | 5 | Low |
| Snow Camp | 773 | 1 | 3 | 0 | 4 | Very Low |
| Christmas Prairie | 455 | 1 | 1 | 1 | 3 | Very Low |
| Debris Torrent | 129 | 1 | 1 | 1 | 3 | Very Low |
| High Prairie | 3,476 | 1 | 1 | 1 | 3 | Very Low |
| Joplin | 441 | 1 | 1 | 1 | 3 | Very Low |
| June | 125 | 1 | 1 | 1 | 3 | Very Low |
| Marquette | 492 | 1 | 1 | 1 | 3 | Very Low |
| Six Rivers | 741 | 1 | 1 | 1 | 3 | Very Low |
| Stover | 544 | 1 | 1 | 1 | 3 | Very Low |
| Timbo | 229 | 1 | 1 | 1 | 3 | Very Low |
| Burley | 255 | 1 | 1 | 0 | 2 | Very Low |
| Cashmere | 861 | 1 | 0 | 1 | 2 | Very Low |
| Cool Springs | 737 | 1 | 1 | 0 | 2 | Very Low |
| Fern Prairie | 509 | 1 | 1 | 0 | 2 | Very Low |
| Headwaters_W | 179 | 1 | 1 | 0 | 2 | Very Low |
| Jena | 246 | 1 | 1 | 0 | 2 | Very Low |
| Santa Fe | 530 | 1 | 1 | 0 | 2 | Very Low |
| Smokehouse | 426 | 1 | 1 | 0 | 2 | Very Low |
| Tom | 259 | 1 | 1 | 0 | 2 | Very Low |
| Ayers | 242 | 1 | 0 | 0 | 1 | Very Low |

### *RESOURCE THREAT AND RESOURCE AT RISK*

This risk analysis uses the same methods used to describe resource threat, but now integrates anadromous salmonids in each sub-watershed as the *resource at risk*. Doing so adds a biological element to the previous analysis that prioritized sub-watershed treatment only in terms of the likelihood for and magnitude of potential erosion, or *resource threat*. In this analysis risk is defined as follows:

Risk = Resource Threat + Resource at Risk

*Resource Threat* was defined in the previous analysis. *Resource at Risk* considers the number of anadromous salmonid species observed in each sub-watershed. Salmonid distribution information for the Redwood Creek watershed is from documented stream surveys performed since 1965 and is shown in Figure H-1 (Appendix H).

The results from this analysis are shown in Figure 10 and Table 19. Lacks and Minor creeks are the highest priority for treatment because both have high sediment threats and support at least three salmonid species. The treatment priority for sub-watersheds such as Coyote, Panther and Pilchuck creeks moved from medium in the previous analysis to high, because they have moderately high sediment threats and support populations of at least two salmonid species. Other subwatersheds, such as Toss-up, Lupton and Wiregrass fell in treatment priority even though each supports one salmonid species. While High Prairie Creek supports two salmonid species, its treatment priority is relatively low because of its low sediment threat.

## CRITICAL CROSSINGS

Stream crossings are a significant sediment threat to aquatic and riparian habitats and water quality because there are so many crossings built throughout north coast watersheds. Crossings that can divert a stream from its natural watercourse are especially problematice, because of the magnitude of erosion that can occur if the stream diverts (see Watershed Improvement Plan). Stream crossings that are especially prone to diversion are those we refer to as 'critical' crossings. Critical crossings are those most likely to divert during a large storm because they have a diversion potential, undersized culvert and at least medium plug potential.

Considerable progress has been made in reducing the number of critical crossings in the upper watershed, but more work needs to be done. To identify areas where the concentration of critical crossings remains high, we performed a GIS spatial analysis that computed the density of critical crossings per square mile across all of the assessment areas. The results of this analysis are shown in Figure 11. The darkest colors represent 'hot spots', or the highest concentrations of critical crossings and areas of the highest risk.

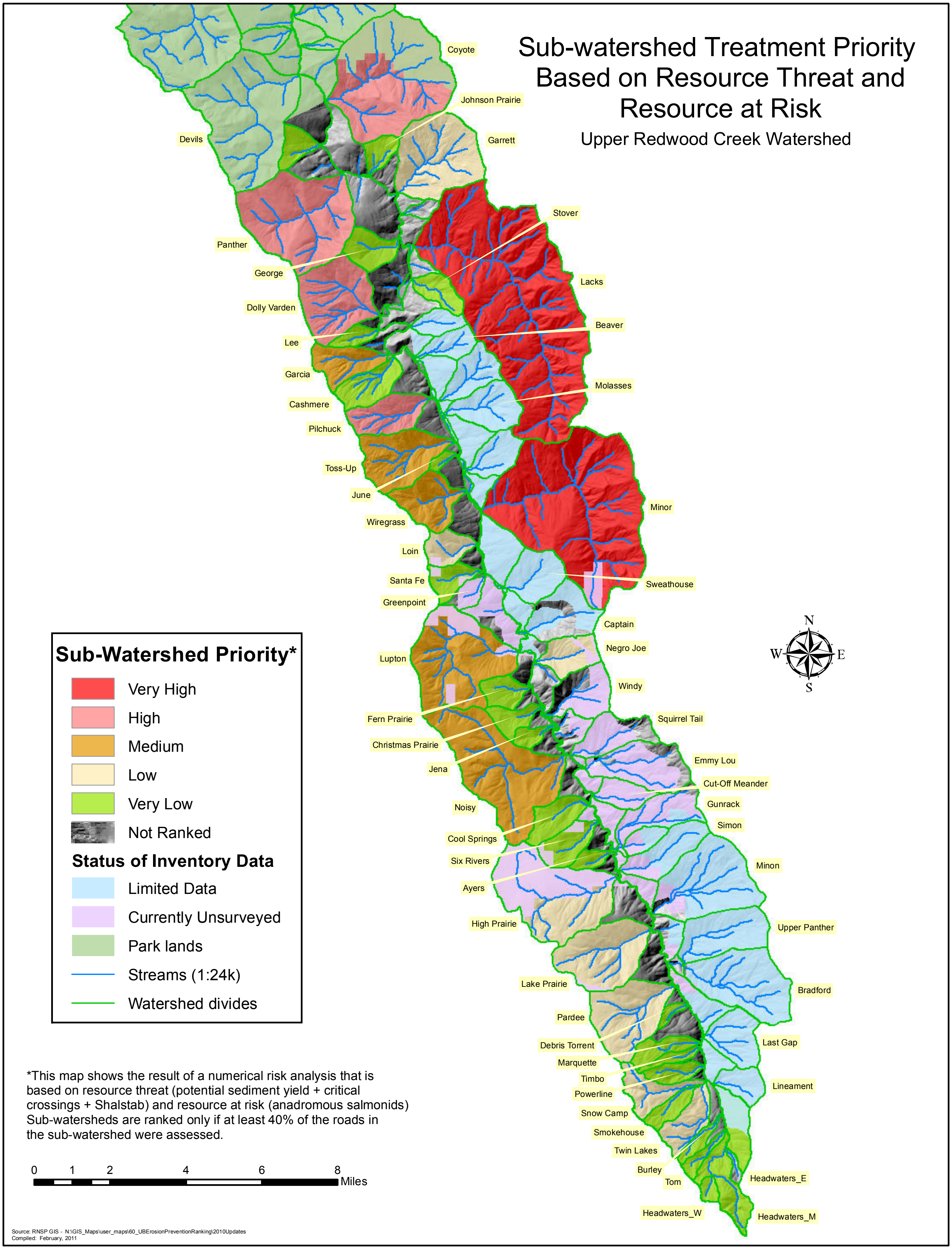


Figure 10. Sub-watershed ranking based on threat and resource at risk.

Table 19. Sub-watershed treatment priority based on resource threat and resource at risk.

| Sub-Watershed | Area (ac) | Fish (Resource at Risk) | | Scores | | Total Score | Sub-Watershed Priority |
|---|---|---|---|---|---|---|---|
| | | # of Species | Weighting Value | Resource Threat | Resource at Risk (3x weight) | | |
| Lacks | 10,977 | 4 | 9.00 | 27 | 27 | 54 | Very High |
| Minor | 8,248 | 3 | 6.75 | 27 | 20 | 47 | Very High |
| Coyote | 5,043 | 3 | 6.75 | 13 | 20 | 33 | High |
| Dolly Varden | 2,151 | 2 | 4.50 | 19 | 14 | 33 | High |
| Panther | 3,800 | 2 | 4.50 | 11 | 14 | 25 | High |
| Pilchuck | 1,086 | 2 | 4.50 | 11 | 14 | 25 | High |
| Toss-Up | 1,709 | 1 | 2.25 | 17 | 7 | 24 | Medium |
| Lupton | 3,329 | 1 | 2.25 | 15 | 7 | 22 | Medium |
| Wiregrass | 1,153 | 1 | 2.25 | 15 | 7 | 22 | Medium |
| Garcia | 905 | 1 | 2.25 | 11 | 7 | 18 | Medium |
| Noisy | 4,030 | 1 | 2.25 | 11 | 7 | 18 | Medium |
| High Prairie | 3,476 | 2 | 4.50 | 3 | 14 | 17 | Low |
| Garrett | 2,643 | 1 | 2.25 | 9 | 7 | 16 | Low |
| Pardee | 1,985 | 1 | 2.25 | 9 | 7 | 16 | Low |
| Lake Prairie | 2,144 | 1 | 2.25 | 7 | 7 | 14 | Low |
| Negro Joe | 806 | 0 | 0.00 | 13 | 0 | 13 | Low |
| Twin Lakes | 811 | 1 | 2.25 | 5 | 7 | 12 | Low |
| Loin | 601 | 1 | 2.25 | 5 | 7 | 12 | Low |
| Snow Camp | 773 | 1 | 2.25 | 4 | 7 | 11 | Low |
| Six Rivers | 741 | 1 | 2.25 | 3 | 7 | 10 | Very Low |
| Smokehouse | 426 | 1 | 2.25 | 2 | 7 | 9 | Very Low |
| Cashmere | 861 | 1 | 2.25 | 2 | 7 | 9 | Very Low |
| Santa Fe | 530 | 1 | 2.25 | 2 | 7 | 9 | Very Low |
| Jena | 246 | 1 | 2.25 | 2 | 7 | 9 | Very Low |
| Johnson Prairie | 386 | 0 | 0.00 | 6 | 0 | 6 | Very Low |
| Lee | 292 | 0 | 0.00 | 5 | 0 | 5 | Very Low |
| Headwaters_M | 1,688 | 0 | 0.00 | 5 | 0 | 5 | Very Low |
| George | 699 | 0 | 0.00 | 5 | 0 | 5 | Very Low |
| Powerline | 408 | 0 | 0.00 | 5 | 0 | 5 | Very Low |
| Joplin | 441 | 0 | 0.00 | 3 | 0 | 3 | Very Low |
| Christmas Prairie | 455 | 0 | 0.00 | 3 | 0 | 3 | Very Low |
| Debris Torrent | 129 | 0 | 0.00 | 3 | 0 | 3 | Very Low |
| Timbo | 229 | 0 | 0.00 | 3 | 0 | 3 | Very Low |
| June | 125 | 0 | 0.00 | 3 | 0 | 3 | Very Low |
| Marquette | 492 | 0 | 0.00 | 3 | 0 | 3 | Very Low |
| Stover | 544 | 0 | 0.00 | 3 | 0 | 3 | Very Low |
| Fern Prairie | 509 | 0 | 0.00 | 2 | 0 | 2 | Very Low |
| Headwaters_W | 179 | 0 | 0.00 | 2 | 0 | 2 | Very Low |
| Cool Springs | 737 | 0 | 0.00 | 2 | 0 | 2 | Very Low |
| Burley | 255 | 0 | 0.00 | 2 | 0 | 2 | Very Low |
| Tom | 259 | 0 | 0.00 | 2 | 0 | 2 | Very Low |
| Ayers | 242 | 0 | 0.00 | 1 | 0 | 1 | Very Low |

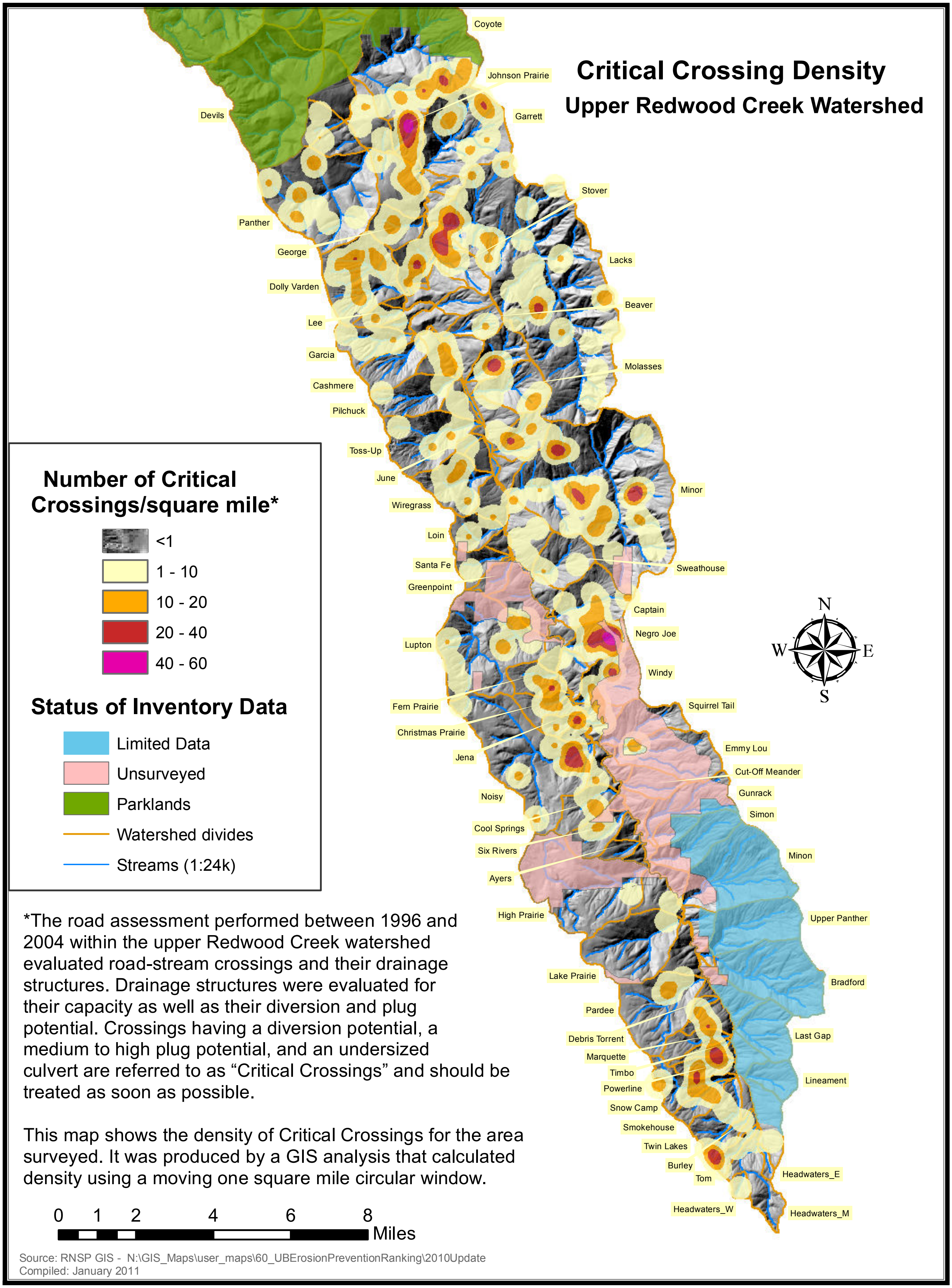


Figure 11. Critical crossing density.

Discussion

Several different analyses have been presented that prioritize erosion control and prevention treatments in the upper Redwood Creek watershed. Each analysis works at a different scale, and has its strengths and weaknesses.

The first analysis established a treatment priority for individual roads and sub-watersheds using database queries. Roads were prioritized based on: 1) total potential sediment yield for the untreated road reach; 2) total potential sediment yield per mile of road, and; 3) treatment cost-effectiveness. Sub-watersheds were prioritized by total potential sediment yield per mile of road. These simple analyses characterize each road and sub-watershed by potential sediment yield and cost-effectiveness, and are based on simple databases queries. Analysis results are most useful when all roads are controlled by a single landowner. Its utility diminishes when roads cross multiple ownership or sub-watershed boundaries, because the analysis lacks a spatial reference.

The second analysis established a treatment priority for areas of high potential sediment yield density or "hot spots" using a GIS spatial analysis. The analysis is blind to sub-watershed boundaries. Its ability to highlight discrete areas containing a potentially high cumulative potential sediment yield is its greatest strength. The spatial reference provided in this analysis is well suited to establishing treatment priorities at all planning scales. A disadvantage to this method is that it does not consider what percentage of an area has been evaluated. Thus, the analysis can miss areas of high potential sediment yield density if adjacent areas have not been fully evaluated and included in the analysis.

The third analysis established a treatment priority for sub-watersheds by performing two separate risk analyses. The first analysis was based only on resource threat (the likelihood for and the magnitude of potential erosion), and the second integrated the resource at risk (anadromous salmonids) into the analysis. Depicting the risk to salmonid populations at a watershed scale is perhaps the greatest strength of this analysis that integrates specific site information such as potential sediment yield and critical crossings, with watershed attributes such as hillslope stability (Shalstab) and salmonids. A disadvantage to this method is that it is based on sub-watershed boundaries and, therefore, does not evaluate interfluves between sub-watersheds. Interfluves tend to have the highest road densities (Table A-1) and they deliver sediment directly to Redwood Creek. We also believe DEMs used to run the Shalstab model tend to underestimate steepness, especially in the confined streamside areas. Underestimating steepness in these areas could reduce the predicted resource threat at individual sites and the sub-watershed ranking.

The risk analysis is also sensitive to how much of a sub-watershed has been assessed. A sub-watershed is considered in the analysis only if at least 40 percent of the road length in the sub-watershed had been evaluated. Therefore, the percentage of roads and/or the number of sites evaluated in each sub-watershed must be considered when reviewing the analysis results.

The final analysis identified areas that contain high concentrations of critical crossings. The analysis is blind to ownership and sub-watershed boundaries, and is well suited to planning efforts at all landscape scales. However, the completeness of road assessments in neighboring areas must be considered when reviewing results.

The ‘best’ prioritization method would probably use a combination of the analyses presented in this report, and would depend on the scale and objectives of the planning effort. For example, a smaller landowner willing to implement an erosion control project might use database queries in combination with the spatial analysis to prioritize work on their land. If the protection of sub-watersheds that supports the greatest number of salmonid species is the objective, then the numeric risk analysis that integrates salmonid information would be appropriate in combination with the database query that considers treatment cost-effectiveness. The spatial analysis could also help pinpoint priority areas within the sub-watershed.

Our preference for prioritizing areas for treatment would consider the importance of limiting sedimentation in the main channel of Redwood Creek, because of its importance to fisheries and the threat sediment poses to the downstream park resources. Outside of the Prairie Creek sub-watershed, the main channel of Redwood Creek represents about 70 percent of all accessible anadromous salmonid habitat in the Redwood Creek watershed (California Resources Agency, 2002), and severe aggradation of the main channel, as experienced during past large storms, would threaten the riparian areas in the park, including the alluvial old-growth groves. Thus, a watershed-wide planning effort that sets sediment reduction to the main channel of Redwood Creek as its primary objective could use the numeric risk analysis based on resource threat in combination with the analysis that identifies the “hot spots” throughout the entire watershed.

# WATERSHED IMPROVEMENT PLAN

We offer the following suggestions for land management practices that can protect aquatic and riparian habitats and move the watershed closer to recovery and meeting the objectives of the Redwood Creek TMDL.

1. Continue Erosion Control and Prevention Efforts in the Upper Watershed
Significant progress has been made in treating potential erosion sites and meeting identified hillslope targets in the TMDL. However, it’s imperative this work continues in the upper watershed, where only 19 percent of the estimated controllable sediment load has been treated. Sediment load reduction should occur throughout the watershed, especially in areas identified as high priority for treatment in this report. Medium to high urgency sites identified in the road assessments should be treated at the earliest possible date. Redwood National and State Parks is willing to help develop projects and facilitate project implementation. The park looks forward to working with private landowners, non-profit organizations and other government agencies to seek funds and help implement erosion-control and prevention work.

2. Treat Stream Crossings that have Diversion Potential
Erosion caused by stream diversions during large storms can be significant and is preventable, and the prevention of diversions is perhaps the most cost-effective erosion control treatment. Diversion potentials at stream crossings should be treated, independent of other established treatment priorities.

Based on our observations in the Redwood Creek watershed, stream diversions can cause severe gully erosion that often leads to significant landslide erosion. Studies performed in the Redwood Creek watershed have shown that: 1) stream diversions can account for a significant portion of a sediment budget during large storms; 2) the erosion volume from diversions can far exceed the volume contained in the crossings from which the streams diverted, and; 3) stream diversions are preventable (Weaver and Hagans, 1987; Best and others, 1995).

Of the approximately 2,540 stream crossings originally evaluated by PCFWWRA and RNSP, nearly 1,590 crossings (63%) had a diversion potential and 464 crossings (18% of all crossings) were critical crossings. Upgrade and decommission projects have treated 336 (21%) of the assessed potential diversion crossings, and 110 (24%) of the assessed critical crossings. Crossings with diversion potential (especially critical crossings) in the upper watershed should receive the highest treatment priority.

Diversion prevention efforts should rely on permanently installed critical dips as defined by Weaver and Hagans (1994). Waterbars are insufficient and are not a substitute for permanent, well-constructed critical dips. If the crossing is the low point of the road and acts as a critical dip, the surface of the road should be insloped towards the culvert inlet to prevent surface runoff from reaching the downstream fillslope that would erode. The outflows of critical dips should be rock armored, especially if the critical dip is centered over the crossing and it drains to the downstream side of the crossing fill.

3. Decrease Road Density
The road density in the upper watershed is too high and should be reduced. The average road density for the entire watershed is about 4.8 miles per square mile. However, roads are not distributed evenly throughout the watershed. In the lower watershed, mostly park lands, road density is about 2.4 miles/square mile while in the upper watershed, mostly private lands, road density is about 6.4 miles/square mile. Road density has been reduced in the upper watershed since cooperative projects have decommissioned roads, but the fact that road density approximates the density of *all* streams (7.5 miles/square mile) in the watershed suggests it is still too high. New roads needed for timber harvest should be built as temporary roads. Roads not needed for a decade or more should be either permanently or temporarily decommissioned. A road density of about 5.0 miles per square mile in any sub-watershed would be a reasonable initial goal. With fewer roads, long-term sediment delivery to Redwood Creek and its tributaries, and maintenance needs and costs would be reduced.

4. Provide Long-Term Road Maintenance
Based upon road assessments and completed work, about 55 percent of the assessed roads in Redwood Creek are being maintained (or are maintenance-free because they have been

decommissioned). In 2004, we reported that about 32 percent of all roads assessed were being maintained (Bundros et al., 2004), so this is a significant improvement. Road inspection and maintenance will be critical for watershed recovery because the potential sediment impacts associated with roads will exist as long as roads remain on the landscape. We encourage landowners to voluntarily adopt measures similar to those found in Green Diamond Resource Company's Aquatic Habitat Conservation Plan (GDRCo, 2006) that contains explicit standards for road inspections and maintenance. Roads should be maintained into perpetuity or they should be permanently or temporarily decommissioned.

5. Improve Stream Crossing Construction Standards
Based on original assessment data, we estimated there were about 5,000 stream crossings in the entire upper Redwood Creek watershed prior to treatments (Bundros et al., 2004). While about 540 crossings have either been subsequently upgraded or decommissioned, there are still a significant number of stream crossings in the upper watershed. Stream crossing design and construction standards should reflect this threat to salmonids and water quality and follow guidelines described by Cafferata and others (2004).

When crossings are reconstructed, sediment accumulated upstream of the crossing should be excavated from the channel before a new culvert is installed. This allows a culvert to be installed deeper and the crossing to be built with a minimum amount of fill. Placing the culvert deeper in the fill will ensure it more closely conforms with the original stream channel grade, which will allow sediment and debris to be transported through the culvert instead of being deposited at the culvert inlet which can plug the culvert and cause failure.

Whether new or reconstructed, crossing fill should be thoroughly compacted by appropriate equipment (not crawler tractors), especially along the outer edge of the fill prism and around the newly placed culvert. Rock armor on the downstream fillslope of the crossing is not a substitute for proper compaction, but it is recommended to more fully protect the crossing if the culvert were to plug or otherwise fail.

6. Avoid Throughcut Road Construction
Throughcut road construction should be avoided because such roads are impossible to drain properly. This is especially important for roads that lead to landings where concentrated surface runoff can saturate the outer landing edge and cause landing failure, or to stream crossings where throughcut road construction would make it difficult to hydrologically disconnect road runoff from the crossing.

7. Drainage, Drainage, Drainage
Road surface drainage is an integral part of all road systems. When properly configured by ditch relief culverts, outsloped road surfaces and/or rolling dips, road surface drainage distributes surface runoff evenly along a road, and prevents concentrated runoff that leads to sheet, rill and gully erosion. Reducing the amount of road and inboard ditch that drains directly into streams reduces sediment delivery to streams. Where inboard ditches are needed and must be improved along existing roads, the ditches can be excavated into the inside edge of the road so that cutbanks are not disturbed. Many roads are wider than needed. By excavating ditch lines into the road as

opposed to the cutbank, cutbank failures can be prevented, and road widths and maintenance costs can be reduced.

8. Account for Highway 299 When Installing Culverts Downslope of the Highway
When sizing culverts it is important to consider the effects state Highway 299 has on the routing of surface water. Standard culvert sizing methods that ignore the effects of the highway will either overestimate or underestimate the drainage area, storm discharge and culvert diameter needed at crossings located below the highway. There are about 11 miles of state Highway 299 in the Redwood Creek watershed.

Hydrologic effects from state Highway 299 are likely to be more pronounced when it crosses middle hillslope positions, where drainage density tends to be high and stream channels are not fully formed. Highway culverts are not always installed for the smallest streams, so streamflow can be diverted by inboard ditches and storm drains to a neighboring drainage. The highway surface also can collect a vast amount of surface runoff that can be discharged onto previously unchanneled hillslope areas. These effects could result in increased channel erosion, because of the flashiness and quantity of runoff, especially when rapid snow melt occurs. Therefore, the surface drainage patterns and the placement of drainage structures along state Highway 299 should be considered when sizing culverts in areas downslope of the highway. Table 20 shows how the length of state Highway 299 is distributed through different sub-watersheds and interfluves.

Table 20. Sub-watersheds and interfluves affected by state Highway 299.
(listings are in an easterly direction along the highway route.)

| Watershed/Interfluve | State Highway 299 | |
|---|---|---|
| | Miles in Watershed (mi) | Density in Watershed ($mi/mi^2$) |
| Santa Fe Creek | 0.7 | 0.9 |
| Greenpoint Creek | 0.7 | 1.4 |
| Greenpoint-Lupton | 1.5 | 1.2 |
| Lupton Creek | 1.0 | 0.2 |
| Lupton-Fern Prairie | 0.5 | 1.3 |
| Negro Joe-Windy | 0.1 | 0.2 |
| Negro Joe Creek | 1.2 | 0.9 |
| Captain Creek | 3.8 | 1.8 |
| Sweathouse-Captain | 0.2 | 0.4 |
| Sweathouse Creek | 0.2 | 0.1 |
| Windy Creek | 0.6 | 0.4 |

9. Restore Riparian Function along Redwood Creek
Riparian conditions along Redwood Creek must improve before large woody debris can once again occupy the main channel of Redwood Creek in sufficient quantities needed for nutrient cycling, channel complexity, pool forming elements, shelter, and over-winter habitat for anadromous salmonids. Once dominated by coniferous forests that provided shade and a source of large woody

debris, today an estimated 60 percent of the riparian corridor along Redwood Creek is dominated mostly by hardwood forests. Outside of the Prairie Creek sub-watershed, the main channel of Redwood Creek represents about 70 percent of all accessible anadromous salmonid habitat in the Redwood Creek watershed (California Resources Agency, 2002).

Riparian restoration opportunities exist through conifer planting and/or release, especially where conifers are already established below hardwood canopies. The greatest restoration opportunities likely exist in the reaches upstream of Highway 299 where the active channel is commonly less than 100 feet wide, well within the growth potential of Douglas-fir that could provide channel spanning structure. Douglas-fir, and in some cases Redwood, are growing below a hardwood canopy along an estimated 12 river miles (20 percent) of the riparian corridor (Bundros et al., 2003).

Conservation easements along the riparian corridor that include steep streamside slopes should also be considered, especially in the inner gorge areas upstream of state Highway 299. Obtained from willing landowners, riparian and inner gorge areas placed into conservation easements would ensure the long-term recruitment of large conifers to the main channel of Redwood Creek. Finally, we are encouraged by improved forest practices that are retaining greater numbers of conifers along streams for large woody debris recruitment and stream water temperature control, and on steep streamside areas where streamside landslides are an important recruitment mechanism for large woody debris.

# CONCLUSIONS

Partnerships have formed around the common objective of improving watershed conditions in Redwood Creek. This includes the formation of the Redwood Creek Watershed Group whose members represent about 90 percent of the ownership and/or management of land in the watershed (RCWG, 2006). These partnerships have spawned collaborative efforts that will ultimately improve and maintain salmonid habitat and water quality in Redwood Creek, and protect the downstream public trust resources in Redwood National and State Parks.

There are about 1,040 miles of road in the upper Redwood Creek watershed. Of those, about 910 miles (87 percent) are on private lands and used for forest and ranch management. Road assessments that have identified treatments and estimated costs have been completed on 463 miles roads. The estimated cost to treat these roads was reported by Bundros and Short (2009) and averaged about $64,600 per mile. Extending unit costs to all roads (not state or county owned), the estimated total cost to treat all remaining logging and ranch roads in the upper watershed is about $44 million.

In the upper watershed, erosion control and prevention work has been performed through cooperative efforts, individual landowner projects and through road work associated with timber harvest plans. Since efforts to prevent erosion from logging roads started in the mid-1990s, 61 miles of roads have been decommissioned and 120 miles of roads have been upgraded. About 294 stream crossings were upgraded with new and properly sized culverts or bridges, nearly 300 stream crossings were decommissioned, and 275 potentially unstable road reaches and/or landings were treated. The total sediment savings from this work was 531,000 $yds^3$ or about 30 percent of the total potential sediment yield from assessed roads in the upper watershed. About $880,000 has been spent on completing road assessments and about $5.8 million on project implementation.

Based on the average potential sediment yield of 2,600 $yds^3$/mile of road on remaining assessed roads we estimate that about 2,340,000 $yds^3$ of potential sediment yield associated with logging and ranch roads remains in the upper watershed. It represents about seven times the long-term annual sediment load of Redwood Creek. Of this total, about 60 percent is associated with fluvial sites such as stream crossings, and about 40 percent is associated with unstable road reaches and landings.

We believe the values for total potential sediment yield are conservative and represent a minimum value. Extreme erosion potential is difficult to estimate, and we know that road assessments do not capture the full risk of stream diversions, landslides or debris torrents originating at roads. Also, we have observed offsite landsliding along confined stream channels caused by the rapid filling of landslide deposits. Potential sediment yield associated with such events is not included in yield estimates when sites are evaluated because doing so would be highly speculative.

The values for total potential sediment yield and sediment saved through erosion control and prevention efforts also do not include estimates for the amount of erosion that occurs from a road's surface or inboard ditch. We know erosion from these surfaces occurs, but the rate of erosion is variable, influenced by such things as road design, the underlying materials of the road, whether or not the road is watered during use, the amount of use, etc. Thus, we chose to ignore volume estimates for surface erosion because of the uncertainties.

The erosion control and prevention work completed in the lower and upper watersheds has made significant progress toward meeting the goals of the Redwood Creek TMDL. Completed work has reduced potential sediment loading by about 36 percent of the TMDL's required 60 percent load reduction. However, 71 percent of the total reduction occurred in the lower watershed, on park lands, compared to a 29 percent reduction in the upper watershed. While both represent significant reductions, more work is needed in the upper watershed to more fully distribute load reduction throughout the watershed. Moreover, seven percent of the load reduction in the upper watershed resulted from upgrading roads. Upgraded roads are not maintenance-free, so they must be maintained over the long-term to fully realize the benefits from the investments that reduced the potential for future road failures.

The trend of the 10-year rolling average annual sediment load for Redwood Creek has been encouraging. During periods of low to moderate flows, the 10-year rolling average fell below the 1,900 tons/square miles/year TMDL target two times and it currently remains below the target. This trend clearly shows the target is attainable, but whether or not it can be sustained over the long-term is the question. The effects from the relatively moderate 1996 and 1997 storms are reminders that widespread erosion from roads will continue to occur during stressing events until the road network throughout the watershed is properly treated. Because of improved land management practices and watershed-wide efforts to prevent erosion, the watershed is recovering from the extreme erosional events in the 1960s and 1970s. However, the objective of the TMDL will not be met without additional work and a commitment to long-term road maintenance. More roads, especially in sensitive geomorphic settings, need to be decommissioned and others need to be upgraded and/or maintained for the 10-year rolling average annual sediment load to remain sustainably below the TMDL target through large storms.

Forest and ranch roads are a conundrum. They are needed for land management, but the high density of roads constructed throughout the upper Redwood Creek watershed is a huge cumulative watershed impact that is largely ignored. While forest road construction standards have improved over the past years, there is still no mechanism for long-term road maintenance. Without a commitment to long-term road maintenance, we will always be addressing "legacy" effects from past forest rotations. We encourage landowners to voluntarily adopt measures similar to those found in Green Diamond Resource Company's Aquatic Habitat Conservation Plan (GDRCo, 2006) that contains explicit standards for road inspections and maintenance. Roads should be maintained into perpetuity or they should be permanently or temporarily decommissioned.

Preventing erosion from logging roads, regardless of location, is important as all sediment is transported to the mainstem of Redwood Creek. Outside of the Prairie Creek tributary located in the lowermost portion of the watershed, the main channel of Redwood Creek represents about 70 percent of all accessible anadromous salmonid habitat in the Redwood Creek watershed (California Resources Agency, 2002). The need to protect the main channel of Redwood Creek is further supported by the presence of the public trust resources found in Redwood National and State Parks, a UNESCO designated World Heritage Site located in the lower watershed. Erosion and sedimentation occurring upstream of the park can significantly impact the parks' resources.

The different spatial and database analyses of road assessment data presented in this report consistently point to several sub-watersheds that should be considered high priority for treatment. Eastside tributaries include Coyote, Lacks and Minor creeks, and portions of Negro Joe Creek. Westside tributaries include Dolly Varden, Garcia, Lupton, Noisy, Panther, Pilchuck, Toss-Up and Wiregrass creeks, and the lower portions of Ayers, Cashmere, Marquette, Powerline and Timbo creeks. Based on the currently available road assessment data, the limited funds available for erosion control and prevention work would be best spent in these areas.

Regardless of how erosion control and prevention treatments are prioritized in the Redwood Creek watershed, it is important to remember that ground conditions change, some landowners are more able and willing to implement erosion control and prevention work than others, and logistics can complicate 'priorities'. The most effective erosion control and prevention strategy for the Redwood Creek watershed should be flexible, and recognize the challenging nature of implementing projects across a large landscape with multiple owners. Erosion prevention efforts should also recognize the importance of the main channel of Redwood Creek to salmonids and the importance of protecting the public trust resources in the national park located at the downstream end of the watershed.

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# GLOSSARY

**Culvert -** a metal, plastic or concrete pipe set below the road surface. Is used to pass streamflow from upslope of the road to downslope of the road. Culverts can also be placed to drain springs and inboard ditch flow from the inside to the outside of the road, beyond the outer edge of the road fill, or fillslope.

**Class I watercourse crossing** – a fish bearing stream as defined by the California Forest Practice Rules.

**Cost-effectiveness –** the cost per unit volume of sediment to prevent it from entering a stream, commonly expressed as $/yd$^3$ "saved".

**Critical crossing –** a haul road crossing at a stream channel that possesses all three of the following characteristics: a diversion potential, an undersized culvert and medium to high plug potential.

**Critical dip** – a broad rolling dip located at a stream crossing that returns streamflow to its natural watercourse if the crossing culvert plugs and streamflow overtops the road. It is a broad, gentle, permanent dip (low spot) across the road surface that allows passage of vehicles, logging trucks and standard logging equipment. They are generally maintenance-free.

**Cross-road drain** - a deep, abrupt ditch constructed across a road to drain water from the road surface and/or inboard ditch. Generally, not drivable and placed at frequent intervals (approx. every 50 - 100 feet) on permanently closed roads. Compare to *rolling dip.*

**Delivery** – the percentage of erosion volume that is actually delivered to a stream. It is used to calculate *yield*. Stream crossings usually have a 100 percent delivery. For landslides the percent delivery can be between 0 and 100 percent. Some landslides fail and deliver to a hillslope or terrace bench with no delivery to streams (0%). Many landslides deliver 100 percent directly to stream channels.

**Diversion** – a condition originating at a stream crossing, where stream flow overtops the road and flows down a road, inboard ditch, or skid trail instead of re-entering its natural watercourse. Stream diversions can cause significant gully and landslide erosion.

**Diversion potential** – normally associated with stream crossings that have continuous road grades through the crossing which allow a stream to flow down a road if the crossing culvert plugs and streamflow overtops the road. The crossing is not the low point of the road as the road passes over the stream channel. Existing diversion potentials can be corrected by installing well-constructed critical dips at the crossing so that streamflow returns immediately to its stream channel if diversion occurs. Proper crossing construction (grade-breaks, critical dips, minimum fill, properly sized culverts) can prevent diversions.

**Decommission** – the process of removing road fill or reshaping a road such that erosion and sedimentation are minimized. A decommissioned road has all culverts removed, all road fill at stream crossings fully excavated and permanent, self-maintaining road surface drainage provided by a combination of outsloping, rolling dips or cross road drains. A road may be permanently or temporarily decommissioned.

**Ditch relief culvert (DRC)** – a drainage structure that intercepts and conveys water from the inside edge of the road to the outside edge of the road.

**Downspout** – normally culvert material bolted and secured to the culvert outlet that conveys water down a fillslope to undisturbed ground to prevent surface erosion. Downspouts may be either full-round or half-round.

**Erosion potential (EP)** – the subjective and relative ranking of the likelihood, not magnitude, of erosion at a site during the next major storm. Expressed as "high", "medium" or "low."

**Erosion volume** – is the amount of material that could eroded from a site. It is expressed in cubic yards and 0-100 percent may reach a stream. Is used with *delivery* to calculate *yield*.

**Extreme erosion potential (EEP)** – A subjective assessment of the capability of a potential erosion site to erode significantly more volume than the estimated potential erosion volume. Expressed as "yes" or "no." It characterizes a worst case scenario that identifies the potential for an unusually large magnitude failure. An example would be a stream diversion that could obliterate inboard ditches, relief pipes, and other crossings during a major storm, or a stream crossing or landing that could fail catastrophically, scouring hillslopes or channels below.

**Extreme potential yield** – The volume of sediment that would be delivered to a stream by a site failing under the extreme erosion potential scenario. Expressed in cubic yards.

**Fluvial erosion –** erosion caused by flowing water. Includes erosion at stream channels, gullies and rills. Compare to landslide erosion, which does not include erosion by flowing water.

**Ford –** a stream crossing that requires a vehicle to drive across and through a stream channel bed. There is no fill or drainage structure in a ford crossing.

**Inboard ditch** – a ditch along the inside edge of the road that collects and conveys road surface runoff and spring discharge. The ditch usually conveys runoff to the next culvert or drainage structure down the road.

**Landing –** a location where logs are collected and loaded onto trucks for transport. Landings are typically located along haul roads.

**Landslide erosion** – erosion associated with mass movement of soil or hillslope. Types of landslides are debris slides, torrents, earthflows, slumps, rock falls and others. Compare to fluvial erosion, which is erosion by flowing water.

**Maintained road** – a road that shows evidence of recent maintenance, including cleaning of culvert inlets, trash racks, and inboard ditches, grading, rolling dip or waterbar reconstruction, brushing, culvert replacement, or reconstruction of fills. Compare to *unmaintained road*.

**Outslope** – a road surface that is shaped to slant toward the outside (downslope side) edge of a road. The slanted surface naturally disperses surface runoff. A road that is outsloped may or may not be drivable depending on the intent of treatment. Outsloped road may or may not have an inboard ditch.

**Outsloping** – the act of changing a flat or insloped road to an outsloped road. For erosion control treatments, substantial fill is removed from the outer edge of the road prism, and spread and shaped along the inside edge of the road, typically against the cutbank. For surface drainage on active roads, the road surface has a mild outslope that is drivable by logging trucks and forms a relatively maintenance-free road surface that disperses road surface runoff.

**Potential sediment yield –** the larger of the *site potential yield* and the *extreme potential yield* (if one exists) for a site. Expressed in cubic yards.

**Road upgrade** – improving a road to current road building standards with the intent of reducing erosion from roads. Upgrading includes; replacing rusted, plugged and undersized culverts, reshaping roads for proper drainage, constructing critical dips at crossings to prevent stream diversions, pulling back steeply perched road or landing fill that can enter a stream, reducing road fill volumes at stream crossings and others.

**Rolling dip -** a broad, shallow, gentle dip (low point) in the road surface that collects road surface runoff and conveys it to the outer edge of the road. It can also drain an inboard ditch.

**Site potential yield -** the expected volume of material that would be delivered to a stream from a single erosion site expressed in cubic yards. It is computed by multiplying the *erosion volume* at a site by the percentage *delivery* to the stream (e.g. 800 $yds^3$ erosion volume x 80% delivery = 640 $yds^3$ site potential yield). Compare to *extreme potential yield* and *potential sediment yield*.

**Skid trail crossing -** a point where a tractor skid trail crosses a defined stream channel. A drainage structure may or may not be present.

**Stream crossing** – the point where a road crosses a defined stream channel. The crossing may be composed of road fill without a drainage structure or may be composed of buried logs (Humboldt crossing), a culvert, a ford, or a bridge.

**Stream diversion -** a condition where streamflow has been diverted from its natural watercourse.

**Unmaintained road** – a road that lacks obvious maintenance to culverts, ditches and road surface. Culverts may be partially or completely plugged, badly rusted or crushed, outlet flow uncontrolled across fillslope or other deficiencies present. Ditches may lack cleaning and vegetation may be encroaching the road and road surface. The road may or may not be drivable.

**Upgrade** – improving a road to current road building standards with the intent of reducing erosion from roads. Upgrading includes; replacing rusted, plugged and undersized culverts, reshaping roads for proper drainage, constructing critical dips at crossings to prevent stream diversions, pulling back steeply perched road or landing fill that can enter a stream, reducing road fill volumes at stream crossings and others.

**Urgency or treatment urgency** – a subjective and relative assessment of the need to treat a site to prevent erosion. Identified as low, medium or high. A low urgency site typically would survive an average winter storm with little threat of experiencing or causing erosion. A medium urgency site may experience erosion during an average winter if left untreated. A high urgency site would likely erode or cause erosion during an average winter if left untreated.

**Waterbar** – a shallow ditch or berm constructed across a road or skid trail that drains the road surface and/or inboard ditch. It is not a permanent structure as they tend to break down with any type of use, including wildlife tramping. They are insufficient to prevent stream diversions at crossings.

**Yield –** the amount of sediment that reaches a stream channel. It is express in cubic yards and may be 1-100 percent of the *erosion volume*.

# APPENDIX A

## AVERAGE ROAD DENSITY BY SUB-WATERSHED AND INTERFLUVE

Table A1. Average road density by sub-watershed and interfluve.

Table A1. Average road density by sub-watershed and interfluve.

| Westside Tributaries | | | | Eastside Tributaries | | | |
|---|---|---|---|---|---|---|---|
| Tributary/Interfluve Name* | Area sq mi | Total Road Miles | Road Density, mi/mi$^2$ | Tributary/Interfluve Name* | Area, sq mi | Total Road Miles | Road Density, mi/mi$^2$ |
| DC-JC | 1.2 | 0.8 | 0.7 | Coyote | 7.9 | 16.5 | 2.1 |
| Joplin | 0.7 | 3.7 | 5.4 | CC-JPC | 1.2 | 6.9 | 5.6 |
| JC-PC | 0.8 | 2.3 | 3.0 | Johnson Prairie | 0.6 | 2.2 | 3.6 |
| Panther | 5.9 | 30.7 | 5.2 | JPC-GC | 0.4 | 2.5 | 6.3 |
| PC-GC | 1.7 | 11.1 | 6.6 | Garrett | 4.1 | 21.1 | 5.1 |
| George | 1.1 | 6.4 | 5.8 | GC-MFC | 0.2 | 1.0 | 5.2 |
| GC-DVC | 1.1 | 7.6 | 6.8 | Monroe Flat | 0.3 | 1.8 | 6.0 |
| Dolly Varden | 3.4 | 23.5 | 7.0 | MFC-LC | 0.4 | 2.4 | 6.0 |
| DVC-LC | 0.1 | 0.1 | 1.1 | Lacks | 17.2 | 82.5 | 4.8 |
| Lee | 0.5 | 3.1 | 6.7 | LC-SC | 0.3 | 2.5 | 8.1 |
| LC-GC | 0.4 | 1.5 | 3.9 | Stover | 0.9 | 4.8 | 5.7 |
| Garcia | 1.4 | 10.1 | 7.1 | SC-RGC | 0.8 | 7.0 | 8.8 |
| Cashmere | 1.3 | 9.3 | 6.9 | Roaring Gulch | 0.7 | 4.9 | 7.0 |
| CC-PC | 0.8 | 3.3 | 4.4 | RGC-BC | 0.6 | 4.7 | 8.2 |
| Pilchuck | 1.7 | 8.8 | 5.2 | Beaver | 0.9 | 4.8 | 5.6 |
| PC-TUC | 0.6 | 3.6 | 6.3 | BC-MC | 0.7 | 5.2 | 7.8 |
| Toss-Up | 2.7 | 15.7 | 5.9 | Mill | 1.3 | 7.6 | 5.7 |
| TUC-JC | 0.1 | 0.4 | 5.2 | MC-MSC | 0.1 | 1.1 | 13.9 |
| June | 0.2 | 0.9 | 4.8 | Molasses | 1.7 | 12.0 | 6.9 |
| JC-WC | 0.4 | 2.1 | 5.4 | MSC-MNC | 0.8 | 5.1 | 6.4 |
| Wiregrass | 1.8 | 9.5 | 5.3 | Moon | 1.2 | 6.7 | 5.8 |
| WC-LC | 0.7 | 4.8 | 6.6 | MNC-MRC | 0.4 | 4.0 | 10.1 |
| Loin | 0.9 | 5.0 | 5.3 | Minor | 12.9 | 84.6 | 6.6 |
| LC-SFC | 0.3 | 1.8 | 7.0 | MRC-SC | 1.3 | 7.8 | 5.9 |
| Santa Fe | 0.8 | 8.7 | 10.5 | Sweathouse | 1.6 | 9.0 | 5.6 |
| Greenpoint | 0.5 | 5.0 | 9.6 | SC-CC | 0.5 | 3.3 | 6.7 |
| GC-LC | 1.3 | 16.8 | 13.1 | Captain | 2.1 | 25.0 | 12.1 |
| Lupton | 5.2 | 41.1 | 7.9 | CC-NJC | 0.3 | 4.5 | 16.5 |
| LC-FPC | 0.4 | 3.5 | 9.5 | Negro Joe | 1.3 | 9.5 | 7.6 |
| Fern Prairie | 0.8 | 6.5 | 8.2 | NJC-WC | 0.6 | 5.3 | 8.5 |
| FPC-CPC | 0.2 | 1.1 | 5.6 | Windy | 1.7 | 14.2 | 8.1 |
| Christmas Prairie | 0.7 | 6.9 | 9.8 | WC-STC | 0.7 | 8.3 | 11.6 |
| CPC-JC | 0.2 | 1.5 | 8.2 | Squirrel Tail | 1.6 | 10.3 | 6.5 |
| Jena | 0.4 | 4.1 | 10.7 | Emmy Lou | 2.6 | 18.9 | 7.3 |
| JC-NC | 0.3 | 2.9 | 8.4 | ELC-COMC | 0.3 | 2.8 | 9.9 |
| Noisy | 6.3 | 46.8 | 7.4 | Cut-Off Meander | 0.9 | 5.1 | 5.7 |
| NC-CPC | 0.5 | 3.0 | 6.0 | COMC-GC | 0.5 | 5.4 | 10.2 |
| Cool Springs | 1.2 | 9.5 | 8.3 | Gunrack | 1.8 | 12.3 | 6.9 |
| CPC-SRC | 0.2 | 0.1 | 0.9 | GC-SC | 0.1 | 0.3 | 3.0 |
| Six Rivers | 1.2 | 9.2 | 8.0 | SF Gunrack | 0.6 | 1.4 | 2.5 |
| SRC-AC | 0.3 | 1.7 | 5.8 | Simon | 1.7 | 5.9 | 3.4 |
| Ayers | 0.4 | 3.6 | 9.5 | SC-MC | 0.4 | 1.3 | 2.9 |
| AC-HPC | 0.2 | 1.9 | 9.9 | Minon | 4.3 | 22.1 | 5.2 |
| High Prairie | 5.4 | 40.1 | 7.4 | MC-UPC | 0.6 | 3.8 | 6.0 |
| HPC-LPC | 0.9 | 8.7 | 9.8 | UPC-BC | 0.1 | 0.9 | 6.4 |
| Lake Prairie | 3.3 | 18.8 | 5.6 | Upper Panther | 2.5 | 11.2 | 4.5 |
| LPC-PC | 0.8 | 3.7 | 4.4 | Bradford | 3.7 | 19.3 | 5.2 |
| Pardee | 3.1 | 23.6 | 7.6 | BC-LGC | 0.9 | 2.6 | 2.9 |
| PC-DTC | 0.1 | 1.4 | 9.8 | Last Gap | 1.6 | 9.1 | 5.8 |
| Debris Torrent | 0.2 | 2.0 | 9.8 | LG-LC | 0.5 | 2.4 | 4.7 |
| DTC-MC | 0.7 | 5.8 | 8.4 | Lineament | 0.9 | 7.8 | 8.7 |
| Marquette | 0.8 | 6.7 | 8.7 | Headwaters_E | 0.2 | 1.3 | 7.2 |
| MC-TC | 0.0 | 0.0 | 0.9 | Headwaters_M | 2.6 | 15.1 | 5.7 |
| Timbo | 0.4 | 3.8 | 10.7 | | | | |
| TC-PC | 0.1 | 1.6 | 13.6 | Totals and Average East Side | 94 | 538 | 5.7 |
| Powerline | 0.6 | 4.3 | 6.8 | Redwood Creek | 2.6 | 4.3 | 1.7 |
| PC-SCC | 0.1 | 0.2 | 2.9 | | | | |
| Snow Camp | 1.2 | 8.2 | 6.8 | | | | |
| Smokehouse | 0.7 | 5.8 | 8.7 | | | | |
| Twin Lakes | 1.3 | 9.8 | 7.8 | | | | |
| TC-BC | 0.2 | 1.4 | 5.7 | | | | |
| Burley | 0.4 | 3.0 | 7.4 | | | | |
| BC-TC | 0.1 | 1.3 | 9.5 | | | | |
| Tom | 0.4 | 2.2 | 5.4 | | | | |
| Headwaters_W | 0.3 | 1.7 | 6.0 | | | | |
| Totals and Average West Side | 72 | 494 | 6.9 | Redwood Creek above RNSP | 162 | 1,036 | 6.4 |

- Interfluve names are comprised of an abbreviation for tributaries that are immediately adjacent to the interfluve.
- Totals may differ slightly from those shown in other tables due to rounding.
- Road density can be affected by the size of a tributary basin, its ownership, land use, and underlying geology. For example, the road density for Lacks Creek is 4.8 mi/mi$^2$ when averaged over the entire sub-basin. However, the road density on the west side of Lacks Creek is about 7 mi/mi$^2$, while the road density on the east side is about 4 mi/mi$^2$.

# APPENDIX B

## FIELD FORM USED BY PCFWWRA AND RNSP

Reviewed by : ___________________
ID No.: _________________________

# REDWOOD CREEK BASIN ROAD INVENTORY FORM
## Redwood National and State Parks
Version 3/27/03

Check ________
ASAP ________

## SECTION I: GENERAL SITE INFORMATION

Road Name:_____________________ Site # ________ Date:__________ By: ___________

Watershed:______________________ Ownership _________________Year built:_________

Quad ID:_________________ Photo# _________________ Photo date:_______________

Current road condition: Drivable [ Maintained Abandoned Decommissioned ]

The road surface is: [ Native Rocked Paved ]

Proposed Treatment: [ Maintain Upgrade Decommission ]

## SECTION II: FLUVIAL SITE (CROSSINGS, RELIEF CULVERTS, GULLY, ETC.)

***FEATURE***: [ Stream Xing Skid Xing Swale *DRC Road reach ] Spring

***PROCESS***: None Gully Streambnk/channel eros. Collapsing Fill failure

Will it debris torrent? **Y N M**

***DRAINAGE STRUCTURE***: Bridge *Culvert: *metal *concrete *plastic

Humboldt Fill Ford Armored fill None

Critical dip@xing? **Y N** Left ditch/road length_______ft. Right ditch/road length_______ft.

***DIVERSION POTENTIAL***: DP? **Y N** Now diverted Past diverted Rd grade_______%

***CONDITION OF FILL***: Intact removed_______% washed-out_______%

***CULVERT INLET INFORMATION***:

*Diameter______in. Headwall height_______in. Rust line: width_______in. depth_______in.

Stream class: **I, II, III, or IV** Upstrm chan: width_____ft; depth_____ft Grade_____%

Sediment transport: **H M L** CMP undersized? **Y M N** Plug potential: **H M L**

*Inlet condition: OK Rust/holes Band separation Trash rack Drop inlet

*crushed_________% *plugged_________%

***CULVERT OUTLET INFORMATION:***

*Condition: OK Rust/holes Functional downspout %crushed_______% Shotgun

Fish-outlet drop: now ________ ft. @bankfull________ ft. Culvert grade_________%

Pool dim.: length_______ft. depth______ft. @bankfull: length_______ft. depth_______ft.

## SECTION III: LANDSLIDE SITE

***FEATURE***: Road reach Landing Cutbank Hillslope

***PROCESS***: [Slow, deep seated Fast, shallow debris slide] Will it debris torrent? **Y M N**

***SETTING***: Streamside: <55% or >55% Swale Headwall Break-in-slope Hillslope

Distance to stream_________ft. Slope________%

***ACTIVITY***: Failed in past? : **Y N** %failed________%

***ASSOCIATION(S)***: Road related Water onto feature Spring Stream undercutting

## SECTION IV: TREATMENTS (Circle all that apply)

Critical dip@xing Install culvert Replace culvert New culv: dia._________in. len________ft.

Drop inlet Flared inlet Trash rack Remove sed@CMP inlet Brush inlet

Reconstruct fill Excavate fill Ford Bridge Other None

Armor fillslope: @inlet _________$ft^2$; Downstream face________$ft^2$ Downspout________ft.

Armored fill: sill height________ft. sill width________ft. Check culvert size______

********** URGENCY: **H M L** COMPLEXITY: **H M L** **********

***ROAD REACH TREATMENTS***

*Clear/est. IBD______ft. Remove IBD______ft. Rock road_______$ft^2$. Remove berm_______ft.*

*Rolling dips: # ______ OS w/out IBD_______ft. OS w/IBD_______ft. Inslope road_______ft.*

*Cross-road drains # ________ Ditch relief culvert #________, ______ ft.*

## SECTION V: FILL AND FUTURE EROSION VOLUMES

Dimensions of landslide or gully: length:________ft. width:__________ ft. depth:_________ft.
(Use Comment Section below to record dimensions of complex features)

Future erosion volume:___________$yd^3$ %delivery:________% Future yield:_________$yds^3$

Erosion Potential: **H M L** Potential for Extreme Erosion? **Y N**

Is the treatment likely to control or prevent erosion?: **Y M N**

Extreme Erosion Potential Volume ($yds^3$): [ <500, 500-1000, 1K-2K, 2K-5K, >5K ]

Comments:

| ✓ | EXCAVATION VOLUMES | ✓ | EQUIPMENT HOURS | COMMENT ON TREATMENT: |
|---|---|---|---|---|
| | Total excavated ($yds^3$): | | Excavatror (hrs): | |
| | Vol. put back in ($yds^3$): | | Dozer (hrs): | |
| | Vol. removed ($yds^3$): | | Dump truck (hrs): | |
| | Vol. stockpiled ($yds^3$): | | Grader (hrs): | |
| | Vol. endhauled ($yds^3$): | | Backhoe (hrs): | |
| | Dist. endhauled (ft): | | Labor (hrs): | |
| | Exca. prod. rate ($yds^3$/hr): | | Other: | |

**Stream Profile through Crossing** (begin at top of crossing) — ***Xing type: 1, 2, 3, 4*** (circle one)

| Angle (deg) (up+, dn-) | Distance (feet) | Code (UES, TOP, IBR, OBR, BOT, XS1, XS2 ….LES) | Comments |
|---|---|---|---|
| *0* | *0* | *UES, TRN* | *in natural channel* |
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**Cross Section(s)** (begin on left side of crossing)

| XS# | Angle (deg) | Distance (feet) | Code (LRP, LEC, CLP,REC,RRP) | Comments |
|---|---|---|---|---|
| *1* | *0* | *0* | *LRP, TRN* | *Base of cutbank* |
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## Site sketch - *Site No. : ______.*

| ***Design Results*** | |
|---|---|
| Decommission vol. (2:1) | |
| Erosion vol. (1:1) | |
| Culvert add/repl. vol. (1:1) | |
| Humboldt crossing (1:1) | |
| Culvert length needed | |

# APPENDIX C

## Redwood Creek Road Assessment Site Maps

There are 16 maps showing roads and assessment site locations for the entire upper watershed.

The maps may not be included in this printed copy of the report, but are in the electronic version, contained on CD at the back of this report. You may request additional copies of the CD or report from Darci Short at Redwood National and State Parks: 707-825-5144 or Darci_Short@nps.gov.

# APPENDIX D

## PROJECTS AND GRANT FUNDING

Table D-1 shows the cooperative erosion control implementation projects in the upper Redwood Creek watershed from 1996 through 2009. Pilot projects prior to 1996 are not shown. Costs for erosion control work implemented by landowners outside of the cooperative efforts are not shown. Those projects include work associated with timber harvest plans and general road maintenance work funded by the landowner.

Table D-1. Cooperative erosion control projects in the Upper Redwood Creek watershed, 1996 through 2009.

| Project No. | Year(s) | Watershed | Lead Group | Funding Source | | |
|---|---|---|---|---|---|---|
| | | | | Landowner | Grant | TOTAL |
| 4 | 1996-1997 | Garrett | RNSP | $9,200 | $104,500 | $113,700 |
| 5 | 1998 | Bradford, etc | NRM | $16,400 | $109,800 | $126,200 |
| 6 | 1999 | Lake Prairie, etc. | RNSP | $94,000 | $128,300 | $222,300 |
| 7 | 2001 / 02 | Panther, George | PCFWWRA | $75,000 | $197,500 | $272,500 |
| 8 | 2002 / 03 | Redwood | PCFWWRA | $129,800 | $214,700 | $344,500 |
| 9 | 2003 / 04 | Dolly Varden / K&K | PCFWWRA | $173,300 | $704,500 | $877,800 |
| 10 | 2004 / 06 | Coyote Creek (N) | PCFWWRA | $188,100 | $440,900 | $629,000 |
| 11 | 2005 / 06 | Redwood | PCFWWRA | $150,000 | $263,900 | $413,900 |
| 12 | 2006 | Redwood/Panther | PCFWWRA | | $206,700 | $206,700 |
| 13 | 2006 / 08 | Coyote (S) | PCFWWRA | $95,000 | $326,100 | $421,100 |
| 14 | 2006 / 08 | Coyote (S) | PCFWWRA | | $464,600 | $464,600 |
| 15 | 2009 | Lacks - BLM | PCFWWRA | $996,000 | $676,500 | $1,672,500 |
| Totals | | | | $1,926,800 | $3,838,000 | $5,764,800 |
| Percent of all Funding | | | | 33% | 67% | 100% |
| Percent of Funding Through 2009, Omits BLM Funded Projects | | | | 23% | 77% | 100% |

For all projects, landowners have provided about 33 percent of the total project costs. In 2009, BLM provided nearly one million dollars for work on BLM lands. If the BLM project is not factored in to the funding totals, landowners have provided about 23 percent of the total funding for implementation work.

# APPENDIX E

## METHODS USED TO ESTIMATE TMDL LOAD REDUCTIONS

### BACKGROUND

The Environmental Protection Agency (EPA) has oversight authority of the Clean Water Act (CWA). Section 303(d)(1)(A) of the CWA delegates to states the authority to implement provisions of the CWA for their waters. It requires states to establish a priority ranking for waters on the 303(d) list of impaired waters and establish TMDLs for such waters. If the state does not establish a TMDL, then the EPA must develop one.

Redwood Creek was 303(d) listed as sediment impaired by the California North Coast Regional Water Quality Control Board (RWQCB) in 1996, and listed as temperature impaired in 2002. When Redwood Creek was listed as sediment impaired, the RWQCB designated the watershed as a high priority for development of a sediment TMDL.

On October 31, 1997, the EPA entered into a consent decree (decree), Pacific Coast Federation of Fishermen's Association, et. al. v. Marcus, (N.D. Cal. No. 95-4474 MHP), which established a timetable for development of TMDLs for several watersheds in northwest California. The decree required development of a TMDL for Redwood Creek by December 31, 1998.

On parallel tracks, the EPA and RWQCB both began work on the sediment TMDL for Redwood Creek in 1997. The RWQCB completed a draft TMDL with Implementation Plan (RWQCB, 1998) and staff report (RWQCB, 1998) in November 1998. An alternative to the RWQCB's Implementation Plan was also developed by private landowners in the Redwood Creek watershed (RCLA, 1998). Because neither the RWQCB nor State Water Resources Control Board adopted a TMDL for Redwood Creek, the EPA in December 1998 established the TMDL for sediment in order to meet the requirements of the decree (EPA, 1998). A sediment TMDL Implementation Plan was never adopted by the state. Instead, the RWQCB adopted the Total Maximum Daily Load Implementation Policy Statement for Sediment Impaired Receiving Waters in the North Coast Region (Resolution No. R1-2004-0087) that relies on existing enforcement and permitting tools to control non-point source pollution.

### METHODS

To estimate the load reductions in relation to TMDL targets requires calculations of load reduction in the lower and upper watersheds since 1998. Load reductions are achieved through road decommissioning and upgrades. Properly decommissioned roads are maintenance-free and sediment sources are removed. In contrast, upgraded roads still contain potential sediment sources because the roads are still in place. But, if roads are upgraded correctly, the likelihood of failure during large storms will be low. In computing the controllable load reductions (or sediment 'saved'; i.e., the amount of sediment prevented from entering a stream by treating the road) since establishment of the 1998 TMDL, the total amount of sediment treated through upgrades was

included, providing the completed work met established standards, and the likelihood of site failure after treatment was determined (through inspection) to be low.
In the lower watershed, one of the Park's primary goals has been to decommission the hundreds of miles of old logging roads that are not needed for park management or visitor use. Because past road assessments occurred on roads the Park knew would be decommissioned, the assessments only measured the amount of material that would be excavated during road decommissioning. The amount of sediment that would be 'saved' by road treatments was not estimated. In contrast, road assessments in the upper watershed routinely estimated the amount of sediment that would be 'saved' by treating the road.

Thus, the challenge in estimating the TMDL load reductions that have occurred throughout the watershed was estimating the controllable load in park areas that existed in 1998 when the TMDL was established and the amount the load has been reduced since 1998. These values were back-calculated by developing correction factors that converted excavation volumes to sediment 'saved' volumes (load reduction). Described below in more detail, the controllable sediment loads that existed in 1998 within park lands and the amount they were reduced (sediment 'saved') by work completed through 2009 were computed by applying a correction factor of 55 percent to the excavation volumes for all stream crossings and a select group of unstable road reach treatments.

For stream crossings, a correction factor was estimated by using data from the upper basin road assessment database and queries that computed the average ratio of the estimated potential sediment yield volume and estimated site excavation volume. Volumes were based on detailed field surveys. The ratio ranged from 46-59 percent and averaged 54 percent. Projects completed in the upper watershed were also considered. The ratios for completed projects ranged from 61-85 percent and averaged 61 percent. Based on those results, we chose a correction factor of 55 percent of the excavation volume to reflect the sediment 'saved' from all stream crossing treatments and to ensure a conservative estimate.

For unstable road reach treatments, we had to consider which and how much of the two primary treatments to include. Export Outslope (EOS) treatments remove a great deal (sometimes all) of the road bench and, because of site characteristics such as instability, moisture and/or slope steepness, excavated road fill cannot be stored locally and must be exported to a stable fillsite. EOS's generally occur in the most unstable geomorphic settings, but the treatment can sometimes be prescribed for purposes other than erosion control, as in the case for Outslope (OS) treatments.

OS treatments store excavated material from the road locally and shape it into the cutbank. While some OS treatments were prescribed to prevent sediment delivery, most were prescribed in the park to reshape the roads. Doing so improves revegetation, lessens the visual scarring of the road on the landscape and ensures permanent surface drainage. Thus, we decided to include most of the EOS treatments, but none of the OS treatments when computing sediment savings from unstable road reach treatments to ensure a conservative yet reasonable estimate. For EOS treatments, we assumed that 75 percent of the EOS treatments were prescribed for erosion control and assumed a 74 percent delivery rate (HSU 2007) if failure occurred. Combining both assumptions created a correction factor of [coincidentally] 55 percent.

Therefore, for the load reduction in the park, we estimated the total sediment ‘saved’ by summing the excavation volumes for all stream crossings and EOS treatments, and multiplying that value by 55 percent. Based on the treatment of 70 miles of roads, from 1998 to 2009, the load reduction averaged about 18,500 $yds^3$ per mile or 28,000 tons per mile.

Estimating the controllable load for the upper watershed and what remains to be treated was straightforward, because the road assessments in the upper watershed routinely estimated the amount of sediment that would be ‘saved’ by the road treatments. From road assessments completed by PCFWWRA and RNSP, we estimated the total potential sediment yield for *all* roads in the upper watershed at about 2.9 million cubic yards (4.3 million tons). We derived that estimate by applying 2,700 $yds^3$ per mile of potential sediment yield (the average potential sediment yield from assessed roads) to unassessed roads and believe it is a conservative and reasonable estimate. Conditions in the watershed did not change that much between 1998 and the time of road assessments, but about 20 miles of new seasonal roads were built. Most were evaluated by the road assessments and were built in stable upper hillslope areas. All were built to better standards than most of the roads built during earlier years. Because the potential sediment yield from these new roads would be a negligible portion of the assessed roads, we chose to use the total potential sediment yield from our assessments as the starting point for the 1998 TMDL and load reduction calculations. The load reduction in the upper watershed was based on the actual work completed through 2009. The load reduction in the upper watershed for the period 1998-2009 was 2,900 $yds^3$/mile, or about 4,400 tons/mile of road.

The difference between the potential sediment ‘saved’ per mile of road in the lower watershed is six times larger than that for the upper watershed. This is not surprising when the nature of these roads is considered. The lower watershed was dominated by old-growth redwood and was logged during an era when large trees ‘needed’ large, wide roads. Mainline roads were built throughout what is now park land as two-lane off-highway roads. Spur roads where single lane roads, but still generously large and wide. In contrast, the upper watershed was dominated mostly by Douglas-fir which are smaller trees. Most of the roads were built with a smaller footprint to one-lane standards, resulting in smaller volume fill.

# APPENDIX F

## RANKING CRITERIA FOR ASSESSED ROADS

Table F-1: Roads ranked by potential sediment yield.

| Road Name | Length (mi) | Total no. of ALL Sites | Total no. of M to H Sites | Potential Sediment Yield for ALL Sites (yds3) | Potential Sediment Yield for M to H Sites (yds3) | Percent of Potential Sediment Yield Volume for M to H Sites | Potential Sediment Yield per Mile for M to H Sites (yds3/mi) | Total Cost for M to H Sites | Cost/Yard "Saved" |
|---|---|---|---|---|---|---|---|---|---|
| Dolly Varden | 11.8 | 155 | 114 | 109,890 | 103,954 | 95% | 8,793 | $1,234,068 | $11.87 |
| Old K&K | 8.3 | 97 | 35 | 43,395 | 33,359 | 77% | 4,042 | $307,439 | $9.22 |
| LC5000 | 2.3 | 26 | 21 | 23,659 | 23,089 | 98% | 10,176 | $59,360 | $2.57 |
| K&K West | 7.9 | 79 | 30 | 37,375 | 23,063 | 62% | 2,909 | $263,580 | $11.43 |
| LC1000 | 6.5 | 42 | 27 | 22,770 | 20,241 | 89% | 3,134 | $191,878 | $9.48 |
| 1400 | 4.6 | 47 | 32 | 19,382 | 17,301 | 89% | 3,753 | $96,655 | $5.59 |
| PR1100 | 5.4 | 69 | 44 | 19,033 | 16,068 | 84% | 2,958 | $141,382 | $8.80 |
| Old HWY 299 | 2.5 | 52 | 39 | 16,040 | 15,064 | 94% | 6,074 | $233,836 | $15.52 |
| 1440 | 1.5 | 18 | 15 | 15,155 | 14,588 | 96% | 9,657 | $31,314 | $2.15 |
| 1000 | 3.9 | 37 | 16 | 14,312 | 14,050 | 98% | 3,616 | $74,023 | $5.27 |
| 809 | 1.8 | 15 | 13 | 16,032 | 12,510 | 78% | 7,032 | $156,745 | $12.53 |
| 808 | 3.9 | 40 | 22 | 19,766 | 11,895 | 60% | 3,087 | $125,299 | $10.53 |
| L2010 | 4.3 | 42 | 27 | 15,483 | 11,689 | 75% | 2,750 | $136,646 | $11.69 |
| MC1000 | 6.4 | 82 | 53 | 15,313 | 10,897 | 71% | 1,691 | $191,235 | $17.55 |
| Mainline | 2.7 | 33 | 16 | 13,611 | 10,585 | 78% | 3,875 | $145,608 | $13.76 |
| PR1106 | 0.6 | 5 | 5 | 10,417 | 10,417 | 100% | 17,639 | $31,477 | $3.02 |
| UPR-10 | 4.7 | 38 | 24 | 14,685 | 10,394 | 71% | 2,197 | $126,230 | $12.14 |
| R3800 | 0.9 | 11 | 10 | 9,796 | 9,774 | 100% | 11,364 | $57,576 | $5.89 |
| LC4000 | 2.5 | 35 | 24 | 17,335 | 9,436 | 54% | 3,849 | $85,283 | $9.04 |
| 1431 | 1.7 | 29 | 22 | 9,479 | 9,375 | 99% | 5,626 | $95,960 | $10.24 |
| RC-2 | 1.5 | 25 | 14 | 10,122 | 9,120 | 90% | 6,168 | $134,682 | $14.77 |
| R1000 | 2.1 | 21 | 13 | 8,914 | 8,775 | 98% | 4,164 | $33,653 | $3.84 |
| Roddiscroft | 5.3 | 55 | 31 | 9,195 | 8,308 | 90% | 1,573 | $113,422 | $13.65 |
| 1410 | 1.9 | 23 | 12 | 8,125 | 7,602 | 94% | 3,994 | $33,660 | $4.43 |
| LC2000 | 2.6 | 17 | 13 | 8,762 | 7,591 | 87% | 2,881 | $108,119 | $14.24 |
| 1020 | 1.7 | 18 | 12 | 8,059 | 7,544 | 94% | 4,465 | $36,317 | $4.81 |
| L2171 | 1.4 | 16 | 12 | 7,884 | 7,532 | 96% | 5,446 | $110,514 | $14.67 |
| CR2900 | 7.2 | 80 | 17 | 18,227 | 7,509 | 41% | 1,045 | $24,776 | $3.30 |
| FP500 | 1.6 | 29 | 18 | 9,014 | 7,351 | 82% | 4,733 | $110,692 | $15.06 |
| 831 | 2.1 | 13 | 7 | 7,699 | 7,338 | 95% | 3,578 | $14,821 | $2.02 |
| DVA | 1.3 | 18 | 15 | 7,480 | 7,292 | 97% | 5,640 | $112,964 | $15.49 |
| 1140 | 0.8 | 15 | 7 | 12,616 | 7,144 | 57% | 9,516 | $23,856 | $3.34 |
| DVD-1 | 1.4 | 12 | 11 | 7,102 | 7,004 | 99% | 5,162 | $69,224 | $9.88 |
| L1000 | 3.2 | 24 | 15 | 7,789 | 6,573 | 84% | 2,031 | $70,951 | $10.79 |
| L2000-CN | 5.4 | 64 | 29 | 7,677 | 5,754 | 75% | 1,070 | $98,520 | $17.12 |

Table F-1: Roads ranked by potential sediment yield.

| Road Name | Length (mi) | Total no. of ALL Sites | Total no. of M to H Sites | Potential Sediment Yield for ALL Sites (yds3) | Potential Sediment Yield for M to H Sites (yds3) | Percent of Potential Sediment Yield Volume for M to H Sites | Potential Sediment Yield per Mile for M to H Sites (yds3/mi) | Total Cost for M to H Sites | Cost/Yard "Saved" |
|---|---|---|---|---|---|---|---|---|---|
| F-1-4 | 1.6 | 20 | 15 | 6,023 | 5,431 | 90% | 3,428 | $28,719 | $5.29 |
| L2011 | 0.6 | 10 | 7 | 5,822 | 5,261 | 90% | 8,177 | $83,782 | $15.92 |
| 800H | 1.3 | 20 | 16 | 5,736 | 4,961 | 86% | 3,775 | $77,114 | $15.54 |
| R3000 | 3.5 | 34 | 17 | 11,253 | 4,895 | 43% | 1,379 | $38,446 | $7.85 |
| R3900 | 1.7 | 16 | 6 | 12,255 | 4,508 | 37% | 2,706 | $16,304 | $3.62 |
| TP1321 | 1.1 | 12 | 7 | 5,365 | 4,258 | 79% | 3,713 | $39,362 | $9.24 |
| 1450 | 3.1 | 24 | 16 | 5,224 | 4,138 | 79% | 1,321 | $45,464 | $10.99 |
| BO1315 | 1.0 | 8 | 5 | 5,084 | 4,131 | 81% | 4,220 | $48,269 | $11.68 |
| LC1100 | 1.1 | 4 | 3 | 4,100 | 4,003 | 98% | 3,633 | $56,894 | $14.21 |
| 1433 | 0.5 | 7 | 7 | 3,978 | 3,978 | 100% | 7,835 | $12,109 | $3.04 |
| FL1025 | 0.8 | 8 | 7 | 3,982 | 3,947 | 99% | 4,671 | $17,178 | $4.35 |
| 820 | 2.8 | 15 | 9 | 5,559 | 3,937 | 71% | 1,387 | $51,349 | $13.04 |
| BO1306 | 0.4 | 4 | 4 | 3,789 | 3,789 | 100% | 10,207 | $46,725 | $12.33 |
| R3500 | 1.3 | 14 | 11 | 3,755 | 3,727 | 99% | 2,838 | $24,725 | $6.63 |
| 800G | 0.3 | 2 | 2 | 3,726 | 3,726 | 100% | 12,298 | $12,236 | $3.28 |
| 1150 | 1.0 | 15 | 8 | 4,640 | 3,608 | 78% | 3,494 | $25,735 | $7.13 |
| 3C2500 | 1.9 | 18 | 7 | 5,881 | 3,554 | 60% | 1,830 | $47,799 | $13.45 |
| 3C2010 | 0.2 | 6 | 5 | 4,000 | 3,500 | 88% | 16,972 | $49,559 | $14.16 |
| LC5005 | 0.5 | 3 | 1 | 7,074 | 3,500 | 49% | 7,405 | $9,095 | $2.60 |
| PR1107 | 0.7 | 3 | 3 | 3,500 | 3,500 | 100% | 4,690 | $9,900 | $2.83 |
| R3810 | 0.1 | 2 | 1 | 5,000 | 3,500 | 70% | 43,126 | $10,165 | $2.90 |
| 3C2800 | 0.8 | 20 | 11 | 4,742 | 3,429 | 72% | 4,501 | $48,288 | $14.08 |
| LC-1 | 8.7 | 50 | 18 | 4,862 | 3,391 | 70% | 389 | $51,327 | $15.14 |
| L2010-B | 0.1 | 1 | 1 | 3,334 | 3,334 | 100% | 44,387 | $35,350 | $10.60 |
| CP1000 | 1.9 | 28 | 7 | 6,248 | 3,293 | 53% | 1,704 | $51,917 | $15.77 |
| D-Line | 1.7 | 22 | 17 | 3,445 | 3,286 | 95% | 1,953 | $59,704 | $18.17 |
| DVG | 0.7 | 16 | 16 | 3,141 | 3,141 | 100% | 4,658 | $42,714 | $13.60 |
| SW-1A | 3.0 | 17 | 11 | 3,669 | 3,003 | 82% | 996 | $54,248 | $18.07 |
| 890C | 0.8 | 7 | 6 | 3,508 | 2,963 | 84% | 3,839 | $66,185 | $22.34 |
| RP1000 | 3.0 | 29 | 17 | 8,200 | 2,893 | 35% | 949 | $26,994 | $9.33 |
| RC-1 | 1.2 | 21 | 11 | 3,367 | 2,770 | 82% | 2,253 | $33,236 | $12.00 |
| 808A | 1.8 | 9 | 9 | 2,756 | 2,756 | 100% | 1,530 | $18,350 | $6.66 |

Additionally ranked roads available upon request.

Table F-2: Roads ranked by potential sediment yield per mile.

| Road Name | Length (mi) | Total no. of ALL Sites | Total no. of M to H Sites | Potential Sediment Yield for ALL Sites (yds3) | Potential Sediment Yield for M to H Sites (yds3) | Percent of Potential Sediment Yield Volume for M to H Sites | Potential Sediment Yield per Mile for M to H Sites (yds3/mi) | Total Cost for M to H Sites | Cost/Yard "Saved" |
|---|---|---|---|---|---|---|---|---|---|
| L2010-B | 0.1 | 1 | 1 | 3,334 | 3,334 | 100% | 44,387 | $35,350 | $10.60 |
| R3810 | 0.1 | 2 | 1 | 5,000 | 3,500 | 70% | 43,126 | $10,165 | $2.90 |
| HP-22 | 0.0 | 3 | 2 | 1,204 | 804 | 67% | 25,588 | $23,005 | $28.60 |
| PR1106 | 0.6 | 5 | 5 | 10,417 | 10,417 | 100% | 17,639 | $31,477 | $3.02 |
| 3C2010 | 0.2 | 6 | 5 | 4,000 | 3,500 | 88% | 16,972 | $49,559 | $14.16 |
| HP-21 | 0.1 | 1 | 1 | 1,014 | 1,014 | 100% | 15,504 | $13,523 | $13.34 |
| 800G | 0.3 | 2 | 2 | 3,726 | 3,726 | 100% | 12,298 | $12,236 | $3.28 |
| R3800 | 0.9 | 11 | 10 | 9,796 | 9,774 | 100% | 11,364 | $57,576 | $5.89 |
| BO1306 | 0.4 | 4 | 4 | 3,789 | 3,789 | 100% | 10,207 | $46,725 | $12.33 |
| LC5000 | 2.3 | 26 | 21 | 23,659 | 23,089 | 98% | 10,176 | $59,360 | $2.57 |
| L2173 | 0.2 | 3 | 3 | 1,845 | 1,845 | 100% | 9,979 | $11,595 | $6.28 |
| 1440 | 1.5 | 18 | 15 | 15,155 | 14,588 | 96% | 9,657 | $31,314 | $2.15 |
| 1140 | 0.8 | 15 | 7 | 12,616 | 7,144 | 57% | 9,516 | $23,856 | $3.34 |
| R1050 | 0.2 | 2 | 1 | 1,829 | 1,778 | 97% | 9,405 | $11,362 | $6.39 |
| Dolly Varden | 11.8 | 155 | 114 | 109,890 | 103,954 | 95% | 8,793 | $1,234,068 | $11.87 |
| AM-4-1 | 0.1 | 1 | 1 | 500 | 500 | 100% | 8,438 | $2,712 | $5.42 |
| UBR | 0.2 | 3 | 2 | 1,775 | 1,723 | 97% | 8,402 | $27,722 | $16.09 |
| L2011 | 0.6 | 10 | 7 | 5,822 | 5,261 | 90% | 8,177 | $83,782 | $15.92 |
| L1000-E | 0.1 | 2 | 2 | 961 | 961 | 100% | 8,082 | $16,272 | $16.93 |
| R4250 | 0.1 | 2 | 2 | 625 | 625 | 100% | 8,031 | $8,981 | $14.38 |
| 3C2002 | 0.1 | 1 | 1 | 1,050 | 1,050 | 100% | 8,007 | $7,458 | $7.10 |
| DVJ | 0.3 | 4 | 2 | 2,792 | 2,269 | 81% | 7,882 | $16,272 | $7.17 |
| 1433 | 0.5 | 7 | 7 | 3,978 | 3,978 | 100% | 7,835 | $12,109 | $3.04 |
| LC5005 | 0.5 | 3 | 1 | 7,074 | 3,500 | 49% | 7,405 | $9,095 | $2.60 |
| R2100 | 0.2 | 2 | 2 | 1,557 | 1,557 | 100% | 7,402 | $4,746 | $3.05 |
| N500A | 0.2 | 3 | 3 | 1,697 | 1,697 | 100% | 7,318 | $8,348 | $4.92 |
| 809 | 1.8 | 15 | 13 | 16,032 | 12,510 | 78% | 7,032 | $156,745 | $12.53 |
| R3351 | 0.1 | 1 | 1 | 750 | 750 | 100% | 6,544 | $1,017 | $1.36 |
| RC-2 | 1.5 | 25 | 14 | 10,122 | 9,120 | 90% | 6,168 | $134,682 | $14.77 |
| Old HWY 299 | 2.5 | 52 | 39 | 16,040 | 15,064 | 94% | 6,074 | $233,836 | $15.52 |
| DVA | 1.3 | 18 | 15 | 7,480 | 7,292 | 97% | 5,640 | $112,964 | $15.49 |
| 831A | 0.2 | 3 | 3 | 1,237 | 1,237 | 100% | 5,633 | $29,838 | $24.12 |
| 1431 | 1.7 | 29 | 22 | 9,479 | 9,375 | 99% | 5,626 | $95,960 | $10.24 |
| 1220 | 0.4 | 6 | 5 | 15,170 | 2,281 | 15% | 5,541 | $18,958 | $8.31 |

Table F-2: Roads ranked by potential sediment yield per mile.

| Road Name | Length (mi) | Total no. of ALL Sites | Total no. of M to H Sites | Potential Sediment Yield for ALL Sites (yds3) | Potential Sediment Yield for M to H Sites (yds3) | Percent of Potential Sediment Yield Volume for M to H Sites | Potential Sediment Yield per Mile for M to H Sites (yds3/mi) | Total Cost for M to H Sites | Cost/Yard "Saved" |
|---|---|---|---|---|---|---|---|---|---|
| PP1010 | 0.1 | 1 | 1 | 323 | 323 | 100% | 5,477 | $3,729 | $11.54 |
| L2171 | 1.4 | 16 | 12 | 7,884 | 7,532 | 96% | 5,446 | $110,514 | $14.67 |
| 3C2512 | 0.3 | 6 | 1 | 3,066 | 1,500 | 49% | 5,349 | $3,729 | $2.49 |
| 200A | 0.3 | 3 | 1 | 1,827 | 1,689 | 92% | 5,294 | $27,120 | $16.06 |
| RV4 | 0.4 | 6 | 6 | 2,068 | 2,068 | 100% | 5,257 | $30,236 | $14.62 |
| LC5001 | 0.1 | 1 | 1 | 750 | 750 | 100% | 5,246 | $2,622 | $3.50 |
| DVD-1 | 1.4 | 12 | 11 | 7,102 | 7,004 | 99% | 5,162 | $69,224 | $9.88 |
| LPC-PC-1 | 0.1 | 3 | 1 | 935 | 750 | 80% | 5,052 | $3,390 | $4.52 |
| F-1-4-0 | 0.2 | 3 | 3 | 1,191 | 1,191 | 100% | 4,942 | $17,930 | $15.05 |
| FP500 | 1.6 | 29 | 18 | 9,014 | 7,351 | 82% | 4,733 | $110,692 | $15.06 |
| RP1200 | 0.3 | 6 | 3 | 1,622 | 1,413 | 87% | 4,699 | $13,560 | $9.60 |
| PR1107 | 0.7 | 3 | 3 | 3,500 | 3,500 | 100% | 4,690 | $9,900 | $2.83 |
| FL1025 | 0.8 | 8 | 7 | 3,982 | 3,947 | 99% | 4,671 | $17,178 | $4.35 |
| DVG | 0.7 | 16 | 16 | 3,141 | 3,141 | 100% | 4,658 | $42,714 | $13.60 |
| 3C2800 | 0.8 | 20 | 11 | 4,742 | 3,429 | 72% | 4,501 | $48,288 | $14.08 |
| 1020 | 1.7 | 18 | 12 | 8,059 | 7,544 | 94% | 4,465 | $36,317 | $4.81 |
| 800F | 0.5 | 2 | 2 | 1,945 | 1,945 | 100% | 4,294 | $44,810 | $23.04 |
| 808D-1 | 0.1 | 1 | 1 | 295 | 295 | 100% | 4,261 | $5,085 | $17.24 |
| BO1315 | 1.0 | 8 | 5 | 5,084 | 4,131 | 81% | 4,220 | $48,269 | $11.68 |
| 3C2501 | 0.3 | 5 | 2 | 2,279 | 1,101 | 48% | 4,200 | $22,130 | $20.10 |
| R1000 | 2.1 | 21 | 13 | 8,914 | 8,775 | 98% | 4,164 | $33,653 | $3.84 |
| HRPR-1 | 0.2 | 3 | 2 | 840 | 807 | 96% | 4,086 | $3,390 | $4.20 |
| Old K&K | 8.3 | 97 | 35 | 43,395 | 33,359 | 77% | 4,042 | $307,439 | $9.22 |
| 1410 | 1.9 | 23 | 12 | 8,125 | 7,602 | 94% | 3,994 | $33,660 | $4.43 |
| UPC-BC-2 | 0.2 | 1 | 1 | 778 | 778 | 100% | 3,921 | $10,848 | $13.95 |
| Mainline | 2.7 | 33 | 16 | 13,611 | 10,585 | 78% | 3,875 | $145,608 | $13.76 |
| LC4000 | 2.5 | 35 | 24 | 17,335 | 9,436 | 54% | 3,849 | $85,283 | $9.04 |
| 890C | 0.8 | 7 | 6 | 3,508 | 2,963 | 84% | 3,839 | $66,185 | $22.34 |
| 895 | 0.6 | 5 | 5 | 2,437 | 2,437 | 100% | 3,838 | $47,405 | $19.45 |
| 802A | 0.1 | 2 | 2 | 247 | 247 | 100% | 3,833 | $2,094 | $8.48 |
| 800H | 1.3 | 20 | 16 | 5,736 | 4,961 | 86% | 3,775 | $77,114 | $15.54 |
| R1005 | 0.4 | 4 | 4 | 1,326 | 1,326 | 100% | 3,755 | $16,606 | $12.52 |
| 1400 | 4.6 | 47 | 32 | 19,382 | 17,301 | 89% | 3,753 | $96,655 | $5.59 |

Additionally ranked roads available upon request.

Table F-3: Roads ranked by cost-effectiveness.

| Road Name | Length (mi) | Total no. of ALL Sites | Total no. of M to H Sites | Potential Sediment Yield for ALL Sites (yds3) | Potential Sediment Yield for M to H Sites (yds3) | Percent of Potential Sediment Yield Volume for M to H Sites | Potential Sediment Yield per Mile for M to H Sites (yds3/mi) | Total Cost for M to H Sites | Cost/Yard "Saved" |
|---|---|---|---|---|---|---|---|---|---|
| UPC-BC | 0.6 | 4 | 3 | 2,194 | 1,694 | 77% | 2,609 | $2,034 | $1.20 |
| R3351 | 0.1 | 1 | 1 | 750 | 750 | 100% | 6,544 | $1,017 | $1.36 |
| 930 | 1.7 | 4 | 1 | 750 | 750 | 100% | 434 | $1,119 | $1.49 |
| N550A | 0.2 | 1 | 1 | 750 | 750 | 100% | 3,276 | $1,356 | $1.81 |
| O-8 | 0.1 | 1 | 1 | 95 | 95 | 100% | 728 | $177 | $1.86 |
| O-4-2-3 | 0.4 | 5 | 2 | 1,468 | 451 | 31% | 1,169 | $908 | $2.01 |
| 831 | 2.1 | 13 | 7 | 7,699 | 7,338 | 95% | 3,578 | $14,821 | $2.02 |
| 1440 | 1.5 | 18 | 15 | 15,155 | 14,588 | 96% | 9,657 | $31,314 | $2.15 |
| 800I | 0.8 | 2 | 2 | 1,517 | 1,517 | 100% | 1,913 | $3,745 | $2.47 |
| 3C2512 | 0.3 | 6 | 1 | 3,066 | 1,500 | 49% | 5,349 | $3,729 | $2.49 |
| LC5000 | 2.3 | 26 | 21 | 23,659 | 23,089 | 98% | 10,176 | $59,360 | $2.57 |
| LC5005 | 0.5 | 3 | 1 | 7,074 | 3,500 | 49% | 7,405 | $9,095 | $2.60 |
| R3970 | 0.2 | 2 | 2 | 910 | 910 | 100% | 3,741 | $2,569 | $2.82 |
| PR1107 | 0.7 | 3 | 3 | 3,500 | 3,500 | 100% | 4,690 | $9,900 | $2.83 |
| R3810 | 0.1 | 2 | 1 | 5,000 | 3,500 | 70% | 43,126 | $10,165 | $2.90 |
| PR1106 | 0.6 | 5 | 5 | 10,417 | 10,417 | 100% | 17,639 | $31,477 | $3.02 |
| 1433 | 0.5 | 7 | 7 | 3,978 | 3,978 | 100% | 7,835 | $12,109 | $3.04 |
| R2100 | 0.2 | 2 | 2 | 1,557 | 1,557 | 100% | 7,402 | $4,746 | $3.05 |
| 800G | 0.3 | 2 | 2 | 3,726 | 3,726 | 100% | 12,298 | $12,236 | $3.28 |
| CR2900 | 7.2 | 80 | 17 | 18,227 | 7,509 | 41% | 1,045 | $24,776 | $3.30 |
| 1140 | 0.8 | 15 | 7 | 12,616 | 7,144 | 57% | 9,516 | $23,856 | $3.34 |
| LC5001 | 0.1 | 1 | 1 | 750 | 750 | 100% | 5,246 | $2,622 | $3.50 |
| R3900 | 1.7 | 16 | 6 | 12,255 | 4,508 | 37% | 2,706 | $16,304 | $3.62 |
| 1055 | 0.3 | 1 | 1 | 89 | 89 | 100% | 263 | $339 | $3.81 |
| R1000 | 2.1 | 21 | 13 | 8,914 | 8,775 | 98% | 4,164 | $33,653 | $3.84 |
| RV-1 | 0.7 | 3 | 3 | 178 | 178 | 100% | 252 | $708 | $3.98 |
| HRPR-1 | 0.2 | 3 | 2 | 840 | 807 | 96% | 4,086 | $3,390 | $4.20 |
| PR1104 | 0.4 | 1 | 1 | 400 | 400 | 100% | 920 | $1,695 | $4.24 |
| FL1025 | 0.8 | 8 | 7 | 3,982 | 3,947 | 99% | 4,671 | $17,178 | $4.35 |
| 1410 | 1.9 | 23 | 12 | 8,125 | 7,602 | 94% | 3,994 | $33,660 | $4.43 |
| LPC-PC-1 | 0.1 | 3 | 1 | 935 | 750 | 80% | 5,052 | $3,390 | $4.52 |
| N750 | 0.3 | 2 | 1 | 426 | 371 | 87% | 1,267 | $1,695 | $4.57 |
| CP1210 | 1.4 | 19 | 1 | 6,324 | 686 | 11% | 491 | $3,210 | $4.68 |
| 1020 | 1.7 | 18 | 12 | 8,059 | 7,544 | 94% | 4,465 | $36,317 | $4.81 |
| N500A | 0.2 | 3 | 3 | 1,697 | 1,697 | 100% | 7,318 | $8,348 | $4.92 |

Table F-3: Roads ranked by cost-effectiveness.

| Road Name | Length (mi) | Total no. of ALL Sites | Total no. of M to H Sites | Potential Sediment Yield for ALL Sites (yds3) | Potential Sediment Yield for M to H Sites (yds3) | Percent of Potential Sediment Yield Volume for M to H Sites | Potential Sediment Yield per Mile for M to H Sites (yds3/mi) | Total Cost for M to H Sites | Cost/Yard "Saved" |
|---|---|---|---|---|---|---|---|---|---|
| LC-7 | 0.7 | 6 | 2 | 1,611 | 649 | 40% | 942 | $3,216 | $4.96 |
| R5000 | 1.4 | 9 | 3 | 1,474 | 814 | 55% | 569 | $4,168 | $5.12 |
| L2000 | 0.5 | 10 | 3 | 1,403 | 1,293 | 92% | 2,484 | $6,734 | $5.21 |
| 1000 | 3.9 | 37 | 16 | 14,312 | 14,050 | 98% | 3,616 | $74,023 | $5.27 |
| F-1-4 | 1.6 | 20 | 15 | 6,023 | 5,431 | 90% | 3,428 | $28,719 | $5.29 |
| 801 | 1.3 | 4 | 2 | 503 | 497 | 99% | 394 | $2,675 | $5.38 |
| AM-4-1 | 0.1 | 1 | 1 | 500 | 500 | 100% | 8,438 | $2,712 | $5.42 |
| N770 | 0.6 | 4 | 4 | 1,645 | 1,645 | 100% | 2,726 | $9,079 | $5.52 |
| 1400 | 4.6 | 47 | 32 | 19,382 | 17,301 | 89% | 3,753 | $96,655 | $5.59 |
| LC2 | 0.3 | 4 | 4 | 923 | 923 | 100% | 3,052 | $5,238 | $5.67 |
| N500C | 1.3 | 3 | 2 | 69 | 69 | 100% | 55 | $392 | $5.68 |
| R3800 | 0.9 | 11 | 10 | 9,796 | 9,774 | 100% | 11,364 | $57,576 | $5.89 |
| R-77 | 0.1 | 1 | 1 | 30 | 30 | 100% | 226 | $177 | $5.90 |
| 3C2810 | 0.5 | 3 | 1 | 783 | 500 | 64% | 976 | $3,051 | $6.10 |
| L2173 | 0.2 | 3 | 3 | 1,845 | 1,845 | 100% | 9,979 | $11,595 | $6.28 |
| R1050 | 0.2 | 2 | 1 | 1,829 | 1,778 | 97% | 9,405 | $11,362 | $6.39 |
| RP900 | 0.7 | 5 | 3 | 1,091 | 1,082 | 99% | 1,485 | $7,060 | $6.52 |
| R3500 | 1.3 | 14 | 11 | 3,755 | 3,727 | 99% | 2,838 | $24,725 | $6.63 |
| 808A | 1.8 | 9 | 9 | 2,756 | 2,756 | 100% | 1,530 | $18,350 | $6.66 |
| R3200 | 1.3 | 13 | 5 | 1,338 | 498 | 37% | 382 | $3,412 | $6.85 |
| R3350 | 0.3 | 5 | 3 | 215 | 145 | 67% | 548 | $1,017 | $7.03 |
| DVM | 1.4 | 10 | 8 | 2,082 | 2,017 | 97% | 1,435 | $14,249 | $7.06 |
| 3C2002 | 0.1 | 1 | 1 | 1,050 | 1,050 | 100% | 8,007 | $7,458 | $7.10 |
| 1150 | 1.0 | 15 | 8 | 4,640 | 3,608 | 78% | 3,494 | $25,735 | $7.13 |
| HP-31 | 0.3 | 1 | 1 | 306 | 306 | 100% | 930 | $2,185 | $7.15 |
| DVJ | 0.3 | 4 | 2 | 2,792 | 2,269 | 81% | 7,882 | $16,272 | $7.17 |
| C1400 | 0.6 | 1 | 1 | 233 | 233 | 100% | 394 | $1,695 | $7.27 |
| FL1030 | 0.3 | 2 | 1 | 252 | 139 | 55% | 495 | $1,070 | $7.70 |
| R3000 | 3.5 | 34 | 17 | 11,253 | 4,895 | 43% | 1,379 | $38,446 | $7.85 |
| FP1000 | 1.5 | 18 | 3 | 151 | 85 | 56% | 57 | $678 | $7.98 |
| DVC | 0.1 | 2 | 2 | 331 | 331 | 100% | 2,511 | $2,712 | $8.20 |
| 800H-1 | 0.1 | 2 | 2 | 391 | 391 | 100% | 2,839 | $3,210 | $8.21 |

Additionally ranked roads available upon request.

# APPENDIX G

## Sub-Watershed Ranking with Weighting Values for Risk Analysis

Table G-1. Sub-watersheds ranked by total potential sediment yield.

Table G-2. Sub-watersheds ranked by number of critical crossings in each sub-watershed.

Table G-3. Sub-watersheds ranked by the number of Shalstab sites in each sub-watershed.

## Sub-Watershed Ranking with Weighting Values for Risk Analysis

This appendix contains the definition of terms and explanation of weighting values for the risk analyses.

***Yield*** –describes the total potential sediment yield in each sub-watershed. It integrates nicely into a risk analysis because it quantifies the amount of sediment that can potentially impact aquatic habitat and water quality. Yield is expressed in cubic yards ($yds^3$).

In this analysis, *potential sediment yield* is always the larger of *site potential yield* or the *extreme potential yield* for each site. The site potential yield was estimated for each site in the field, and represents the volume of material that can potentially erode and be delivered to a stream during a large storm. The extreme potential yield is the volume of sediment that can potentially be delivered during an extreme erosional event (e.g., a debris torrent initiating at a stream crossing), when the possibility for an extreme event had been identified in the field. The extreme potential yield is always larger than the site potential yield. The potential sediment yield for all sites in a sub-watershed was summed and sorted from the highest to lowest values. Weighting values (odd values from 1-9) were assigned to each sub-watershed based on the 20 percent breaks for cumulative potential sediment yield.

Table G-1 ranks each sub-watershed by total potential sediment yield and assigns a weighting value for the risk analysis. Potential sediment yield ranged from 479 $yds^3$ in Six Rivers Creek to more than 142,300 $yds^3$ in Lacks Creek which is the largest sub-watershed in the upper Redwood Creek watershed. Minor Creek is the next largest sub-watershed in the upper Redwood Creek watershed. When compared to Lacks Creek, it is about 30 percent smaller, but has less than half of the potential sediment yield. Because the potential sediment yield for Lacks Creek was nearly twice as much as Minor Creek's value, Lacks Creek was not considered in the range of values when weighting values were assigned. Excluding Lacks Creek, the average potential sediment yield was about 13,930 $yds^3$ and the median yield was about 8,900 $yds^3$. Only sites that had medium to high erosion potentials were considered, because low sites were considered relatively stable.

***Critical crossings (CXings)*** – have a diversion potential, an undersized culvert for a 100-year flood, and a medium to high plug potential. They are road-stream crossings that are the most likely crossings to divert streams from their natural watercourses, and represent a potentially significant source of sediment from erosion that occurs along a road and/or on the hillslope that receives the diverted streamflow. The risk analysis considers how many critical crossings are found in each sub-watershed. The potential volume of sediment from the failure of a critical crossing cannot be measured before failure occurs and volume estimates would be highly speculative. However, studies performed in Redwood Creek show that stream diversions can lead to significant gully and landslide erosion (Best and others, 1995; Weaver and Hagans, 1987).

Diversion and culvert plug potentials were evaluated in the field. Culvert diameter sizing was based on field evaluations and the use of standard culvert sizing methods for the 100-year storm. For each sub-watershed, the number of critical crossings was summed and then totals were sorted from high to low values. Weighting values for each sub-watershed were then assigned based on the 20% break in the cumulative number of CXings.

Table G-2 ranks each sub-watershed by the number of critical crossings found in each sub-watershed, and assigns a weighting value for each sub-watershed. Critical crossings ranged from one crossing in seven of the sub-watersheds to 41 crossings in Lacks Creek. The average and median number of CXings per sub-watershed was seven and three, respectively.

***Shalstab*** – The risk analysis considers how many of the sites evaluated in a sub-watershed fall within a potentially unstable zone based on Shalstab interpretation of the landscape. Shalstab is a GIS-based model used for mapping the potential of shallow slope instabilities (Dietrich et al., 2001; Dietrich and Montgomery, 1998) and applied to the Redwood Creek watershed (Hare, 2003). Model output has been used extensively in the Redwood Creek watershed during the field review of proposed timber harvest plans. While not precise, model output has been field evaluated throughout the watershed and has shown good correlation with actual geomorphic conditions.

Shalstab output described here are results from a model run on a 10 meter drainage enforced Digital Elevation Model (DEM) of the entire Redwood Creek Basin. The DEMs were created at Redwood National and State Parks using the TOPOGRID function in ArcInfo with a contour crenulated drainage network for drainage enforcement. Parameters used to run the model are those suggested for regional applications (phi=45 degrees, and soil density = 1700 $kg/m^3$) (Dietrich and Montgomery, 1998). For the purpose of this analysis, Shalstab values of $\log(q/T) <= -2.8$ defined the slope stability classes where shallow landsliding could occur. The number of potential Shalstab sites in each sub-watershed was summed and the totals sorted from high to low values. Weighting values for each sub-watershed were then assigned based on the 20% break in the cumulative number of Shalstab sites.

Table G-3 ranks each sub-watershed by the number of Shalstab sites found in each sub-watershed, and assigns a weighting value for each sub-watershed. The number of Shalstab sites in each sub-watershed ranged from zero in several sub-watersheds to 59 in Lacks Creek. Of the 42 sub-watersheds considered, more than half had fewer than two Shalstab sites in the sub-watershed. The average and median number of Shalstab sites were seven and three, respectively.

Table G-1. Sub-watersheds ranked by total potential sediment yield.

| Sub-Watershed | Acres | %Roads Evaluated | Total Potential Sediment Yield (yds$^3$) | Total Potential Sediment Yield (%CumYield) | Weighting Value |
|---|---|---|---|---|---|
| Lacks | 10,977 | 85% | 142,333 | outlier | 9 |
| Minor | 8,248 | 87% | 73,535 | 100% | 9 |
| Dolly Varden | 2,151 | 92% | 44,327 | 87% | 9 |
| Toss-Up | 1,709 | 97% | 43,662 | 79% | 7 |
| Lupton | 3,329 | 62% | 35,637 | 72% | 7 |
| Wiregrass | 1,153 | 92% | 34,515 | 65% | 7 |
| Coyote | 5,043 | 57% | 30,159 | 59% | 5 |
| Pilchuck | 1,086 | 92% | 24,398 | 54% | 5 |
| Panther | 3,800 | 95% | 21,767 | 50% | 5 |
| Garcia | 905 | 90% | 20,627 | 46% | 5 |
| Noisy | 4,030 | 73% | 19,326 | 42% | 5 |
| Garrett | 2,643 | 62% | 18,688 | 39% | 3 |
| Lee | 292 | 100% | 17,546 | 36% | 3 |
| Headwaters_M | 1,688 | 72% | 16,112 | 33% | 3 |
| Lake Prairie | 2,144 | 82% | 14,035 | 30% | 3 |
| Loin | 601 | 81% | 12,515 | 27% | 3 |
| Negro Joe | 806 | 72% | 12,380 | 25% | 3 |
| Twin Lakes | 811 | 90% | 11,875 | 23% | 3 |
| Pardee | 1,985 | 68% | 11,280 | 21% | 3 |
| Stover | 544 | 56% | 9,885 | 19% | 1 |
| Smokehouse | 426 | 74% | 9,210 | 17% | 1 |
| Powerline | 408 | 94% | 8,874 | 16% | 1 |
| Timbo | 229 | 94% | 8,769 | 14% | 1 |
| George | 699 | 100% | 8,145 | 13% | 1 |
| High Prairie | 3,476 | 50% | 8,011 | 11% | 1 |
| Johnson Prairie | 386 | 87% | 7,338 | 10% | 1 |
| Fern Prairie | 509 | 73% | 7,310 | 8% | 1 |
| Snow Camp | 773 | 66% | 6,262 | 7% | 1 |
| Cashmere | 861 | 80% | 5,554 | 6% | 1 |
| Tom | 259 | 93% | 4,067 | 5% | 1 |
| Headwaters_W | 179 | 52% | 3,740 | 4% | 1 |
| Cool Springs | 737 | 45% | 3,592 | 4% | 1 |
| Christmas Prairie | 455 | 73% | 3,033 | 3% | 1 |
| Santa Fe | 530 | 65% | 3,003 | 3% | 1 |
| Marquette | 492 | 91% | 2,747 | 2% | 1 |
| Jena | 246 | 47% | 2,715 | 2% | 1 |
| Burley | 255 | 91% | 2,564 | 1% | 1 |
| June | 125 | 100% | 1,694 | 1% | 1 |
| Joplin | 441 | 90% | 657 | 0% | 1 |
| Debris Torrent | 129 | 91% | 559 | 0% | 1 |
| Ayers | 242 | 97% | 511 | 0% | 1 |
| Six Rivers | 741 | 57% | 479 | 0% | 1 |

Table G-2. Sub-watersheds ranked by number of critical crossings in each sub-watershed.

| Sub-Watershed | Miles of Roads | | | #CXs | %Cum# of CXings | Weighting Value |
|---|---|---|---|---|---|---|
| | 2004 | %Evaluated | 2010 | | | |
| Lacks | 90.0 | 85% | 82.5 | 41 | 100% | 9 |
| Minor | 84.6 | 87% | 84.6 | 30 | 85% | 9 |
| Negro Joe | 9.5 | 72% | 9.5 | 20 | 74% | 7 |
| Dolly Varden | 28.2 | 92% | 23.5 | 20 | 67% | 7 |
| Coyote | 48.7 | 57% | 16.5 | 17 | 59% | 5 |
| Noisy | 51.2 | 73% | 46.8 | 17 | 53% | 5 |
| Johnson Prairie | 2.2 | 87% | 2.2 | 12 | 47% | 5 |
| Garrett | 22.0 | 62% | 21.1 | 11 | 43% | 5 |
| Lupton | 43.6 | 62% | 41.1 | 9 | 39% | 3 |
| Panther | 40.4 | 95% | 30.7 | 9 | 35% | 3 |
| Powerline | 4.6 | 94% | 4.3 | 8 | 32% | 3 |
| Garcia | 10.1 | 90% | 10.1 | 5 | 29% | 3 |
| Toss-Up | 16.6 | 97% | 15.7 | 5 | 27% | 3 |
| Pardee | 26.4 | 68% | 23.6 | 5 | 26% | 3 |
| Wiregrass | 9.7 | 92% | 9.5 | 5 | 24% | 3 |
| George | 7.3 | 100% | 6.4 | 5 | 22% | 3 |
| Snow Camp | 8.3 | 66% | 8.2 | 5 | 20% | 3 |
| Burley | 3.2 | 91% | 3.0 | 4 | 18% | 1 |
| Tom | 2.7 | 93% | 2.2 | 4 | 17% | 1 |
| Stover | 4.8 | 56% | 4.8 | 3 | 15% | 1 |
| Cool Springs | 9.6 | 45% | 9.5 | 3 | 14% | 1 |
| Twin Lakes | 9.8 | 90% | 9.8 | 3 | 13% | 1 |
| Christmas Prairie | 6.9 | 73% | 6.9 | 3 | 12% | 1 |
| Six Rivers | 9.2 | 57% | 9.2 | 3 | 11% | 1 |
| Smokehouse | 5.8 | 74% | 5.8 | 3 | 10% | 1 |
| Timbo | 4.0 | 94% | 3.8 | 3 | 9% | 1 |
| Debris Torrent | 2.0 | 91% | 2.0 | 2 | 8% | 1 |
| Loin | 5.4 | 81% | 5.0 | 2 | 7% | 1 |
| Fern Prairie | 6.5 | 73% | 6.5 | 2 | 6% | 1 |
| Headwaters_M | 16.4 | 74% | 15.1 | 2 | 5% | 1 |
| Joplin | 4.7 | 90% | 3.7 | 2 | 5% | 1 |
| Lee | 3.3 | 100% | 3.1 | 2 | 4% | 1 |
| Pilchuck | 9.3 | 92% | 8.8 | 2 | 3% | 1 |
| Headwaters_W | 1.7 | 52% | 1.7 | 1 | 3% | 1 |
| High Prairie | 42.0 | 50% | 40.1 | 1 | 2% | 1 |
| Jena | 4.1 | 47% | 4.1 | 1 | 2% | 1 |
| June | 0.9 | 100% | 0.9 | 1 | 1% | 1 |
| Marquette | 6.7 | 91% | 6.7 | 1 | 1% | 1 |
| Santa Fe | 9.3 | 65% | 8.7 | 1 | 1% | 1 |
| Lake Prairie | 25.5 | 82% | 18.8 | 1 | 0% | 1 |

Table G-3. Sub-watersheds ranked by the number of Shalstab sites in each sub-watershed.

| Sub-Watershed | Miles of Roads | | | Number of Shalstab Sites | %Cumulative Number of Shalstab Sites | Weighting Value |
|---|---|---|---|---|---|---|
| | 2004 | % Evaluated | 2010 | | | |
| Lacks | 90.0 | 85% | 82.5 | 59 | 100% | 9 |
| Minor | 84.6 | 87% | 84.6 | 53 | 81% | 9 |
| Toss-Up | 16.6 | 97% | 15.7 | 27 | 63% | 7 |
| Wiregrass | 9.7 | 92% | 9.5 | 17 | 54% | 5 |
| Pilchuck | 9.3 | 92% | 8.8 | 15 | 49% | 5 |
| Lupton | 43.6 | 62% | 41.1 | 14 | 44% | 5 |
| Panther | 40.4 | 95% | 30.7 | 12 | 39% | 3 |
| Lake Prairie | 25.5 | 82% | 18.8 | 11 | 35% | 3 |
| Garcia | 10.1 | 90% | 10.1 | 9 | 31% | 3 |
| Negro Joe | 9.5 | 72% | 9.5 | 9 | 28% | 3 |
| Pardee | 26.4 | 68% | 23.6 | 8 | 25% | 3 |
| Dolly Varden | 28.2 | 92% | 23.5 | 8 | 23% | 3 |
| Coyote | 48.7 | 57% | 16.5 | 8 | 20% | 3 |
| Timbo | 4.0 | 94% | 3.8 | 6 | 17% | 1 |
| Lee | 3.3 | 100% | 3.1 | 5 | 16% | 1 |
| George | 7.3 | 100% | 6.4 | 5 | 14% | 1 |
| Garrett | 22.0 | 62% | 21.1 | 4 | 12% | 1 |
| June | 0.9 | 100% | 0.9 | 4 | 11% | 1 |
| Cashmere | 9.3 | 80% | 9.3 | 3 | 10% | 1 |
| High Prairie | 42.0 | 50% | 40.1 | 3 | 9% | 1 |
| Joplin | 4.7 | 90% | 3.7 | 3 | 8% | 1 |
| Debris Torrent | 2.0 | 91% | 2.0 | 3 | 7% | 1 |
| Twin Lakes | 9.8 | 90% | 9.8 | 3 | 6% | 1 |
| Loin | 5.4 | 81% | 5.0 | 3 | 5% | 1 |
| Headwaters_M | 16.4 | 74% | 15.1 | 2 | 4% | 1 |
| Noisy | 51.2 | 73% | 46.8 | 2 | 3% | 1 |
| Marquette | 6.7 | 91% | 6.7 | 2 | 2% | 1 |
| Stover | 4.8 | 56% | 4.8 | 2 | 2% | 1 |
| Powerline | 4.6 | 94% | 4.3 | 1 | 1% | 1 |
| Christmas Prairie | 6.9 | 73% | 6.9 | 1 | 1% | 1 |
| Six Rivers | 9.2 | 57% | 9.2 | 1 | 0% | 1 |
| Fern Prairie | 6.5 | 73% | 6.5 | 0 | 0% | 0 |
| Smokehouse | 5.8 | 74% | 5.8 | 0 | 0% | 0 |
| Santa Fe | 9.3 | 65% | 8.7 | 0 | 0% | 0 |
| Headwaters_W | 1.7 | 52% | 1.7 | 0 | 0% | 0 |
| Jena | 4.1 | 47% | 4.1 | 0 | 0% | 0 |
| Cool Springs | 9.6 | 45% | 9.5 | 0 | 0% | 0 |
| Burley | 3.2 | 91% | 3.0 | 0 | 0% | 0 |
| Tom | 2.7 | 93% | 2.2 | 0 | 0% | 0 |
| Johnson Prairie | 2.2 | 87% | 2.2 | 0 | 0% | 0 |
| Ayers | 3.8 | 97% | 3.6 | 0 | 0% | 0 |

# APPENDIX H

## SALMONID DISTRIBUTION IN THE REDWOOD CREEK WATERSHED

Figure H-1. Anadromous salmonid distribution by sub-watershed.

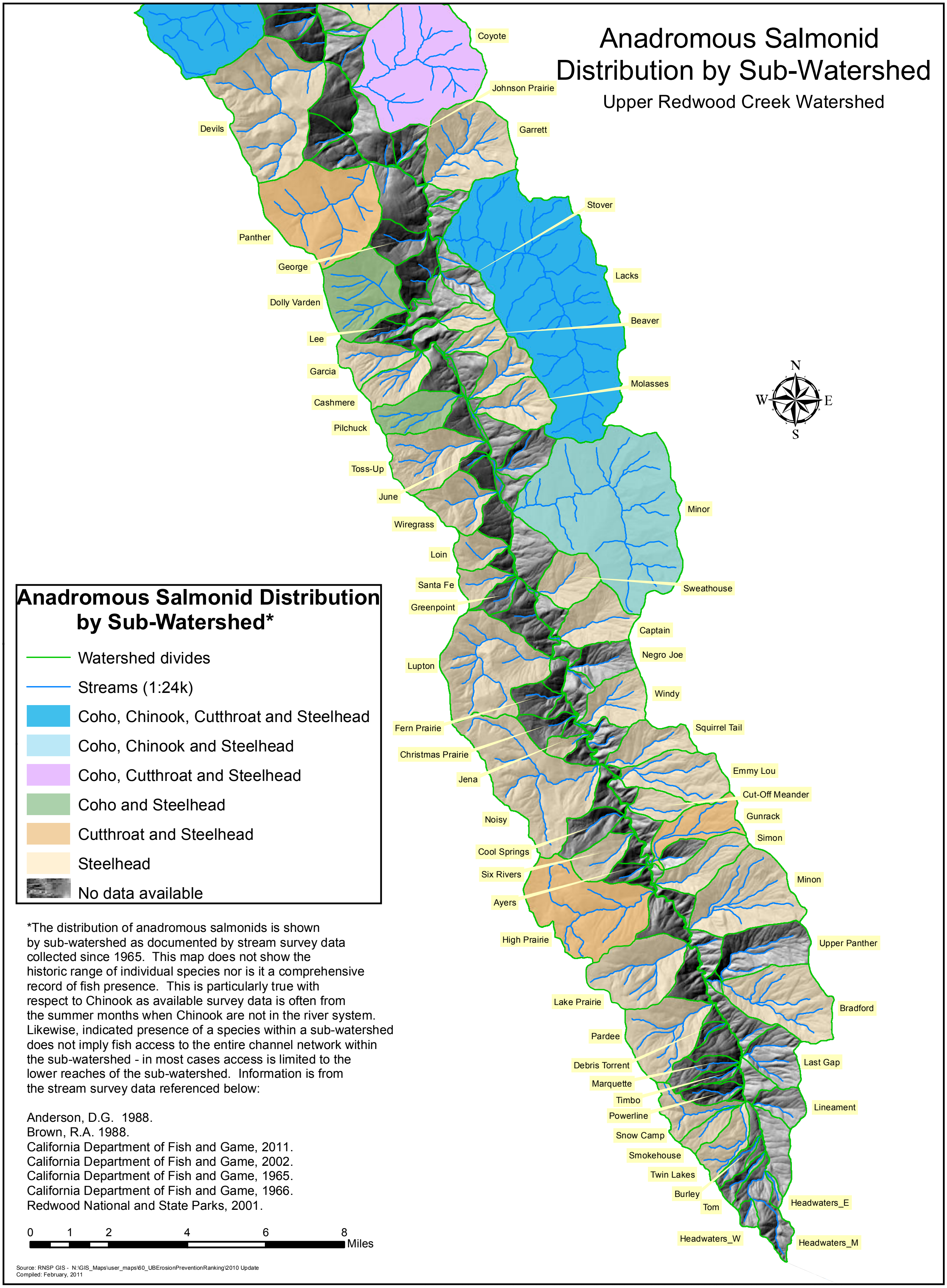


Figure H-1. Anadromous salmonid distribution by sub-watershed.