Freshwater Creek Watershed Analysis

Cumulative Effects Assessment

Prepared for:
Pacific Lumber Company (PALCO)
Scotia, CA

Prepared by:

Domoni Glass
Watershed Professionals Network

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1.0 INTRODUCTION

The Pacific Lumber Company (PALCO) initiated the Freshwater Watershed Analysis per the requirements in their Habitat Conservation Plan (HCP) (PALCO 1999). As part of this watershed analysis, a distinct cumulative effects assessment is required. This document details the results of that cumulative effects assessment. The assessment follows the methods detailed in the Watershed Assessment Methods for PALCO Lands (Palco, 2000), which were developed in coordination with the SRT. The cumulative effects assessment addresses the individual and synergistic effects of management practices on aquatic resources.

The cumulative effects assessment draws upon the information detailed in several resource reports. These resource reports include assessments of the effects of management practices on the inputs of coarse and fine sediment (mass wasting and surface erosion reports), flow (hydrology report), heat (riparian report), and large woody debris (LWD, riparian report). These resource reports also include assessment of the current condition of channels, fish habitat, and amphibian habitat (channel condition report, fish report and amphibian report, respectively). Finally, these reports contain a substantial amount of information on the linkages between the various inputs and the condition of channels, fish, and amphibian habitat, including many of the synergistic interactions. The reader is encouraged to review these reports for details on information used in this cumulative effects assessment report.

The information provided in the resource reports and additional information provided in this report is used to identify the cumulative effects of forest practices on aquatic resources. Once linkages between management practices and cumulative effects have been identified, Causal Mechanism Reports are developed that address the specific management actions determined to have significant effects on the aquatic resources. A Prescription Team has been convened to develop prescriptions or methods of operation in the watershed that address the identified linkages between management practices and watershed effects. All prescriptions are subject to the constraints specified in the HCP.

This Cumulative Effects Assessment focuses on past and ongoing management effects. The Prescription Team, which included scientists and resource professionals from PALCO and federal and state agencies, has developed a set of prescriptions based on the best available science. In this case, the best available science is the Freshwater Creek Watershed Analysis.

The multi-disciplinary Prescription Team has approved the resulting prescriptions as they are written in the Final Report. The prescriptions, as written, are designed to "maintain or achieve, over time, properly functioning aquatic habitat conditions". This goal was met in part, by ensuring the prescriptions will address the impact sources and pathways described in the Causal Mechanism Reports included in this CWE. To ensure that these new prescriptions will perform as designed, an exhaustive monitoring plan has also been developed to track the effectiveness of the prescriptions. In addition, the results of the monitoring program will be evaluated after a five year period, at which time the monitoring results will be used to evaluate and modify, if necessary, the current prescriptions to further ensure that they will maintain or achieve, over time, the properly functioning conditions of aquatic habitat. Wildlife agency letters approving the Freshwater prescriptions are included at the end of this chapter for interested readers.

1.1 PURPOSE

The purpose of this Cumulative Effects Assessment is to assess the effects of management practices, both individually and cumulatively, on aquatic resources, to document pertinent information and justification supporting the delineation of sensitive areas, and to identify specific management actions affecting aquatic resources.

Among other things, this report includes a summary of the results of the Resource Assessment Team's work as it pertains to the identification of effects and the completion of the Prescription process. Although attempts have been made to summarize the most pertinent information, neither the reader nor the Prescription Team should assume that all pertinent information has been captured here. This report also documents the public scoping process and the Synthesis process through which cumulative effects are analyzed. Finally, this report presents the Causal Mechanism Reports (CMRs), which are summaries of the sensitive situations identified by the Assessment Team. The Prescriptions Team will address these CMRs as part of the upcoming prescriptions process.

1.2 APPROACH AND PROCESS

The scientists conducting the resource assessment used the methods outlined in the "Methods to Complete Watershed Analysis on Pacific Lumber Company Lands in Northern California," which were published in April 2000 (PALCO 2000). These methods are based on Washington's "Standard Methodology for Conducting Watershed Analysis" (Washington Forest Practices Board 1997), modified to reflect situations unique to California, to include an analysis of forest practices effects on amphibians and reptiles, and to enhance the cumulative effects assessment of that document. These modifications were specified in the HCP.

This document contains the following general sections:

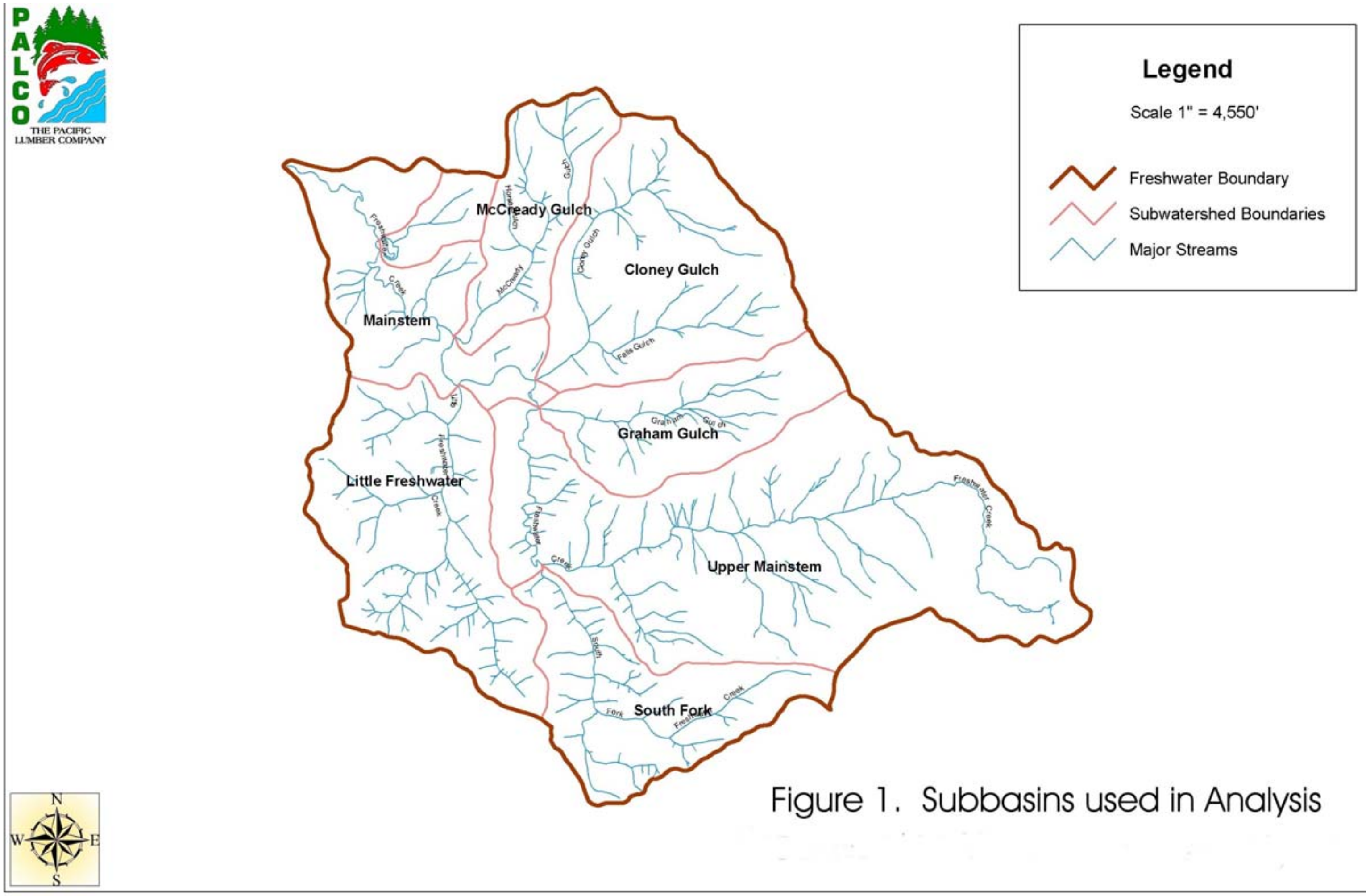
1) A watershed overview section that provides background information for the watershed areas;
2) A summary of the issue scoping process;
3) A summary of the scientific module results;
4) A summary of the Synthesis process, including generated CMRs.

The detailed assessment module reports are included as lettered appendices.

1.3 SUBBASIN DELINEATION

In consultation with the hydrology and stream channel analyst, eight sub-basins were selected within the Freshwater Watershed to localize the study of watershed processes. These sub-basins correspond to the major tributaries, and include Upper Freshwater, South Fork Freshwater, Little Freshwater, Graham Gulch, Cloney Gulch, McCready Gulch, School Forest, and Lower Freshwater (Figure 1).

Figure 1. Subbasins used in the analysis.



2.0 WATERSHED OVERVIEW

This section provides an overview of the physical attributes and land management activities within the Freshwater basin. The topics covered in this section are addressed in more detail within the individual module reports (Appendices A through G)

2.1 GEOGRAPHIC SETTING

The Freshwater Creek watershed is a 31-mi^2 drainage basin located approximately 5 miles east of Eureka, California in Humboldt County (Figure 2). Freshwater Creek drains into Humboldt Bay through the Freshwater and Eureka Sloughs at the north end of Eureka. Freshwater Creek is the primary stream flowing through the basin. Major tributaries of Freshwater Creek include Cloney Gulch, South Fork Freshwater Creek, Little Freshwater Creek, McCready Gulch, and Graham Gulch.

Elevations within the analysis area range from sea level at the mouth of the watershed to approximately 2,850 ft along Barry Ridge, located in the southwest corner of the analysis area. Slopes in the Freshwater Watershed are generally moderate (less than 35% slope gradient). Steep slopes (over 65% slope gradient) are found along portions of the inner gorge areas of Freshwater Creek and the major tributaries, including Cloney Gulch, Graham Gulch, the upper mainstem, the South Fork, and Little Freshwater Creek.

There are roughly 270 miles of stream within the basin. Of these, 36.5 miles are Class I streams (fish-bearing), 76 miles are Class II streams (supporting aquatic life), and 167 miles are Class III streams (small, seasonal headwater drainages). Overall stream density is approximately 9 miles of stream per square mile.

2.2 OWNERSHIP AND LAND USE

Approximately 24 mi^2 (15,400 acres), or 77% of the watershed, is owned and managed for timber by PALCO (Figure 3). Small private residences and several ranches comprise most of the remainder of the landowners in the basin. A number of small home sites and several large ranches occupy acreage around the eastern perimeter of the watershed in the Greenwood Heights and Kneeland areas. The lower watershed, including most of the Freshwater Creek floodplain and the adjacent terraces downstream from Freshwater County Park and the town of Freshwater, is privately owned by a number of small landowners. Some of the valley side slopes near and downstream from these valley bottom areas are also privately owned.

Major land uses in the watershed are forestry (91% of the watershed area), agricultural/ residential (8%), and power line right-of-way (1%) (Figure 4). The primary paved public roads in the watershed include Old Arcata Road, which passes through the watershed near the mouth; Greenwood Heights Drive, which follows the ridgeline on the north side of the watershed; and the Freshwater-Kneeland Road, which travels up the Freshwater valley from the mouth, intersecting Greenwood Heights Drive by way of Graham Gulch.

2.3 GEOLOGY AND SOILS

Sediments and rocks present within the Freshwater Creek Watershed consist of primarily three groups: the Wildcat Group, the Franciscan Central Belt Group, and the Yager Formation (Figure 5). The Wildcat Group is found most extensively in the western 60% of the watershed. This group is composed primarily of mudstone, siltstone, claystone, fine-grained sandstone, and minor conglomerate. Wildcat sediments are both erodible and potentially unstable by nature. Their silty and sandy composition results in rapid weathering and the development of granular, non-cohesive soil materials. Because the sediments are primarily silt- and sand-sized and are geologically young sediments (not indurated into hard rock), they are quite erodible when exposed. Gravels in the streambed that are derived from the Wildcat are typically very soft and can be broken between one's fingers. Hence, they weather quickly into fine materials once in the stream.

The eastern 40% of the watershed is composed primarily of Franciscan Central Belt metasedimentary rocks, separated from the Wildcat by the steeply dipping Greenwood Heights reverse fault (Knudsen 1993). It consists of a pervasively sheared matrix of fine sediments surrounding exotic blocks of greenstone, blueschist, serpentinite, graywacke, metagraywacke, and chert ranging from several meters up to hundreds of meters in size. Rocks in this group consist of a matrix of fine sediments with included blocks of harder metamorphic rocks. Like the Wildcat Group, this group weathers rapidly to sand, silt, and clay; however, it has a higher fraction of larger rocks that weather more slowly.

Yager Formation rocks underlie Wildcat sediments and have been exposed where major tributary stream channels have downcut through the younger sedimentary blanket. The Yager Complex consists of dark gray indurated mudstones, shales, graywackes, siltstones, and conglomerates, with interbedded limey siltstones. Rocks from the Yager Formation are much harder and generate larger classes of gravel and cobble. Yager sandstone and conglomerate clasts can travel down channels and not immediately crumble. However, the shale rock components of the Yager formation will crumble in

Figure 2: The vicinity of the Freshwater Watershed.

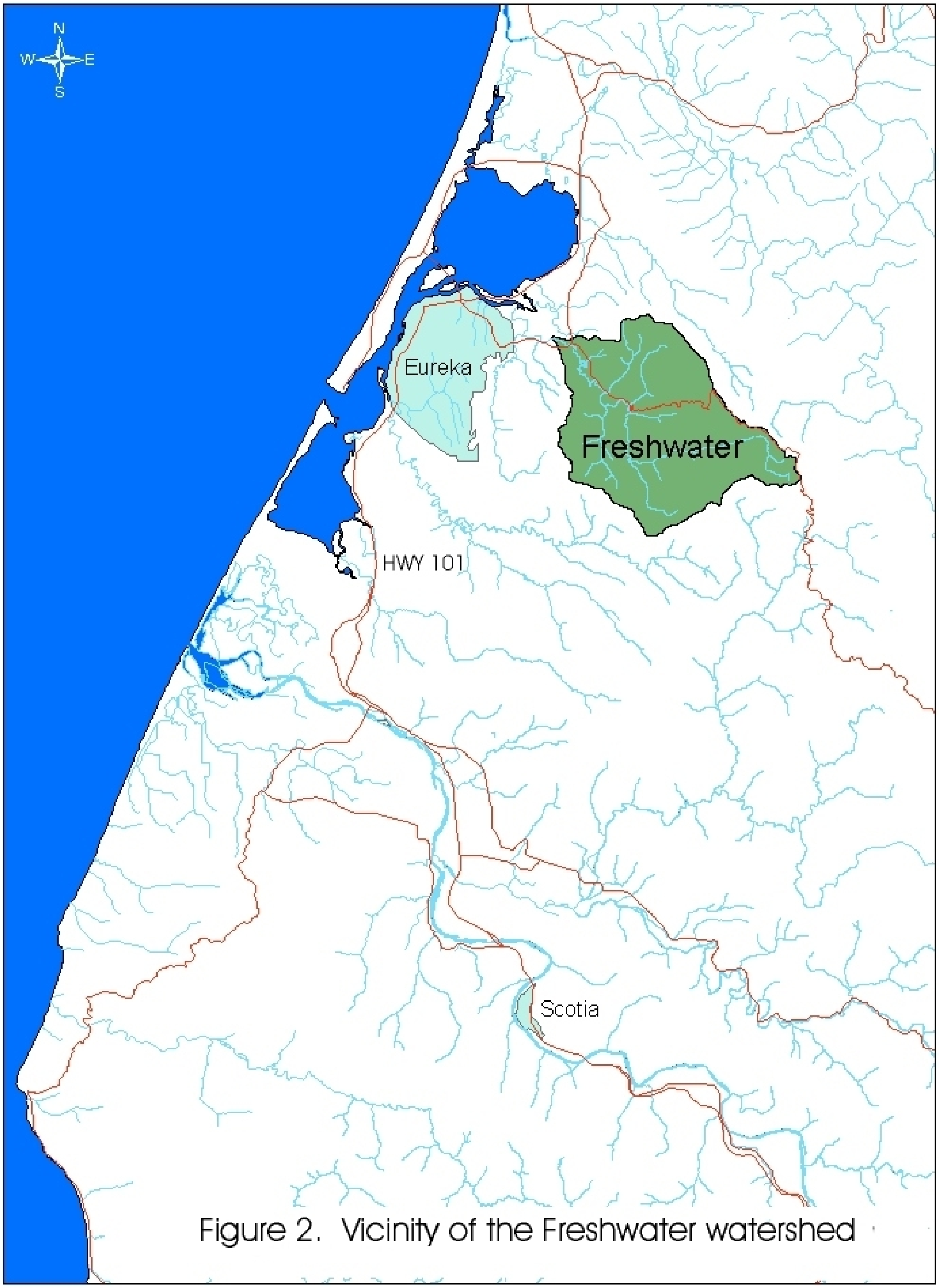


Figure 2. Vicinity of the Freshwater watershed

Figure 3: PALCO ownership within the Freshwater Watershed.

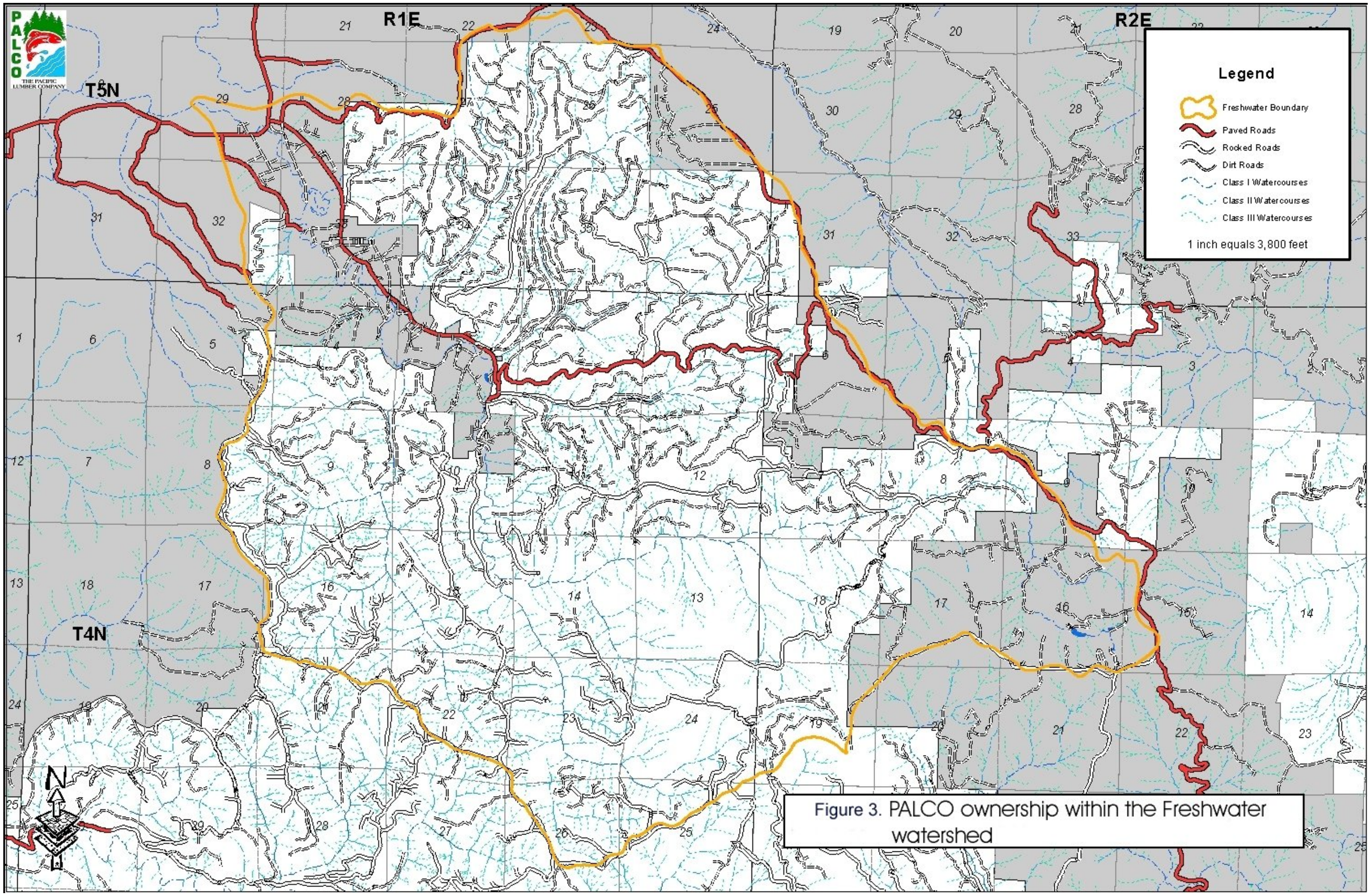


Figure 4: Major land use groups within the Freshwater Watershed. Including forest lands (shown in black), agricultural/residential areas (shown in light gray), and power line right-of-way (shown in gray).

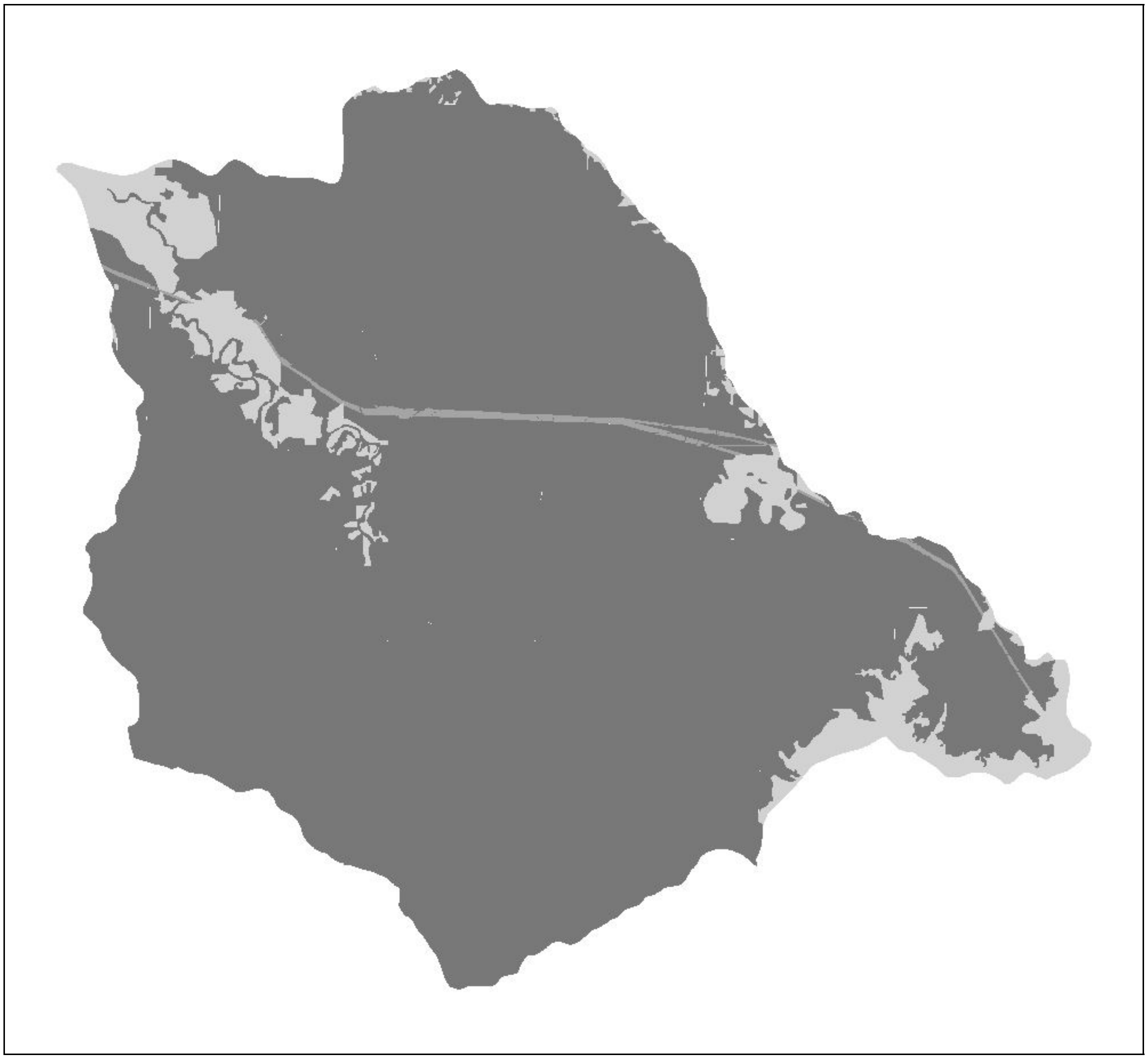
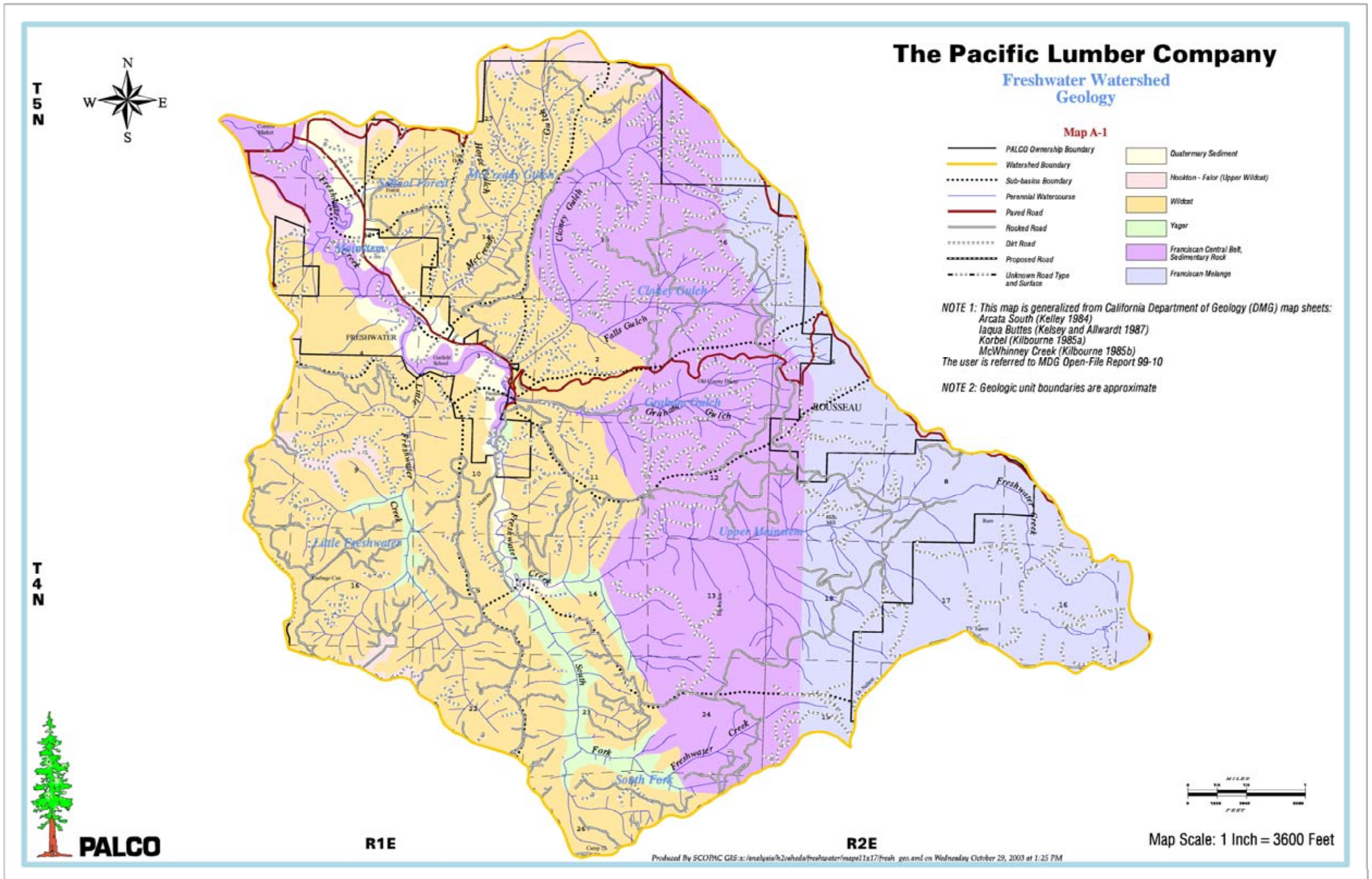


Figure 5: Freshwater Watershed geology.



one season in streams if it is exposed to more than a few wetting and drying cycles. For this reason, attrition in the Yager is bimodal: the sandstones are competent, and the shale is weak.

Large expanses of Quarternary alluvium are also found in the lower watershed, mostly located within numerous privately owned parcels along Freshwater Creek. This rock has been deposited over time in the floodplain and active channel of Freshwater Creek. The material is typically comprised of unconsolidated, poorly sorted sands and sandy pebble conglomerate.

Rates of hillslope erosion and downcutting by major streams within the soft rocks of the Wildcat Formation are geologically rapid, so topography in the western portion of the basin consists of lower gradient hillslopes and streams (Figures 6 and 7). In contrast, topography of the eastern side of the watershed, which is dominated by Franciscan bedrock, is often steep and convex in profile, probably because channel downcutting has not kept pace with local uplift rates.

Soils are roughly correlated with underlying geology, with Larabee soils in areas of Wildcat geology in the western half of the basin and Hugo, Atwell, Melbourne, and small areas of other soils on Franciscan geology in the eastern portions of the basin. Bottomland and farmland soils are developed on the Quaternary alluvium in the lower mainstem.

2.4 FISH AND AMPHIBIAN SPECIES AND DISTRIBUTION

2.4.1 Fish

The primary fish species of concern in the basin include coho and chinook salmon, steelhead/rainbow trout, and coastal cutthroat trout. Speckled dace, prickly sculpin, riffle sculpin, Pacific lamprey, brook lamprey, and three-spine stickleback are also found in the basin.

Coho are found in each of the sub-basins (Table 2-1), with the possible exception of School Forest, up to the point where either natural barriers or increasing stream gradient limits their distribution. The highest densities of coho can be found in the lower reaches of Cloney Gulch, Upper Freshwater, McCready Gulch, and possibly the mid- to lower mainstem. Upstream adult spawning migration generally occurs from mid-October to mid-February. Fry emerge in late winter or early spring. The young fish rear in the basin for 10 to 15 months before moving downstream to enter the ocean. This outmigration typically starts around March when the coho are about one year old.

Table 2- 1: Occurrence of salmonid species in Freshwater Watershed by subbasin.

CDF Planning Watersheds	Eddysville (110.00012)				Freshwater (110.00011) Includes Upper Main above SF		Camp 12 (110.00014) Includes portions of upper main below SF	
	Mainstem	School Forest*	McCready Gulch	Cloney Gulch	Graham Gulch	Upper Freshwater	Little Freshwater	SF Freshwater
Coho	High	UKN	High	High	Low**	High	Mod.	High
Chinook	High	UKN	Low	Low	Low	Low	Low	Low
Steelhead	High	UKN	Low	High	High	High	Mod.	Mod.
Cutthroat	Mod.	UKN	High	Mod.	Low	Mod.	Mod.	Mod.

* No fish data were available regarding presence in School Forest. In addition, surveys (underwater and electrofishing) failed to detect any fish in School Forest. This sub-basin doesn't have any suitable habitat for chinook.

** Based on 1993-1994 electrofishing index reach sampling, Graham Gulch appeared to have a fair density and biomass of coho prior to the earthflow reinitiating in the mid 1990s.

Steelhead are found in each of the sub-basins, with the possible exception of School Forest, up to the point where either natural barriers or increasing stream gradient limits their distribution. They are most common in Upper Freshwater Creek. Winter run steelhead generally enter the watershed in early December through spring and begin spawning soon after. Upon emerging from gravel, the fry rear in edgewater habitats and move gradually into pools and riffles as they grow larger. Juvenile steelhead spend 1 to 3 years in fresh water before migrating to the ocean. Downstream migration takes place in spring and early summer.

In the Freshwater basin, chinook tend to be found primarily in Lower and Middle portions of the mainstem of Freshwater Creek and lower portions of South Fork Freshwater Creek where significant deposits of coarse gravel from the Franciscan formation are found. Their distribution in Upper Freshwater is limited by the presence of natural barriers. Chinook salmon generally leave ocean waters and enter Freshwater Creek in early November through mid-January. Spawning usually occurs from November through January. The eggs develop in the gravel for 50-60 days before hatching, depending on water temperature. Young salmon emerge from gravel after the yolk sac is absorbed 2 to 4 weeks later. Juvenile chinook generally begin their downstream migration soon thereafter. Downstream migration is usually complete by late June, but some fish may remain in estuaries until fall and enter the ocean as yearlings.

Coastal cutthroat trout are found in each of the Freshwater Creek sub-basins, with the possible exception of School Forest. Although, present in low numbers in the lower

Figure 6: Freshwater Watershed analysis topographic analysis relief map.

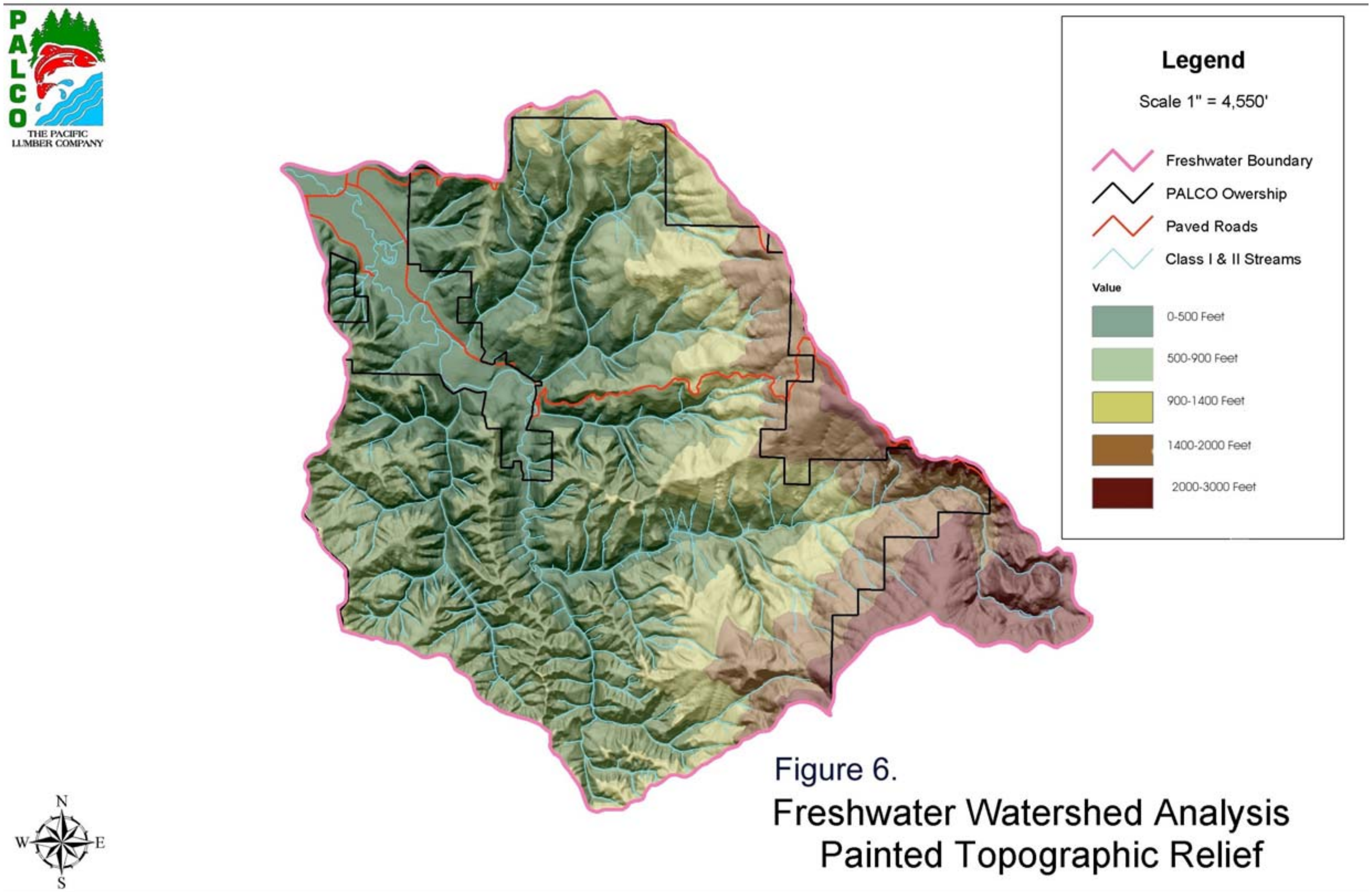


Figure 7: Geologic cross-section of the Freshwater watershed.

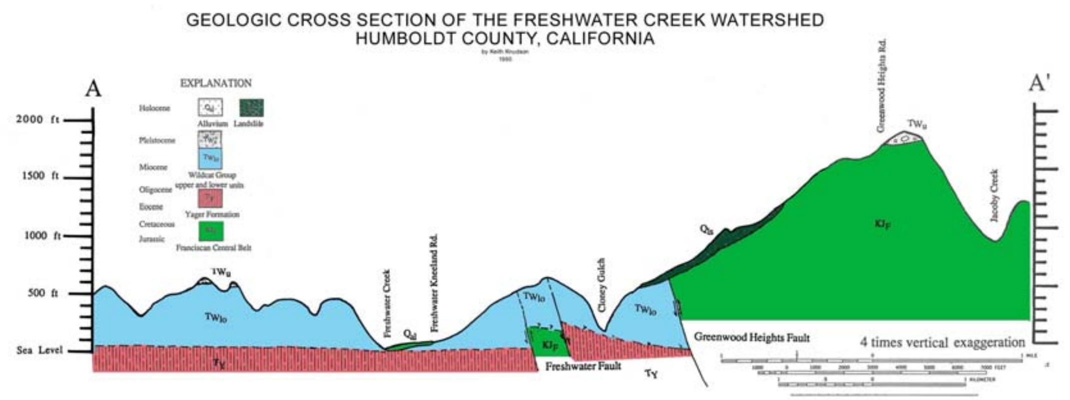


Figure 7. Geologic cross-section of the Freshwater watershed.

portion of the stream network, they are the dominant species upstream of barriers to steelhead and salmon. The populations upstream of migration barriers are resident populations. Populations below the barriers may include both resident and anadromous populations. Spawning usually occurs in the late fall or early winter. Juveniles of anadromous strains generally rear for two or more years in freshwater before migrating to the estuaries or the sea.

2.4.2 Amphibians and Reptiles

There are five amphibian and reptile species covered in the HCP (PALCO 1999). Three of these five reptile species were found in the watershed: the southern torrent salamander, the northern red-legged frog, and tailed frogs. A fourth species, foothill yellow-legged frog, is believed to be present in the watershed. Northwest pond turtles have not been documented in the basin. Local residents have reported seeing a turtle in the lower basin, but the species is unknown. See Table 2-2.

Table 2- 2: Distribution of amphibians in Freshwater Watershed based on sample data.

	Eddysville (110.00012)				Freshwater (110.00011) Includes Upper Main above SF		Camp 12 (110.00014) Includes portions of upper main below SF	
	Mainstem	School Forest	McCready Gulch	Cloney Gulch	Graham Gulch	Upper Freshwater	Little Freshwater	SF Freshwater
# Sites Sampled	13	0	3	5	3	0	4	5
Yellow-legged frog	0	-	0	0	0	-	0	0
Red-legged frog	√	-	0	0	0	-	√	√
Northern pond turtle	0	-	0	0	0	-	0	0
Tailed frog	√	-	0	√	√	-	√	√
Torrent salamander	√	-	0	√	√	-	0	√

√ Verified presence
0 Not found
- No sampling conducted, Unknown

The southern torrent salamander is highly aquatic, usually found within a few meters of seeps, saturated talus, or the splash zones of streams. They are found in cold seeps and non-fish-bearing headwater streams with substrates larger than sand. Within the Freshwater basin, southern torrent salamanders are most commonly found in non-fish-bearing streams underlain by Franciscan Central Belt geology, where larger substrate can be found. They were not generally found in streams that flow over Wildcat Group due to the lack of coarse substrate. Exceptions may include areas where Yager geology has been exposed in the bed of streams that flow primarily through Wildcat geology.

Tailed frogs occupy aquatic habitats very similar to those used by the southern torrent salamander. The tailed frog is most commonly found in or immediately adjacent to cold, permanent, headwater streams, and prefers streams with unembedded cobble/boulder sediments. The tailed frog has been found 20 to 30 m from water during wet weather but is most commonly found in or immediately adjacent to permanent streams. Within the Freshwater basin, tailed frogs are most commonly found in non-fish-bearing streams underlain by Franciscan Central Belt geology, where larger substrate can be found. They were not generally found in streams that flow over Wildcat Group geology due to the lack of coarse substrate. Tailed frogs, however, were found in one Wildcat-dominated stream segment where Yager Foundation rocks are exposed, thereby providing the needed coarse material. This species may also be present in other areas with exposures of Yager Foundation rocks.

The foothill yellow-legged frog is a river-dwelling frog typically breeding in shallow, low-velocity habitats adjacent to shallow, wide stream reaches with cobble and larger substrate. This species is typically found in or immediately adjacent to streams. During winter, adults have been found up to 5 m from the streams, possibly hibernating. Foothill yellow-legged frogs are thought to be present throughout the basin in fish-bearing streams, although none was observed during field surveys.

The northern red-legged frog prefers a variety of slow-moving water habitats, ranging from lakes, ponds, stream backwaters, and sloughs to roadside ditches. Breeding habitat (ponds, ditches, and very slow-moving streams with emergent vegetation) is thought to be an important limiting factor. This species is expected to occur throughout the watershed in appropriate habitat. The terrestrial needs of this species are not well understood; although adults have been found 200 to 300 m from water, upland habitat requirements have not been well documented. Northern red-legged frogs are believed to be present throughout the basin in fish-bearing streams.

2.5 CLIMATE AND HYDROLOGY

The analysis area experiences climatic conditions typical of coastal northern California. The northern California coast has a completely maritime climate, marked by high levels of humidity throughout the year. The rainy season runs from approximately October through April, during which time approximately 90 percent of the annual precipitation occurs. The dry season lasts from May through September. During the dry season, morning low clouds and fog are common, often clearing by early afternoon, and returning by evening. The Freshwater Creek Watershed receives an average of 40-75 inches of rain per year, with lower amounts of rain in the lower mainstem and increasing precipitation at higher elevations. The majority of the precipitation falls as rain, with snow uncommon in most of the basin. Estimated mean annual precipitation for the analysis area is 60 inches. Mean monthly precipitation estimates for the entire watershed range from 0.25 inch for the month of July to 11 inches for the month of December.

Air temperatures in the north coast area are moderate, and the annual fluctuation is one of the smallest in the conterminous United States. Seasonal air temperature variation is small due to the proximity to the Pacific Ocean. The prevailing northwest winds cross cold up-welling waters usually present along the Humboldt County coast. The record high temperature in Eureka is only 85^0F, and the record low only 20^0F. Mean minimum temperature in Eureka for the month of January is 41^oF, and the coldest low temperatures in a typical winter are in the mid 30s. Mean maximum temperature in Eureka for the month of September is 63^oF, while the highest temperatures are typically in the mid 70s.

Streamflow patterns tend to follow the precipitation patterns, with the greatest flows in winter and spring, and lowest flows in summer (Figure 8). Major storm events were difficult to synthesize due to the paucity of the data available from within the watershed and the often weak correlation between in-basin flows and other stream gages. Nevertheless, it appears that major storm events occurred in 1953, 1955, 1964, 1972, 1975, 1986, 1996, and 1997. From 1984-1994, peak flow events tended to be near or slightly lower than the long-term average. The period from 1994-1998 contained numerous peak flow events that exceeded the long-term average.

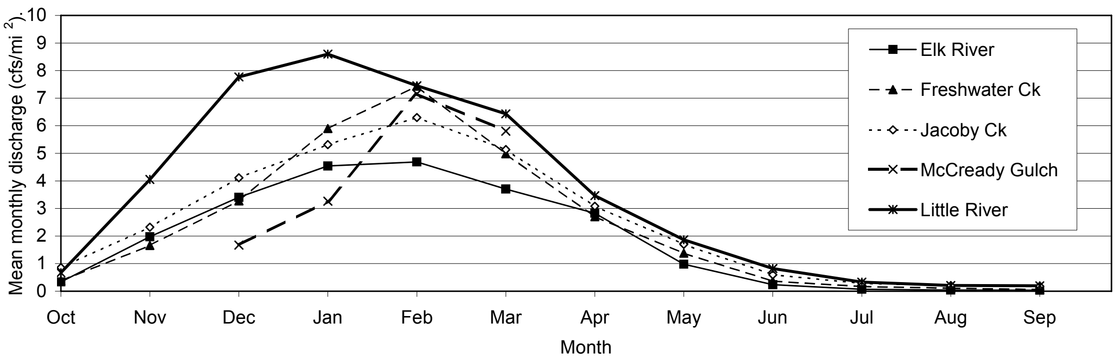


Figure 8: Mean monthly discharge at several stream gages in the vicinity of the analysis area.

2.6 VEGETATION

Redwood (*Sequoia sempervirens)* is endemic to the western United States and is the dominant tree species within much of this area. Other important tree species in this area include *Pseudotsuga menziesii* (Douglas-fir), *Abies grandis* (grand fir), *Tsuga heterophylla* (western hemlock), *Picea sitchensis* (Sitka spruce), *Lithocarpus densiflorus* (tanoak), and *Arbutus menziesii* (Pacific madrone). Redwood plant associations are prevalent throughout most of the Freshwater basin.

The pre-European forest condition in Freshwater was redwood – fir forests except for within ½ mile of Three Corners and the uppermost portion of upper Freshwater Creek. The very lowest portion of the basin consisted of grass tide flats. Tidal flooding and wind-borne high salt spray aerosols have probably always prevented redwoods from establishing in the very lowest portion of the watershed.

Currently, the portion of the Freshwater basin within about ½ mile of Three Corners and downstream is part of the coastal prairie-shrub mosaic characterized by *Baccaris* sp., *Danthonia* sp., and *Festuca* sp. Sitka spruce and Douglas-fir, both salt spray tolerant species, were likely more prevalent along the edge of the tidal zone as forests quickly transitioned to redwood – fir plant associations. Redwoods are the dominant species throughout the watershed for both current and historical (pre-European) forests for almost the entire Freshwater drainage. Total overstory canopy for old-growth redwood forests typically does not exceed 85% when averaged over stands. Understory herbaceous plants of this plant association include *Polystichium munitum, Vaccimium ovatum,* and *Vacinium parviloium*.

The majority of the riparian forest in the Freshwater is approximately 70-year-old second-growth redwood plant communities. These stands are even-aged with a fairly uniform overstory canopy. Mixed stands of redwoods and hardwoods occupy 10% of the total streambank length in the basin. Mixed stands are more prevalent along Class I streams. Hardwoods account for 4% of the streambank length for all streams or 11% of Class I streambank length. There are almost no hardwoods along Class II streams. Most of the hardwood stands are concentrated in the lower residential reaches of Freshwater Creek. Mixed stands with a hardwood component also occur along the uppermost reaches of upper Freshwater Creek.

The cool, humid climate and generally moist conditions of lower elevation redwood forests do not provide a good medium for wildfire initiation or propagation. As a result, fire recurrence intervals in undisturbed redwood forests are considered to be on the order of 25-50 years for low intensity fires, and 500-600 years for high intensity, stand-replacing fires.

2.7 BASIN HISTORY

Logging in the Freshwater basin began in the 1860s in the School Forest sub-basin of the lower watershed. Steam donkey and railroad logging spread up the drainage in the 1870s through the turn of the century. These early entries included McCready Creek (1870s), lower Cloney Gulch (1880s and 1890s), Falls Gulch (1880s), Graham Gulch (1880s and 1890s), and lower Little Freshwater Creek (1870s and 1890s). Railroad logging recommenced in the 1920s along the main stem of Freshwater Creek, within the Little Freshwater Creek drainage and lower portions along South Fork Creek. Railroad grades were commonly placed within the riparian areas or up the stream channel; examples of streamside railroad grades include McCready, Cloney, Graham, and portions of the South Fork. Railroad timbers and logging debris used to fill crossings of small lateral tributaries still contribute to in-channel woody debris within some stream sections.

Early logging, prior to the late 1950s, was almost exclusively by clearcutting and cable yarding. Virtually the entire watershed was logged (clearcut) by the 1950s, with overall harvesting and clearcutting rates for this period peaking in the 1930s at nearly 600 acres/year.

With the exhaustion of old-growth timber, harvesting rates declined in the 1940s and 1950s and then picked up again in the late 1960s as lower basin second-growth forests were commercially thinned. Between 1966 and 1974, the first truck roads were built into the lower basin, and widespread tractor logging was being employed to commercially thin portions of the advanced second-growth forest. Between 1966 and 1974, approximately 49 miles of haul roads were constructed in the basin. Some of the main truck roads utilized the existing railroad grades within riparian areas.

Beginning in 1973, revisions to California's Forest Practice Rules resulted in more restrictive logging practices and a general trend of reduced disturbance and wider stream buffers than during previous decades. Since about 1987, riparian buffers of 100-ft width have been left where clearcut harvest units adjoined Class I and II streams.

In recent years (1995-1997), harvesting rates have systematically increased as second-growth forests have again achieved harvestable ages/sizes. Clearcutting has increased to an average of just under 400 acres per year, and overall harvesting rates (clearcutting plus partial cutting) have risen to an average of approximately 1,200 acres per year in the same period. Over the past decade, the majority of the harvest has occurred in the Little Freshwater, Cloney Gulch, South Fork Freshwater, and Upper Freshwater (Table 2-3).

Table 2- 3: Acres harvested (clearcutting plus thinning) 1989 to 1999 by subbasin.

Subbasin	Acres Harvested
Mainstem	211
School Forest	61
McCready Gulch	370
Cloney Gulch	1776
Graham Gulch	1045
Upper Freshwater	1338
Little Freshwater	2109
South Fork Freshwater	1482
Total	**8392**

3.0 SCOPING OF ISSUES

On July 1, 1999, a public meeting was held to solicit input regarding the local issues of concern within the Freshwater Creek Watershed. Attendees provided comments regarding issues via written notes, which were subsequently assembled. These comments are listed in their entirety in Addendum A. Comments were received on a wide range of subjects (Table 3-1). Some of the comments included more than one subject and are listed more than once in Addendum A and Table 3-1.

Table 3-1: Numbered of public comments received by each subject.

Subject	Number
Air Quality	3
Habitat and Channel Morphology	21
Bay Ecology	4
Biodiversity/Terrestrial Resources	9
Domestic and Agricultural Water Use	4
Economics	8
Hydrology	19
Mass Wasting	10
Quality of Life/Private Property	8
Riparian Condition	8
Sediment Production and Transport	22
Soil Productivity	5
Water Temperature	3
Multiple Subjects Covered	6
Other	12

The comments were carefully reviewed and screened per the methods detailed in the Watershed Assessment Methods for PALCO Lands (2000). Each comment was put into one or more of the following categories:

1) Issue out of the Watershed Analysis (WSA) scope
2) Untested theory: may need to incorporate into assessment
3) Not feasible to address per the definition in the methods
4) Issues to address

4a) Issue is addressed in the default analysis methods

4b) Issue is partially addressed in the default WSA methods and partially falls into categories 1, 2, or 3 above

4c) Issue is partially addressed in the default WSA methods; modifications to methods may be needed for this analysis

4d) Issue is not explicitly addressed in default methods; modifications to methods may be needed for this analysis

5) Comment is either a statement that could not be translated into a theory relating management practices to effects on aquatic resources, or comment does not address a specific issue (too vague)

The majority of the comments received addressed issues that were fully or partially addressed by the default methods (Table 3-2). These comments covered the entire range of issues addressed by the standard watershed analysis methods. Those comments that are listed under category 4b were all primarily addressed in the standard methods, but some component of the comment fell out of scope for the analyses. The issues that fell partially out of scope included estimation of the population of turtles, livestock effects, change in impervious surfaces associated with residential development, quality of swimming holes, areas that lie outside of the watershed, herbicide use as it affects water quality, and economic effects. The category 1 (out of scope) issues that were identified also included concerns regarding global climate change, aquaculture, bay ecology, commercial fisheries, air quality, terrestrial resources, noise, tourism, and economics. These are all explicitly excluded from the assessment goals and objectives.

Eleven comments were received regarding the effects of flooding on residential properties. The default methods include an assessment of the effects of forest practices on peak flow events (flooding) but do not directly evaluate the effects of those changes on residential developments on the floodplain (listed under Category 4c in Table 3-2). The methods used in the Freshwater Watershed Analysis were subsequently modified to provide an in-depth assessment of potential flooding effects on floodplain developments. Hypotheses regarding the linkages and an in-depth discussion of the methods and results of the analysis are provided in the Stream Channel Condition Module. These are also summarized in Section 4.0 of this document. The flow chart of issues addressed by the assessment was updated to reflect the addition of the linkage between forest practices and flooding of residential developments (Figure 9). No other issues were identified that are not at least partially addressed in the standard methods.

Table 3- 2: Number of public comments that fell into each of the screening categories. Comments that included more than one subject were not double counted in this table.

Category Number	Screening Category	Number
1	Out of the Watershed Analysis Scope	31
2	Untested Theory	1
3	Not Feasible to Address	1
4a	Addressed in Default Methods	57
4b	Partially Addressed in Default Methods, Partially in one of the Above Categories	15
4c	Partially Addressed in Default Methods, Modifications to Methods Required	11
4d	Not Addressed in Default Methods, Modify Methods	0
5	Comment Vague, Could Not Be Interpreted	4

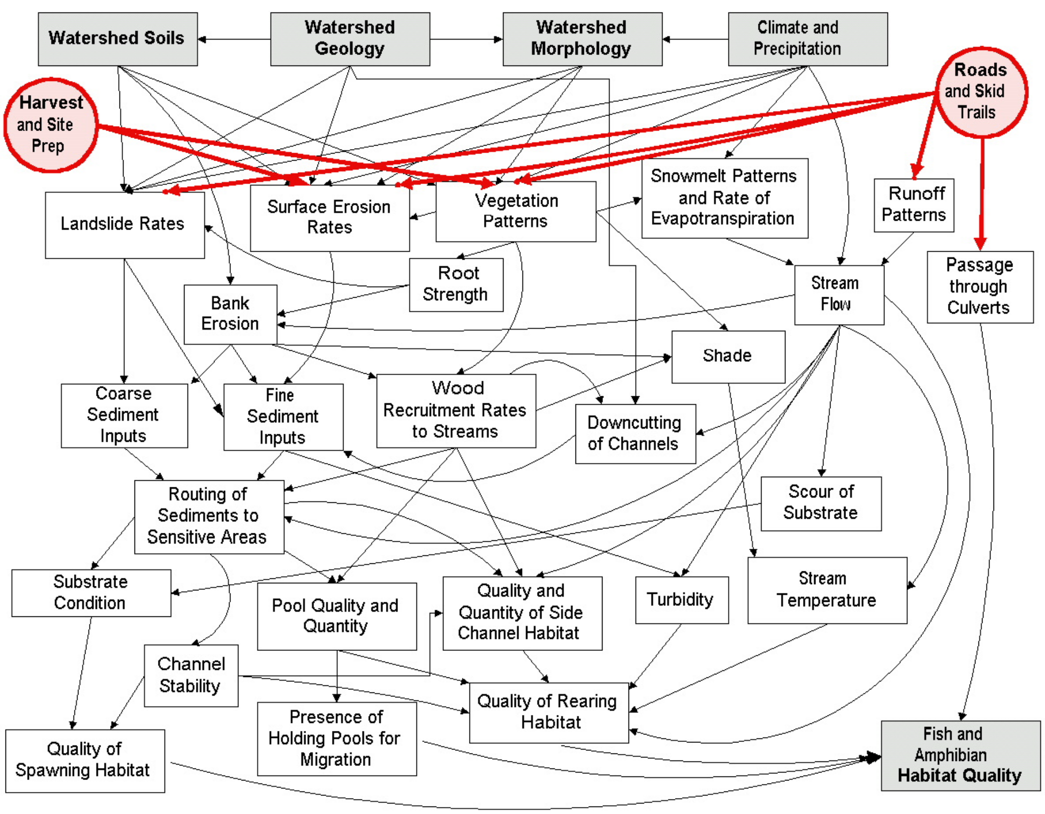


Figure 9: Updated flow chart reflecting additional potential linkage between forest practices to flooding of residential developments.

4.0 MODULE SUMMARIES

The Watershed Analysis included in-depth assessments of mass wasting, surface erosion, hydrology, riparian condition, fish habitat, amphibian and reptile habitat, and channel condition. In each of these assessments, the effects of forest practices were evaluated to identify significant linkages between management practices and subsequent effects on aquatic resources. These assessments are provided in detail in the individual module reports, included as Appendices A through G. The module summaries provided below provide the key findings of each of the modules.

Note that no specific chapter has been written addressing water quality directly. Water quality is addressed throughout the various sections as it pertains to watershed processes. Hence, issues regarding turbidity are addressed under mass wasting and surface erosion (sediment inputs) and fish habitat (fish response to sediment inputs). Likewise temperature is addressed in the riparian section (processes affecting water temperature) and under fish habitat (fish response to temperature).

Confidence is the assessment is highly variable. In some cases, a great deal of data was available and the confidence in conclusions is very high. In other cases, assessments draw on limited data or poorly calibrated models. In these cases, confidence in the conclusions is much lower. A discussion of the confidence in the assessments is provided in section 4.9. Readers desiring additional information regarding the overall assessments or details on confidence in conclusions are referred to the module reports themselves.

4.1 MASS WASTING

Two approaches were taken to evaluate the landslide occurrences and identify landslide hazard areas. One of these methods was an empirical approach that relied on assessing the relative density of landslides over time as a function of landform. The other relied on a modeling approach (deterministic approach). The shallow landslide inventory involved the identification of landslides on aerial photos dating from 1942 through to 1997, a 55-year period of record. In addition, all smaller landslides reaching streams that initiated at roads that were identified in the field were plotted on the landslide inventory map.

Landslide rates were evaluated relative to geologic unit, landform, and slope class. Landforms used in the assessment included planar, incised, headwall, convex, and complex hillslopes. Slope classes included steep (>30 degrees), moderate (20-30 degrees), and gentle terrain (< 20 degrees). The plots included in this document represent trends in central tendency. Those interested in the confidence limits around the values are referred to plots and discussion in the Mass Wasting Report.

The sections that follow address sediment inputs through actual landslide events alone. It is recognized that once a landslide occurs, sediment can erode from the surface of that slide at a rate greater than would be seen in the absence of the slide. This sediment can be delivered to a stream regardless of whether the actual landslide reached the stream if the slide location was in close enough proximity to allow for transport of that sediment. The effects of surface erosion from landslides are addressed in the discussion on surface erosion (Section 4.2).

4.1.1 Hillslope Landslides

Hillslope landslides are those slides that are not associated with roads. There appears to be more landslides on the Yager Formation than on other geologic units (Figure 10), however the number of slides found on Yager Formation is small due to the limited spatial extent of this geology. Hence, there is a substantial amount of uncertainty regarding whether this apparent difference is significant (see Mass Wasting Module Report for details on variability). Landslide frequencies in general appear to be lower than are seen in other areas in the region. For example, a study of landslide rates in Bear Creek (PWA 1999) found over an order of magnitude greater landslide sediment inputs to streams than were documented in this assessment for the Freshwater Watershed.

Landslides densities vary substantially between landform/slope classes (Figure 11). The highest cumulative density of landslides occurred on steep planar hillslopes. Landslide densities were also high on steep convex slopes. More moderate landslide densities were found on moderate convex, steep incised, moderate planar, and headwall areas. The stochastic modeling found similar results, with the exception that convex steep hillslopes were found to have a higher probability of failure (Figure 12).

Each of the landforms has been given a descriptive hazard call, which reflects the potential for a landslide to occur (Table 4-1). The reader should note, however, that the actual hazard ratings given to any area on the landscape were based on a statistical analysis of the data that related landslide frequency to a variety of parameters, including slope, geology, local topography, and other factors. Details of this analysis are provided in the Mass Wasting Report. The ratings in Table 4-1 represent a relative rating of the various landforms. On average, the highest hazard areas were determined to be the convex steep, planar steep, and headwall landforms.

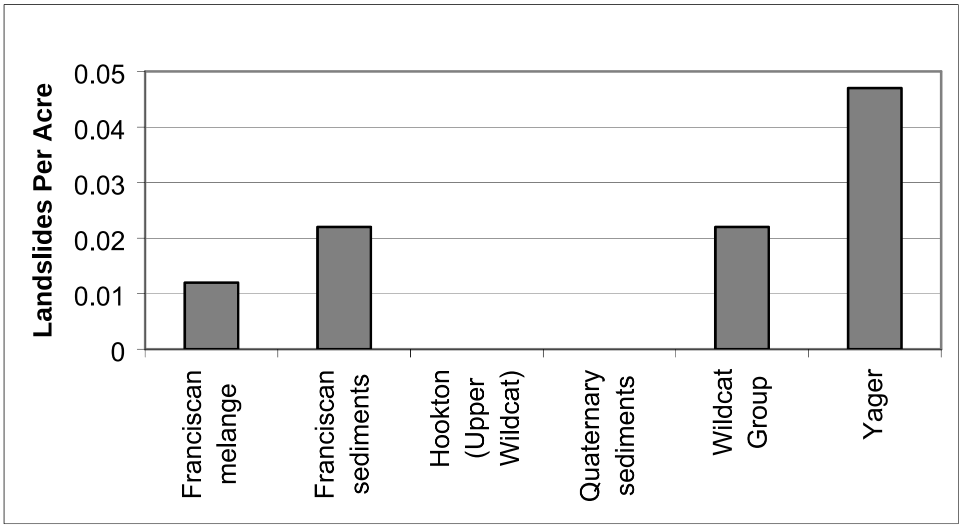


Figure 10: Hillslope landslides per acre by geologic unit.

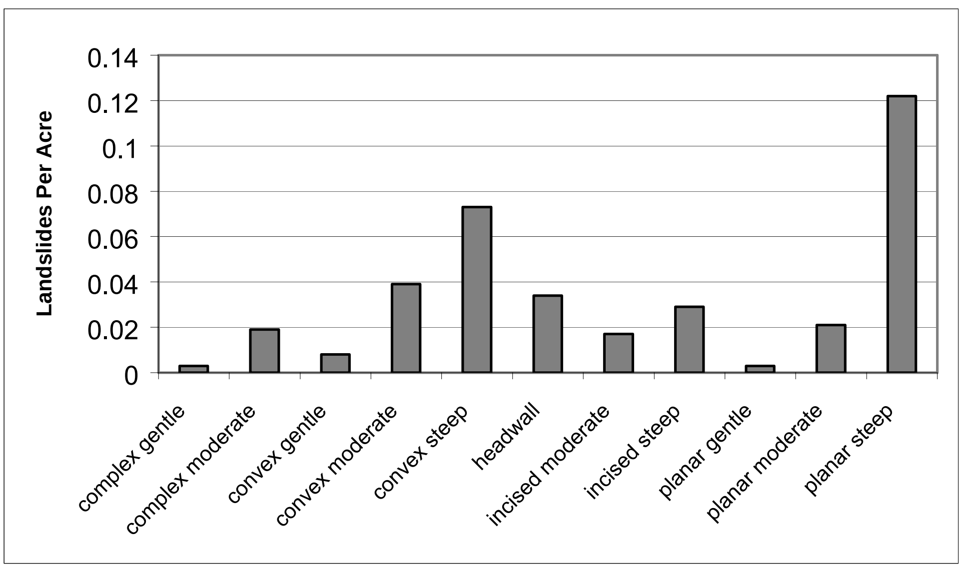


Figure 11: Hillslope landslides per acre by landform/slope class.

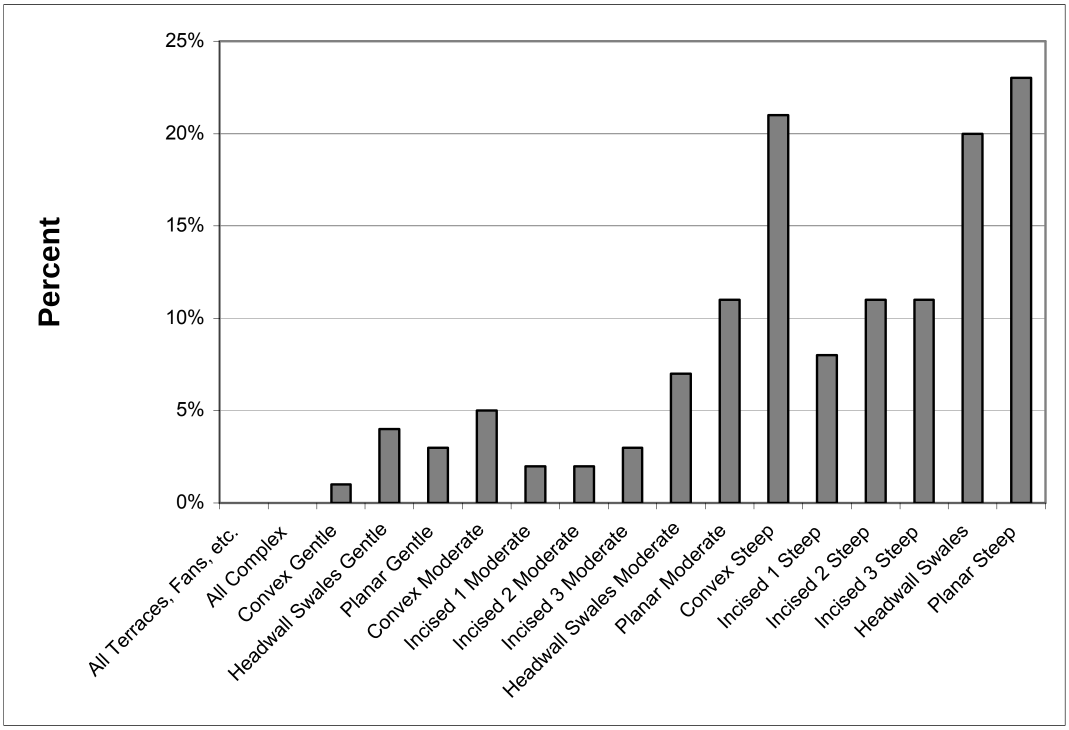


Figure 12: Probability of slides based on the stochastic modeling.

Table 4- 1: Landslide hazard calls (no delivery factored in) for various landforms.

Landform/Slope Class	Hazard Call
All Terraces, Fans, etc.	Very Low
All Complex	Very Low
Convex Gentle	Low
Headwall Swales Gentle	Low
Planar Gentle	Low
Convex Moderate	Low
Incised 1 Moderate	Low
Incised 2 Moderate	Low
Incised 3 Moderate	Low
Headwall Swales Moderate	Low
Planar Moderate	Moderate
Convex Steep	High
Incised 1 Steep	Moderate
Incised 2 Steep	Moderate
Incised 3 Steep	Moderate
Headwall Swales	High
Planar Steep	High

Areas of concern to aquatic resources are those that may potentially slide AND deliver sediment to a stream. The potential for a slide to reach a stream was evaluated based on landslide runout data (e.g., how far landslides traveled downslope after they initiated). The density of slides in any area was then weighted by the probability that the slide would reach a stream to determine the landslide delivery density of any area in the watershed.

The results of these calculations are depicted on Map A-6 of the Mass Wasting Report. The areas with highest potential for a landslide to occur that subsequently delivers to streams (0.08 to 0.09 landslides per acre) are found on the right bank of upper McCready Gulch, in an area midway up Cloney Gulch, in a couple of areas in lower Little Freshwater, in scattered areas in the headwaters of Little Freshwater, South Fork, and Upper Mainstem, and in several areas along a tributary on the right bank of the upper mainstem. Additional scattered areas can be found in other areas of the watershed. The acres affected by these hazard calls are depicted in Figure 13.

The effect of management on landslide rates was also evaluated. The dataset for this assessment was substantially smaller, and conclusions derived from these data should be used with caution. The data suggest that when all landform types are combined, the number of slides associated with thinning treatments is similar to those seen in unthinned stands and substantially lower than seen in clearcuts (Figure 14). This pattern appears to vary somewhat between landforms (Figure 15), although some of these apparent differences between landforms may be a reflection of the small sample size rather than an indication of true patterns (see Mass Wasting Module Report for further discussion).

4.1.2 Road-Related Landslides

Yager and Wildcat Group sediments have the highest road landslide frequencies, followed by Franciscan sediments and the Franciscan melange (Figure 16). Road-related landslide densities vary substantially between landform/slope classes (Figure 17). The highest density of landslides occurred on headwall, complex moderate, and planar steep hillslopes. More moderate landslide densities were found on convex moderate, incised steep, and planar moderate areas.

Hazard calls were given for road-related slides in each of the landform/slope classes (Table 4-2). The reader should note, however, that the actual hazard ratings given to any area on the landscape were based on a statistical analysis of the data that related landslide frequency to a variety of parameters, including slope, geology, local topography, and other factors. Details of this analysis are provided in the Mass Wasting Assessment Report. The ratings in Table 4-2 represent a relative rating of the various landforms.

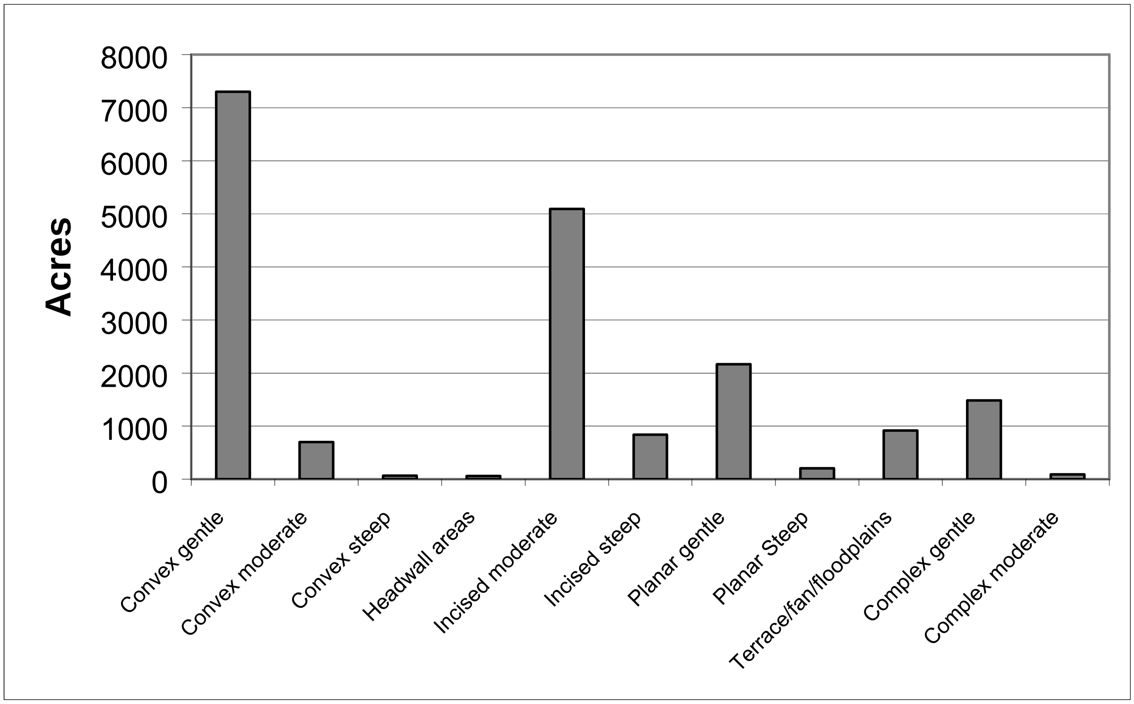


Figure 13: Acres in the Freshwater basin by landform/slope class.

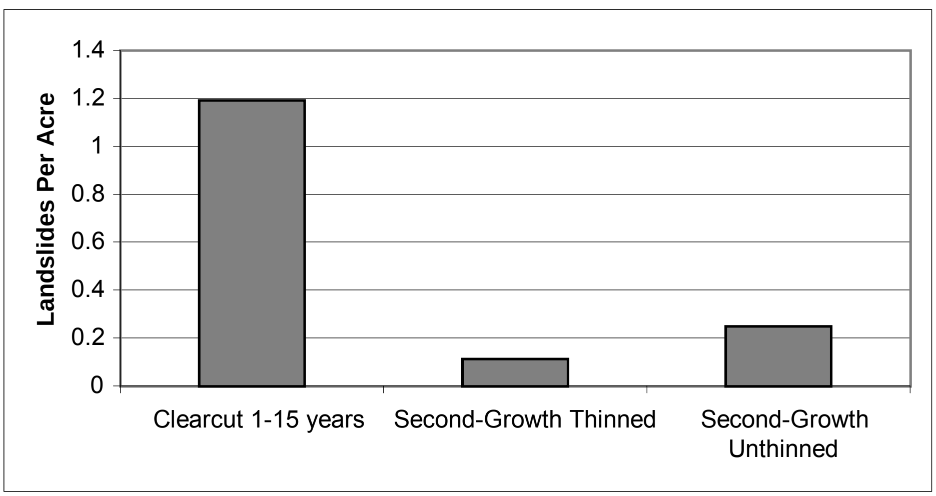


Figure 14: Landslides per acre by management treatment.

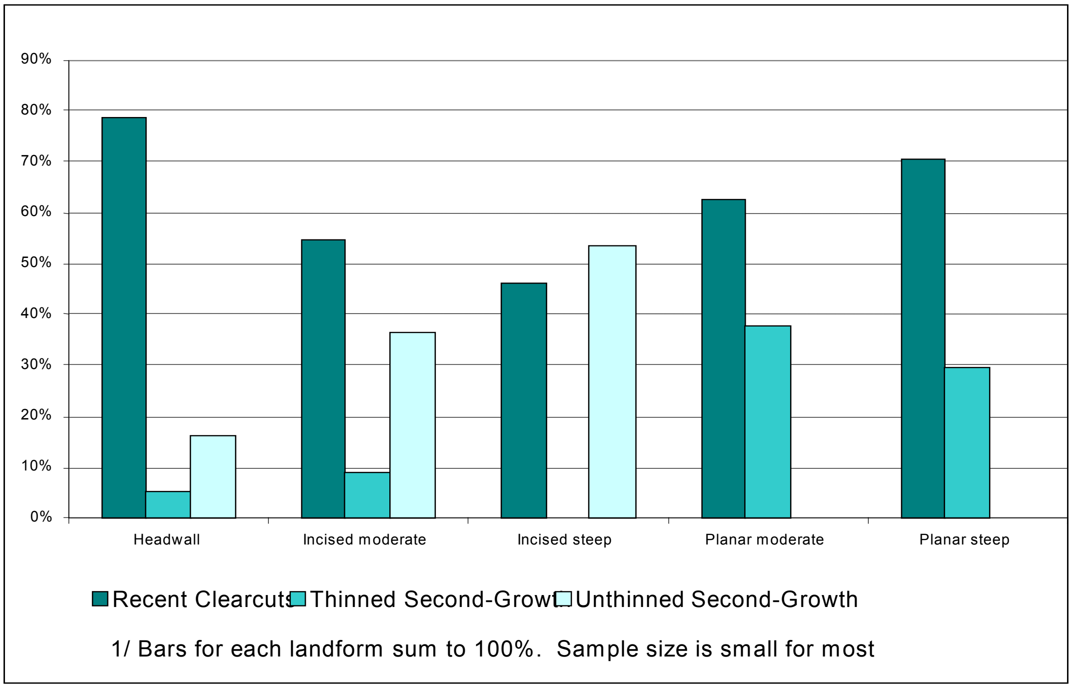


Figure 15: Relative proportion of landslides in each landform by management treatment. Bars for each landform sum to 100%. Sample size is small for most landforms, which significantly affects the results.

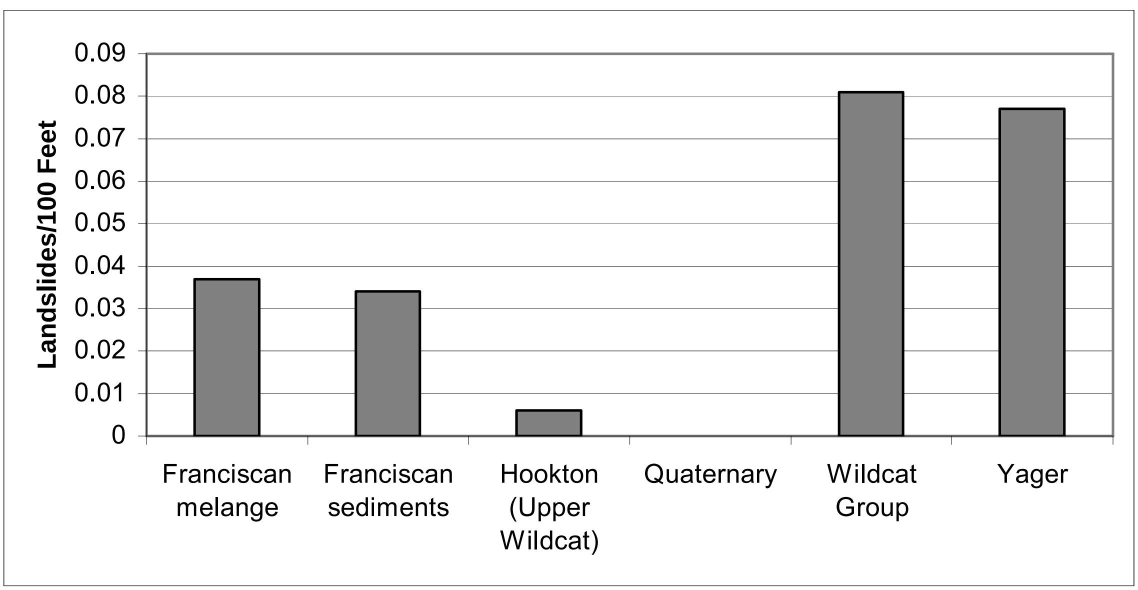


Figure 16: Road-related landslides per 100 linear ft of road by dominant geologic unit.

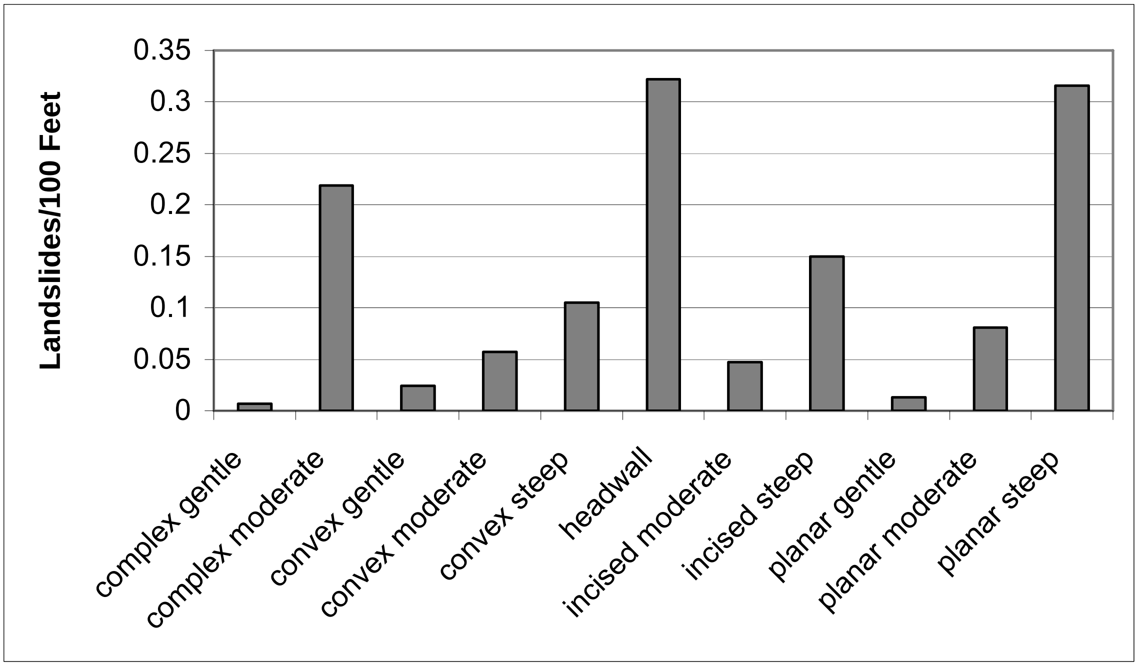


Figure 17: Road-related landslides per 100 linear ft of road by landform/slope class.

Table 4-2: Hazard calls (landslide potential) along roads.

Landform/Slope Class	Hazard Call
Convex Gentle	Low
Complex Gentle	Low
Planar Gentle	Low
Complex Moderate	Moderate
Convex Moderate	Moderate
Incised Moderate	Moderate
Planar Moderate	Moderate
Convex Steep	Moderate
Incised Steep	Moderate
Headwall Swales	High
Planar Steep	High

On average, the landforms with the highest landslide hazard are planar steep and headwall swales. The potential for a slide to reach a stream was evaluated based on landslide runout data. The density of slides in any area was then weighted by the probability that the slide would reach a stream to determine the landslide delivery density of any area in the watershed.

The results of these calculations are depicted on Map A-7 of the Mass Wasting Module. The areas with highest potential for a landslide to occur that subsequently delivers to streams (0.08 to 0.09 landslides per acre) are found in areas similar to the areas of highest potential for hillslope slides.

The characteristics of roads and/or road drainage systems that triggered road-related landslides were not documented in this assessment. Nonetheless, road-related landslides are most commonly triggered by: (1) oversteepened fill slopes, (2) concentration of water on steep slopes and/or steep fill slopes, (3) failure of undersized culverts, and (4) oversteepened cutslopes (less common and typically much lower volume).

4.1.3 Deep-seated Landslides

Deep-seated landslides are common in the Freshwater Watershed; 245 possible deep-seated landslides were recognized in the field and from interpretation of aerial photographs. They are quite variable in type, size, and activity level, and appear to be related, in part, to the underlying bedrock type, distribution, and structure. The activity level of most of the deep-seated landslides in the Freshwater Watershed is best characterized as dormant-historic. That is, they currently demonstrate no evidence of active movement and may have been stable for extended periods of time (e.g., hundreds to thousands of years). In rare cases, these landslides may reactivate. Active, deep-seated landslides are also rare in Freshwater. There are two known active, deep-seated landslides in the Freshwater. One of these is a slide in Graham Gulch, and the other is located in the Upper Freshwater subbasin.

There is no evidence that timber harvest activities (cutting of trees) have reactivated deep-seated landslides in the Freshwater Watershed. Published studies from other areas indicate that deep-seated landslides can be remobilized by cutting the toe of the slope. This can occur through road or skid trail construction or through erosion of the toe by an adjacent stream. Changes in groundwater pore pressure through natural or management causes may also reactivate deep-seated landslides. This mechanism is, however, less common. It should be noted that one deep-seated landslide was remobilized in the basin through quarry operations associated with road construction activities. In this situation, quarry spoils were cast onto the old slide face. The weight of the material was sufficient to remobilize the slide.

4.2 SURFACE EROSION

The Surface Erosion Module evaluated portions of the background sediment yield as well as the effects of roads, timber harvesting, and other land uses on surface erosion in the Freshwater Creek Watershed. Specific discussions of the methods used to estimate sediment inputs through each of these processes are explained in detail in the Surface Erosion Module Report. The sediment inputs estimated in the Surface Erosion Module Report were combined with estimates of inputs through mass wasting and stream channel erosion processes to develop a cumulative sediment budget for the basin. Development of this sediment budget is described in detail in the Stream Channel Condition Module Report. A summary of the confidence that the analysts had in the various component of the assessment is summarized in Section 4.8 of this document and provided in detail in the module reports themselves.

4.2.1 Sensitivity of Soils to Erosion

An erosion hazard map of the watershed was prepared based on CDF guidelines, which rate erosion hazard from soil texture, depth, hillslope gradient, precipitation intensity, and ground cover conditions. With all protective vegetation removed, soils in the eastern part of the watershed underlain by Franciscan rocks have moderate erosion potential, and soils in the western half of the basin underlain by the Wildcat Group have high erosion potential. Areas with the steepest slopes (over about 60%) on Wildcat soils have an extreme erosion hazard.

4.2.2 Estimation of Sediment Inputs

The average annual cumulative inputs of sediment were estimated for all major and some minor sources for six time periods. The time periods included first-cycle logging (pre-1942), 1942 to 1954, 1955 to 1966, 1967 to 1974, 1974 to 1987, and 1988 to 1997. Sources of inputs were divided into natural background sources and management sources. For the period from 1988 to 1997, the management sources were further divided into sources associated with legacy situations (management practices that took place in the past but are no longer used) and sources that are associated with ongoing management activities. Unless otherwise indicated, numbers are reported as the total sediment inputs for the time period. The sources addressed included those listed in Table 4-3. Details on the methods used to estimate these inputs are provided in the Channel, Mass Wasting, and Surface Erosion Module reports.

Natural background sediment inputs have varied substantially over the analysis period (Figure 18). The highest background rates are estimated to have occurred during the period from 1988-1997 coincident with increases in management activities and the lowest background rates are estimated from the period between 1967-1974.

Table 4- 3. Sediment sources addressed in surface erosion module.

Management Sources	**Legacy Sources**	**Background Sources**
• Road Surface Erosion	• Bank Erosion (Fish enhancement structures, RR ties, etc)	• Deep-Seated Landslides
• Road-Related Landslides	• Scour of Tractor Fill in Streams	• Shallow Landslides
• Deep-Seated Landslides	• Cutting of Headwater Streams	• Bank Erosion
• Shallow Landslides	• Streambank Slides	• Soil Creep
• Harvest-Related Surface Erosion		• Streambank Slides
• Harvest-Related Bank Erosion		

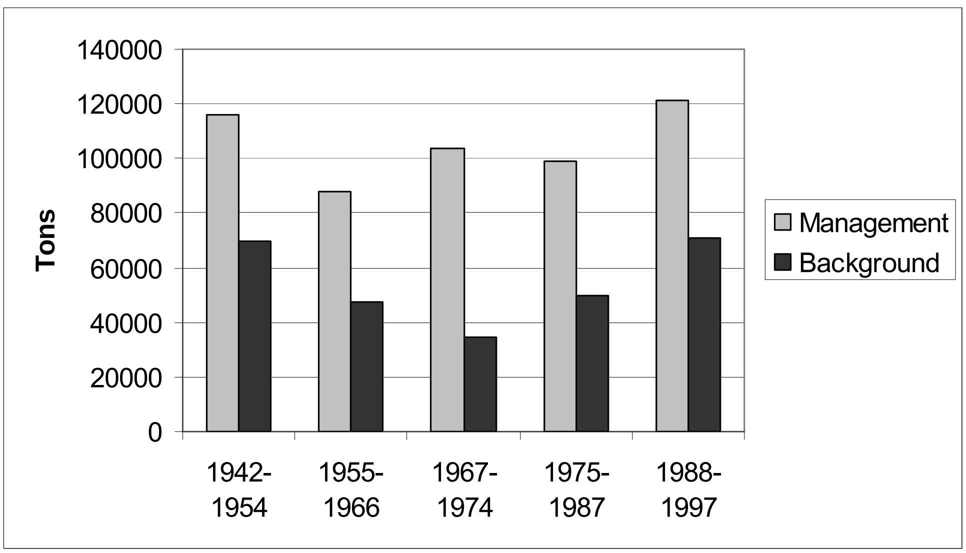


Figure 18: Trend in background and management-related sediment inputs over time. (Note that “management for the period of 1988-1997 includes that portion attributed to legacy inputs in discussions regarding the recent period).

Management-related sediment inputs have also been quite variable. The variation in inputs reflects both climatic effects and the extent of management in each subbasin over time. Sediment inputs also varied between subbasins, reflecting local weather effects and management activities (Figure 19, Figure 20). Note that much of the variability in Figure 19 is also due to variations in subbasin size. Figure 20 depicts the same data adjusted for basin size.

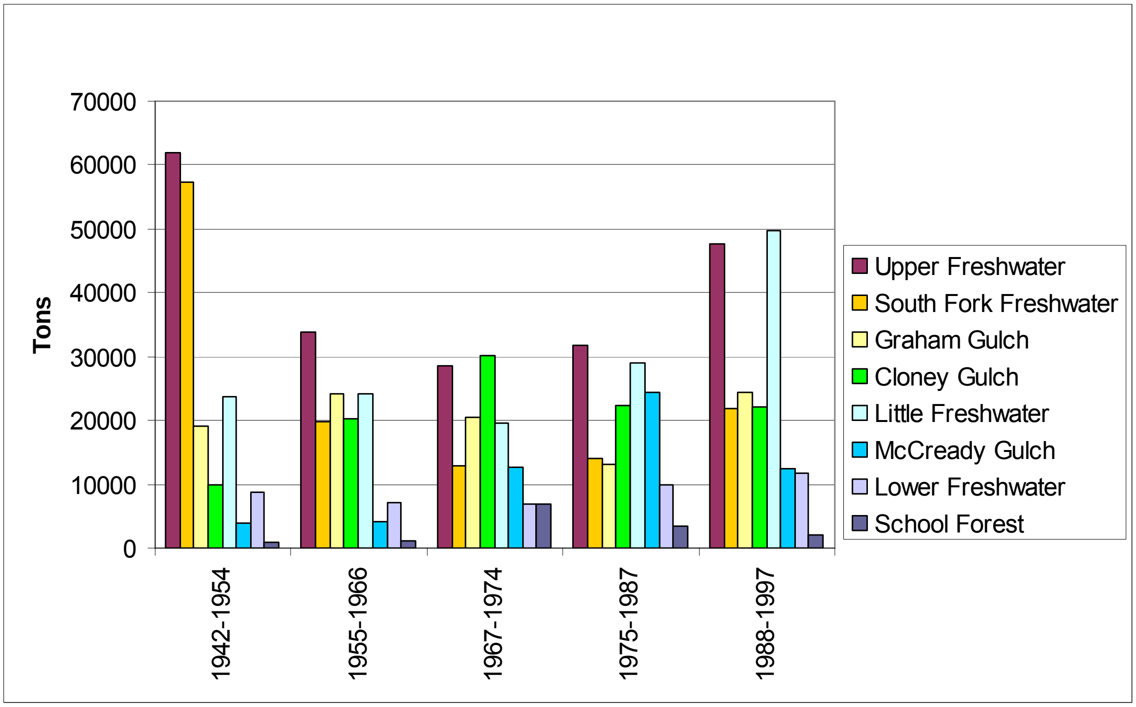


Figure 19: Trends in total sediment inputs by subbasin over time.

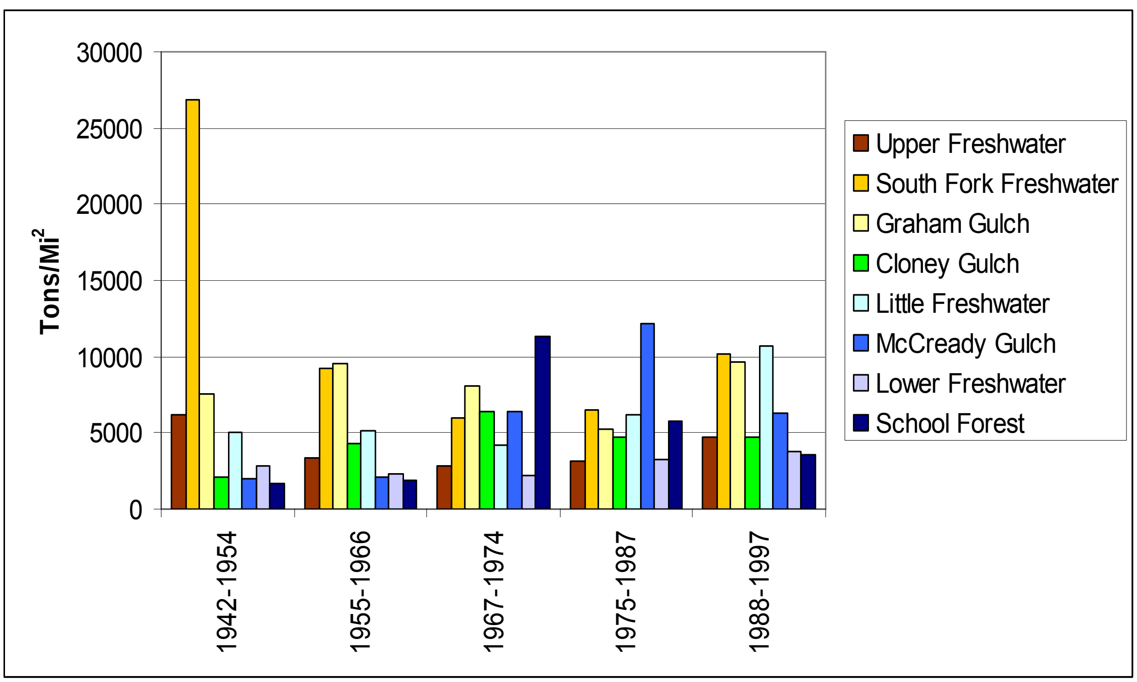


Figure 20: Trends in sediment inputs per square mile over time.

In the period from 1988 to 1997, road surface erosion is the largest source of management-related sediment (Figure 21). Sediment inputs generated by road-related landslides contribute roughly half as much sediment as road surface erosion. Shallow landslides also contribute sediment, but this input type is a much smaller portion of the management-related sediment inputs. Basin wide, total management inputs (108,400 tons excluding legacy inputs) in the period from 1988 to 1997 were roughly 1.6 times as high as natural background inputs (71,108 tons).

A number of legacy situations also contributed to the total sediment inputs during the most recent period. For the purposes of estimating legacy effects, those activities that are truly historical and not ongoing effects were defined as legacy effects. Sediment inputs from historical management practices that are at least affected by ongoing management activities were categorized as “management effects”. These would include road effects and ongoing erosion from harvest units that were harvested using today’s management practices. We recognize that road effects are to some extent a legacy situation. If the road system were built today, it would probably be significantly different from what we currently see in the watershed. Nevertheless, use of the road system is ongoing and therefore was not categorized as a legacy effect. Likewise, older landslides could be considered legacy situations. These were, however, included in the management category as the practices that trigger slides have not changed significantly. Hence, they represent an ongoing management practice.

These legacy situations included bank erosion induced by the fish enhancement structures, bank erosion influenced by the presence of railroad ties and corduroy roads in the streambed, erosion of sediments deposited in the stream during previous harvest activities (skid trails in the channel), and erosion-related adjustment of headwater channels following the first-cycle harvest. The present contribution of these legacy sources of sediment is small (roughly 7% of total) relative to the background and ongoing management inputs. This figure would increase significantly if erosion and slides from historically constructed roads and landings were included as legacy sources.

The majority of the sediment inputs in the period from 1988 to 1997 originated in the Upper Freshwater and Little Freshwater subbasins, the two largest subbasins (Figure 22). Cumulatively, road surface erosion was the largest contributor of management related sediment in all subbasins except the Little Freshwater, where sediment input through road related landslides exceeded the road surface erosion inputs (Table 4-4). Road surface erosion constituted roughly 60% of all management related sediment input basin wide.

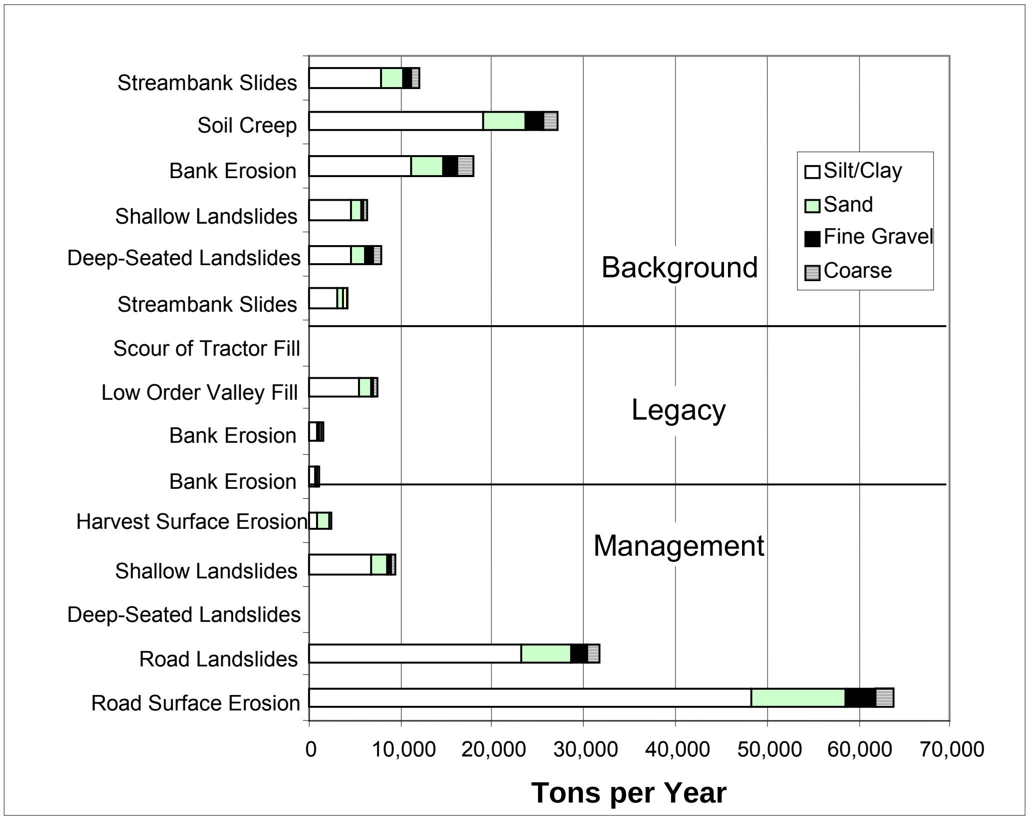


Figure 21: 1988 to 1997 total sediment inputs by source.

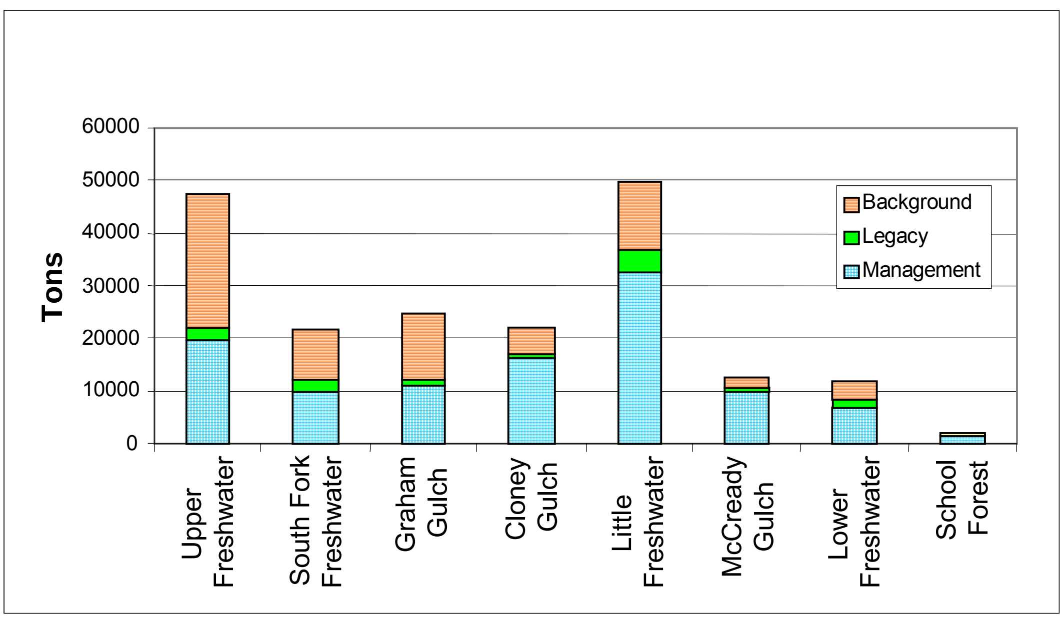


Figure 22: Total Sediment Inputs by Subbasin, 1988-1997.

Table 4-4: Summary of sediment inputs, 1988-1997, by subbasin and sediment source (in total tons over the 10-year period).

	Source	Upper Freshwater	South Fork	Graham Gulch	Cloney Gulch	Little Freshwater	McCready Gulch	Lower Freshwater	School Forest
Management Related	Road Surface Erosion	12300	6610	5930	13610	12960	8170	3150	1060
	Road Landslides	4950	2200	1840	2480	14970	1710	2960	590
	Deep-Seated Landslides	0	0	0	0	0	0	0	0
	Shallow Landslides	1200	60	2540	80	4590	40	840	20
	Harvest Surface Erosion	680	780	410	220	300	20	100	0
	Bank Erosion	480	240	340	0	0	0	0	0
Legacy Inputs	Bank Erosion	610	300	430	0	0	0	0	0
	Low Order Valley Fill	860	1030	450	710	2040	810	1380	0
	Scour of Tractor Fill	0	0	0	0	0	0	0	0
	Streambank Slides	1160	1040	40	0	2020	0	20	0
Natural Background	Deep-Seated Landslides	980	0	6880	0	0	0	0	0
	Shallow Landslides	800	40	1690	50	3060	30	560	10
	Bank Erosion	9740	3920	1290	1530	660	250	420	0
	Soil Creep	7380	3540	2390	3440	6320	1490	1980	500
	Streambank Slides	6570	2110	200	0	2910	0	370	0

Road surface erosion is primarily affected by high traffic levels, concentration of water that is directed to the stream rather than diverted onto the forest floor, and surfacing. The majority (65%) of the road sediment is produced from the many miles of native surfaced roads in the watershed. Gravel-surfaced mainline roads produce another 25% of the road-related surface erosion. Approximately 24 miles (13%) of roads in the watershed deliver directly to streams, and an estimated 80 additional miles (38%) are within 200 ft of a stream and deliver a portion of their sediment to streams. Road-related landslides can be related to undersized culverts failing during storm events, oversteepened fill slopes, concentration of water diverted onto steep slopes or steep fill, and, less frequently, oversteepened cutslopes.

Although non-road-related shallow landslides are the next largest source of management-related sediment, this is still a relatively small source, accounting for only 8.6 percent of management related inputs. These tend to occur most frequently in the steepest portions of the basin, particularly in headwall swales and in deeply incised areas (e.g., inner gorges).

The above discussion indicates that roads are the primary management-related source of the cumulative sediment inputs in the Freshwater Creek Watershed. Road surface erosion and road-related landslides accounted for 88% of the total cumulative management-related sediment inputs in the watershed in the period from 1988 to 1997.

Sediment inputs from surface erosion related to harvest operations (i.e., from bare ground exposed during harvest) contributed only 1.3% of the total management-related sediment inputs. The primary activities affecting these inputs are high densities of bladed skid trails in tractor yarded units and erodible soils. Little surface erosion occurs on cable-yarded or helicopter yarded units. Broadcast burning, particularly hot burns or burns combined with mechanical site preparation, results in some surface erosion on steeper slopes. Field observations suggested that the use of spot herbicide applications did not noticeably increase surface erosion (the Surface Erosion Module Report). These field observations indicate that input of sediment from harvest units drops rapidly within 2 to 3 years following harvest.

Surface erosion from home building and the Freshwater stables were evaluated and yielded small amounts of erosion (1-4 tons/year). At present, there is little dispersed grazing in forest lands or use by recreational vehicles, so little erosion is associated with these land uses.

Grain Size Delivered to Streams

Inputs from surface erosion and other sediment sources, including mass wasting sources, were compiled into an overall sediment budget for Freshwater Creek. Surface erosion from all sources delivers primarily silt and clay-sized particles to streams in the watershed, with about 70% of sediment silt- and clay-sized, 25% sand-sized, and the remainder fine gravel (Figure 23). This is because most of the soils in the watershed have a very high silt and clay content, and surface erosion generally does not have enough energy to move particles larger than sand size. The silt and clay contribute to turbidity and suspended sediment concentrations in streams in the watershed.

Fine-grained sediments (<2 mm) tend to remain suspended and contribute to turbidity of water. Coarser grained sediments (>2 mm) are likely to settle out in the channel bottom, although they may at times be carried in suspension, depending on the stream power (which is a function of the gradient of the stream and the magnitude of flow).

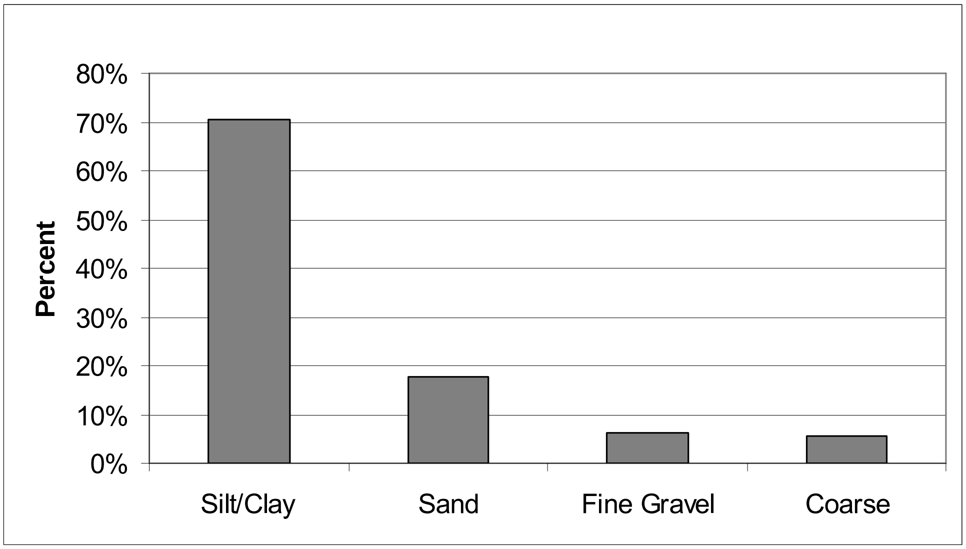


Figure 23: Grain size of sediment inputs in the Freshwater Watershed.

4.3 HYDROLOGY

The hydrology assessment included evaluations of the effects of harvest, compaction, and roads on peak flows. Estimates of the change in peak flows as a function of the magnitude of event were developed for 49 Hydrologic Assessment Units (HAUs). In-depth discussion of the methods and results of this assessment can be found in the Hydrology Module Report.

4.3.1 Harvest Effects

Estimated relative increases in peak flows due to harvest-related changes in canopy interception/evapotranspiration loss are greatest in the high-frequency, low-magnitude events, and decrease with increasing event size (Table 4-5). These results are consistent with the findings of the North Fork Caspar Creek study (summarized in Ziemer 1998), and are not unexpected given that the modeling methodology used in this analysis was based on the Caspar Creek results (i.e., Lewis et al. In Press). The Caspar Creek model as applied in the Freshwater analysis is probably conservative (i.e., tends to predict greater changes in peak flows). This is because the Caspar Creek model was developed for much smaller basins than the 19,000+ acre Freshwater Creek Watershed, and because instantaneous delivery of flows from upstream to downstream areas was assumed in the model.

Table 4- 5: Estimated increases in peak flows based on average antecedent conditions for the entire Freshwater basin (ranges based on estimates for the 49 HAUs that were evaluated).

Peak Flow Recurrence Interval	Average Frequency of Occurrence Historically	Current Flow Recurrence Interval	Current Average Frequency of Occurrence
0.25	4 times/year	0.25-0.22	No or very slight change
0.5	2 times/year	0.5-0.36	2-3 times/year
1.0	1 time/year	1.0-0.7	1-1.25 times/year
2.0	Once every other year	2.0-1.7	Once every other year to approx. once every 20 months
5.0	Once every 5 years	5.0-3.7	Once every 5 year to once every 3.7 years
10.0	Once every 10 years	10.0-7.9	Once every 10 years to once every 7.9 years
15.0	Once every 15 years	15.0-11.3	Once every 15 years to once every 11.3 years

The lower Freshwater basin, where substantial rural residential development has occurred on the floodplain, is of particular importance. Those peak flows with a recurrence interval of 2 to 15 years are of a magnitude large enough to cause overbank flooding, the severity of the flooding generally increasing with increasing peak flow recurrence interval. Within the flood-prone hydrologic units (those that drain to portions of Freshwater Creek that are prone to flooding of private, non-PALCO property), the estimated cumulative percent increase in the peak flow with a recurrence interval of 2 years ranges from 9% to 11% for average antecedent wetness conditions (Table 4-6). Peak flow increases in other subbasins were variable (Table 4-7). The highest cumulative increases were predicted in the Little Freshwater subbasin.

Table 4-6: Estimated increases in peak flows based on average antecedent conditions for the areas of the lower watershed where rural residential development is present in the floodplain.

Peak Flow Recurrence Interval	Average Frequency of Occurrence Historically	Current Flow Recurrence Interval
2.0	Once every 2 years	1.9-1.8
5.0	Once every 5 years	4.5-4.3
10.0	Once every 10 years	9.8-9.1
15.0	Once every 15 years	13.5-13.0

Table 4-7: Mean (range) of estimated peak flow increases within each sub-basin (assuming average antecedent wetness conditions).

CDF Planning Watersheds	Eddysville (110.00012)				Freshwater (110.00011) Includes Upper Main above SF.		Camp 12 (110.00014) Includes portions of upper main below SF	
Peak flow return period (years)	**Mainstem**	**School Forest**	**McCready Gulch**	**Cloney Gulch**	**Graham Gulch**	**Upper Mainstem**	**Little Freshwater**	**South Fork**
0.25	12% (11%-13%)	10% (7%-15%)	14% (12%-15%)	17% (15%-18%)	14% (12%-17%)	6% (2%-10%)	20% (8%-27%)	13% (1%-22%)
0.5	11% (9%-11%)	9% (6%-12%)	12% (11%-13%)	14% (13%-15%)	12% (10%-14%)	5% (1%-9%)	17% (7%-23%)	11% (0%-19%)
1	9% (8%-10%)	8% (6%-11%)	10% (9%-11%)	13% (11%-13%)	11% (9%-13%)	4% (1%-8%)	15% (6%-20%)	10% (0%-17%)
2	11% (9%-11%)	8% (6%-12%)	12% (11%-13%)	14% (13%-15%)	12% (10%-14%)	5% (1%-9%)	17% (7%-23%)	11% (0%-19%)
5	7% (6%-8%)	6% (4%-8%)	8% (7%-8%)	9% (8%-10%)	8% (7%-10%)	3% (1%-6%)	11% (4%-15%)	8% (0%-13%)
10	4% (4%-4%)	3% (2%-5%)	4% (4%-5%)	5% (5%-6%)	5% (4%-5%)	2% (1%-3%)	6% (2%-9%)	4% (0%-7%)
15	2% (2%-2%)	2% (1%-2%)	2% (2%-2%)	3% (2%-3%)	2% (2%-3%)	1% (0%-2%)	3% (1%-4%)	2% (0%-4%)

4.3.2 Compacted Area Effects

Estimates of the effects of compacted areas (i.e., roads, skid trails, residential development, etc.) on streamflows were made using a Rational Method modeling approach. Modeling was limited to peak flow events with a recurrence interval of 2, 5, and 10 years due to model and data availability constraints. Unlike the modeled results for relative changes due to harvest effects on canopy interception/ evapotranspiration loss, the results from the compacted-area modeling were constant over the range of recurrence intervals. The estimated percent increase in peak flows with a recurrence interval of 2, 5, and 10 years ranged from 0 to 4% (median value of 2%) within the Freshwater Watershed. The estimated percent change in peak flows within the flood-prone areas of the watershed for peak flows with a recurrence interval of 2, 5, and 10 years was 1% to 2%.

The estimates of relative changes due to compacted areas were not included in the overall estimates of changes in peak flow magnitudes, or changes in recurrence interval summarized above, for two reasons. First of all, the hydrology analyst has lower confidence in the results of the Rational Method modeling than in the canopy interception /evapotranspiration loss modeling. Second, and more importantly, a certain amount of compaction due to roads, skid trails, etc. is inherently included in the Caspar Creek equations that have been modified for use in the PALCO methodology to estimate harvest effects presented above. It should also be noted that the estimated effects are well within the measurement errors of open channel flow.

4.3.3 Road Drainage Connectivity Effects

The percent increase in the effective drainage network (i.e., length of connected ditches/length of stream, expressed as a percentage) ranged from 0% (no connected ditches) in 12 of the 49 hydrologic subbasins to 23%, with a median value of 6%. The limited extent to which the road system is connected to the stream system in the Freshwater Watershed has resulted in a relatively small increase in the effective drainage density as compared to other locations in the Pacific Northwest where increases in flow associated with roads has been estimated.

Relative changes in peak flows due to connectivity of the road drainage system were also modeled using a Rational Method modeling approach. A primary simplifying assumption required to use this modeling approach was that road drainage ditches capture 100% of the water moving from upslope areas. Although this assumption has been shown to be valid in some locations, it is probably wrong for the Freshwater Watershed, given the relatively deep soil profiles found in the area. Hence, the estimated effects of roads on peak flows are probably overestimated. The complexity of the analysis and time constraints limited the modeling effort to three of the hydrology subbasins. The three that were selected were with the highest percent increase in the effective drainage network. Modeling was completed for peak flow events with 2-, 5-, and 10-year recurrence intervals. Estimated increases in peak flows ranged from 1 to 3%.

It appears that road drainage connectivity generally results in a slightly earlier rise to peak flow as compared to the historical condition. The value of the instantaneous peak flow, that is the amount that road connectivity changes the total volume of runoff, may be slightly higher or slightly lower than the historical condition, depending on whether the arrangement of connected road ditches serves to synchronize or desynchronize overall storm runoff.

The estimates of relative changes due to connectivity of the road drainage system to the stream system were not included in the overall estimates of changes in peak flow magnitudes or changes in recurrence interval summarized above because the hydrology analyst has lower confidence in the results and because the analysis was only completed for three of the 49 hydrology subbasins in the watershed. Keeping in mind that the small increases in peak flow discussed above are likely over-estimated and that the results reflect the worst-case scenario, the effects of roads on peak flows were assumed to have an insignificant effect on peak flow increases in the basin.

4.4 RIPARIAN CONDITION

Coast redwood (*Sequoia sempervirens*) is the dominant tree species within much of this area but does not form the sort of continuous distribution characteristic of more widespread conifers. Other important tree species in this area include *Pseudotsuga menziesii* (Douglas-fir), *Abies grandis* (grand fir), *Tsuga heterophylla* (western hemlock), *Picea sitchensis* (Sitka spruce), *Lithocarpus densiflorus* (tanoak), and *Arbutus menziesii* (Pacific madrone). *Sequoia sempervirens* "almost without exception" sprouts from the root crown, trunk, or stump following damage or harvest (Olsen et al. 1990). Five or more root crown sprouts forming a ring around a stump is not unusual, with each sprout forming its own root system over time (Olsen et al. 1990). Sprouts are generally considered to form strong trees and can grow to near 2 m high in their first year.

Redwood seedling establishment in undisturbed, mature stands is poor to nonexistent. Seedlings are generally killed by moisture stress (the seedlings lack root hairs) or soil-borne pathogens. Seeds that germinate in disturbed or otherwise exposed soils fare better; indeed, most observers note that redwood seeds must germinate on soils disturbed by fire or harvest to become established as seedlings. Once established, redwood seedlings grow can grow at a prodigious rate (46 cm annually, and 2 m annually as saplings) under good or moderate conditions. Under less ideal conditions, they can remain in a suppressed state for many years, often dying back and resprouting multiple times.

The current conditions of riparian forests were determined through a combination of aerial photo interpretation, plot data, and other field investigations. Details of the methods are discussed in the Riparian Condition Module Report and the Methods to Complete Watershed Analysis on Pacific Lumber Company Lands in Northern California (2000). Through the various data collection methods, current riparian condition along each side of each stream was classified using two different coding methods to reflect the current size and density of the stands. The first of these methods draws upon the California Wildlife Habitat Relationships (CWHR) System. The second set of codes combines some of the CWHR codes to reflect local conditions.

4.4.1 Current Riparian Stand Condition

The majority of the riparian forest in the Freshwater Creek Watershed is approximately 70-year old second-growth redwood plant communities. These stands are even-aged with a fairly uniform overstory canopy. The majority of the riparian forest on PALCO land is greater than 21.4 inches in mean diameter with greater than 90% canopy closure (Table 4-8). The riparian areas in the lower basin in the rural residential area are, however, dominated by hardwoods and grass.

Table 4- 8: Current condition of riparian stands.

			Percent Total Streambank Length[1]			
Combined Code	**CWHR CODE**	**DESCRIPTION**	**Class I & II**	**Class I**	**Class II**	**Class III**
LC	RDW5d and RDW5M	Large/Medium Redwood: QMD 21.4 in.; >90%CC	68.4%	51.4%	77.8%	59.3%
SC	RDW4D and RDW4M	Small tree Redwood: QMD 20.3 in.; >90%CC	4.8%	2.3%	6.2%	22.9%
YC	RDW 2-3D/M	Young Redwood: QMD 15.7 in.; 40-90%CC	4.4%	3.5%	4.8%	11.0%
SP	RDWS and RDWP	Sparse to Open Redwoods: QMD 16.1 in; <40% CC for Dom/Co-Dom	6.1%	6.4%	5.9%	6.9%
CH	RDW/HWD, HWD/RDW	Mixed redwood/hardwood: QMD 17.8 in, %CC variable	10.1%	21.3%	4.0%	
G		Grass	2.2%	4.4%	1.0%	
H		Hardwoods	4.1%	10.8%	0.4%	

[1]*Streambank = 2 * channel length*

With the exception of the mixed conifer hardwood stands and hardwood-dominated stands, current conifer densities range from 80.7 to 163.6 trees per acre (tpa) (Table 4-9), which is roughly 1.5 to 3 times as many trees as are found in the old-growth forests of lower Redwood Creek (Table 4-10). The mean diameters of the dominant and co-dominant trees in these stands range from 19 inches to 56 inches diameter at breast height (dbh).

The character of crown layers can indicate something of redwood forest growth dynamics. Individual redwood trees show a low susceptibility to suppression mortality. Growth of individual understory trees slows as the overhead crown layers shade them. The result is that a suppressed crown layer has developed in the older stands (17.1 redwood/acre), but suppression is minimal within the younger stands (3.6 redwood/acre). The growth of the shorter understory trees in older stands has slowed. Average diameters of redwoods in the intermediate and suppressed crowns continue to show little increase as the dominant crown layer increases over time to achieve the larger size (>24 in. dbh).

Table 4- 9: Size and density of current riparian stands estimated from plot data.

Code	Mean dbh dominant crown	Mean dbh co-dominant crown	QMD (inches)	Total tpa conifer	Total tpa hardwood
LC[1]	44" @ 2.1 tpa	27" @ 44.3 tpa	21.4	149.5	36.3
LC[2]	42" @ 1.3 tpa	29" @ 33.3 tpa	22.8	159.3	96.0
SC	46" @ 1.4 tpa	26" @ 49.3 tpa	20.3	135.0	42.1
YC	27" @ 2.7 tpa	19" @ 25.5 tpa	15.7	163.6	89.1
SP	56" @ 0.7 tpa	24" @ 17.3 tpa	16.1	80.7	44.7
CH	53" @ 1.9 tpa	19" @ 10.6 tpa	17.8	16.9	53.8

[1]*Adjacent harvest units impinged on the outer edge of the plot area*
[2]*Plot data unaffected by harvest edge effects*

Table 4- 10: Stand character for an old growth redwood forest[1].

Density in trees (by size class) per acre				
dbh (in inches)	**Redwood**	**Douglas-fir**	**Other Whitewood**	**All Conifers**
08 - 36	16.10	3.33	13.96	33.39
40 – 48	4.05	1.03	0.14	5.52
50 – 58	2.70	1.00	0.11	3.81
60 – 78	3.90	1.07	0.05	5.02
80 – 98	2.11	0.12	0.01	2.24
100 – 118	1.01			1.01
>119	0.56			0.56
TOTAL	***30.43***	***6.55***	***14.57***	***51.55***

[1] Based on complete inventory of 2,796 acres along lower Redwood Creek, CA.

4.4.2 Large Woody Debris Recruitment

Total LWD recruitment to a stream is a function of the rate of debris entering the channel and the rate of export. Wood recruitment may enter by a variety of natural processes including bank erosion, windthrow, disease, suppression mortality, breakage, landslides, and downstream transport within the channel. These processes often work in concert. The dominant process of wood recruitment varies by stream channel type, forest stand condition, and geologic setting.

LWD recruited to the channel within the last two years was identified during Freshwater field studies by the Channels Module Team (see Stream Channel Condition Module Report for details). The input rate of wood was estimated based on recruitment within the last two years (Table 4-11). This period includes a large flood event that may bias the recent recruitment rate relative to long-term rates.

Table 4- 11: Recent recruitment of LWD to channels.

CGU[1]	LWD m^3/km/yr	St. Dev	St. Error	# reaches sampled
C1	157	184	82	6
C2/3	13	16	7	2
GG/CG	48	49	22	5
MS1/2/3	24	42	19	7
U1	297	26	15	3

Based on actual in-channel wood counts of LWD recruited within an estimated period of no more than two years.

[1] *CGU refers to channel segments with similar characteristics. See Section 4.5 of this report for a summary description of the codes*

The amount of wood in the channel is a function of both the LWD recruitment rate and longevity of wood in the channel or depletion rate. Wood longevity is affected by many factors including species decay resistance, size of channel and corresponding stream power available to move wood, and the size of individual pieces of LWD. Pieces of wood that were dated in undisturbed redwood forest basins found redwood LWD that had been in the channel for 50 years to periods exceeding 200 years (Keller et al. 1995). This suggests that larger pieces of LWD of redwood origin can last several centuries within mid order channels. Observations of remnant old-growth pieces of redwood in Freshwater basin channels (exclusive of the lower mainstem) are at least nearly a century old. Cutting history in Freshwater indicates that the oldest legacy pieces of logging debris could date from the late 1800's. Much of the old wood in the streams recruited at a very large size. Wood recruited from second or third-growth redwood may not remain in the stream as long as large pieces. Likewise, non-redwood LWD (Douglas-fir, hemlock, spruce) is not expected to last as long in streams as redwood.

A substantial portion of the LWD in the channels of the Freshwater basin is part of the legacy of historical management. Remnant woody debris from the time of the first harvest entry and earlier is present in the channels and on the forest floor. Logging debris (saw cuts obvious) accounted for 40% of the down wood on the riparian forest floor within the surveyed plots. The amount of wood in the channels was affected by active removal of wood in the 1950s.

Direction of fall and subsequent recruitment to the channel has been estimated for a wide range of forests in the west (see Riparian Module Report). The relationships that were developed in these studies were used to estimate the direction of fall and ultimate recruitment of trees within the Freshwater basin by adjusting the previously developed relationships to reflect site potential tree height in the basin. The recruitment of trees as a function of distance from a stream is depicted based on empirical data (Figure 24) and modeled recruitment (Figure 25). The development of these curves is discussed in greater detail in the Riparian Module Report. These curves are applicable to trees falling as a result of stand suppression and can be used to estimate the amount of wood that recruits to a stream as a result of such stand suppression. Stand modeling confirms that suppression mortality within redwood-dominated stands is a relatively minor component of wood recruitment and is confined to smaller diameter classes.

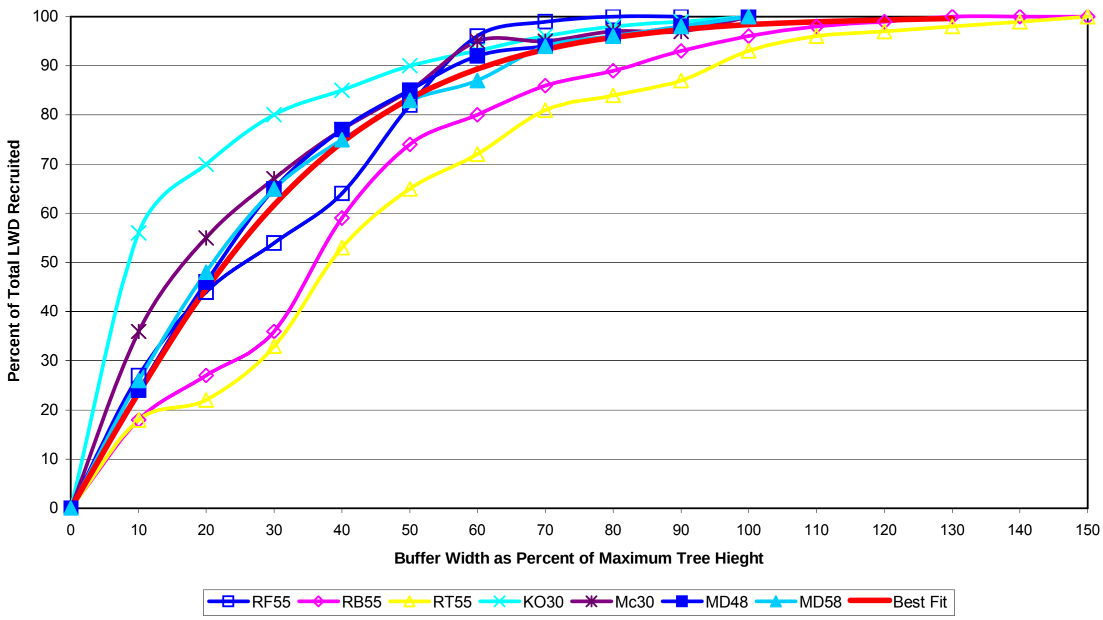


Figure 24: Source distance curves for empirical data. See the Riparian Condition Module Report for further explanation.

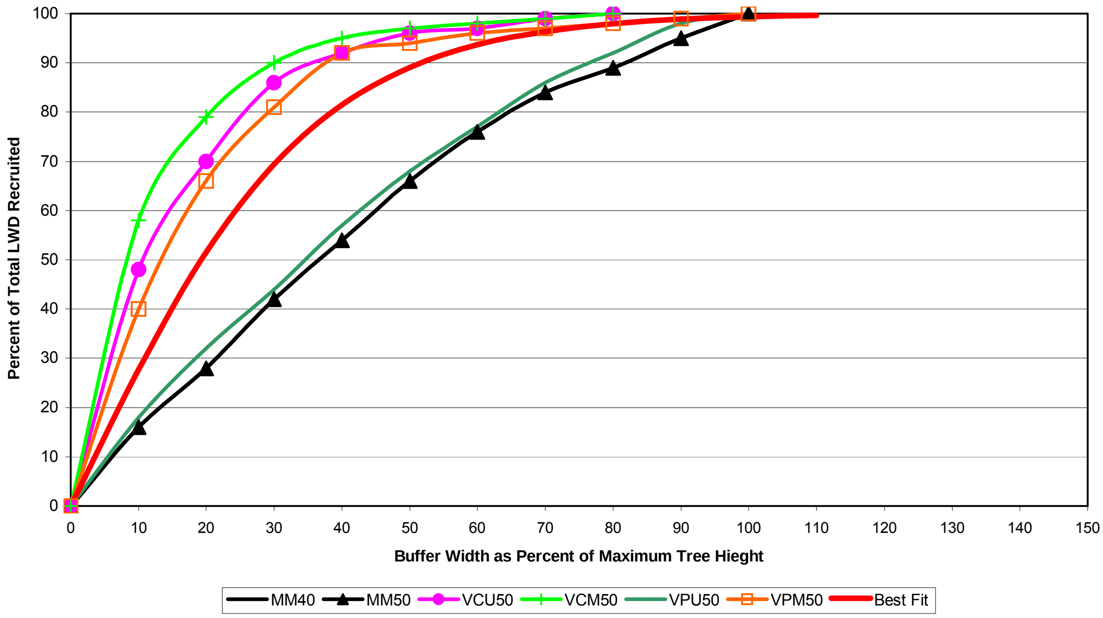


Figure 25: Source distance curves for modeled (theoretical) data. See the Riparian Condition Module Report for further explanation.

Bank erosion, historical disturbance, disease, and breakage generally account for a greater proportion of mortality than suppression. Mass wasting, particularly small streambank slides associated with bank erosion, introduces LWD to the channel. These features are found throughout the Freshwater drainage. This recruitment mechanism is most evident for stream channels of moderate to steep gradient (3.5% – 20%) within consolidated geology and within steep gradients (>6.5%) within unconsolidated geology. On average, small streambank slides account for 0.4 pieces LWD/km/year and 0.004 key pieces/100 ft channel/year recruited to the channel. This represents a small portion of the total estimated annual recruitment.

The LWD recruitment rate from bank erosion exclusive of small slide areas was not quantified, but field observations indicate that it is the predominant mechanism for recruiting wood to the channel. The importance of bank erosion for recruitment generally increases in a downstream progression within watersheds. Trees growing with roots in the streambank are most likely to be recruited to the channel due to their proximity and bank undercutting.

While windthrow does not appear to be a dramatic problem for most areas of the Freshwater basin, it is a primary LWD recruitment mechanism in localized areas. Excessive windthrow, as evidenced by large portions of stands in buffers adjacent to clearcuts, was only apparent in the vicinity of the confluence of the South Fork with Freshwater Creek. Elsewhere, windthrow within the surveyed plots was dispersed over time and space. The cause of fall could be determined for 110 of 220 pieces of down wood inventoried in the plots. Approximately one third of the pieces with a known cause of fall were attributed to windthrow.

Redwoods are the dominant species throughout the watershed both currently and historically (pre-European) for almost the entire Freshwater drainage. The pre-European forest condition in Freshwater was redwood – fir forests except for within ½ mile of Three Corners and the uppermost portion of upper Freshwater Creek. The highest elevations in Upper Freshwater were both historically and currently Douglas fir - hardwood plant communities The very lowest portion of the basin consisted of grass tide flats. Pre-European riparian forests likely had younger redwood stands growing closest to channels in lower Freshwater where periodic major flood disturbance toppled trees.

The majority of the current riparian forest in the freshwater is approximately 70 year old second growth redwood plant communities. These stands are even aged with a fairly uniform overstory canopy. Riparian conditions within 100 ft of Class I and II streams achieve standards for properly functioning conditions (PFCs) along 68% of the Class I streambank length and 89% of Class II streambank length. Most of stream segments not meeting properly functioning conditions are located in the lower Freshwater basin downstream of PALCO’s ownership. In total, development in the lower basin affects 15% of the total streambank length for the Freshwater drainage.

Harvesting within the last 25 to 30 years has limited the near-term LWD recruitment potential from the 0-100 ft riparian width area for 10% of both Class I and Class II streambank length. Clearcut harvesting practices prior to recent forest practice rules (mostly pre-1973) have reduced stand age along 2% of the streambanks for Class I streams. Narrow riparian buffers are found along 3% of the Class I streambank length; these areas are mostly vegetated by open stands of $\geq$24 in. dbh redwoods. Four percent of Class II streambank length has been recently clearcut within 0 – 100 ft. In most cases, some trees were retained in a narrower buffer. Although short-term LWD recruitment may be affected in these areas, these stands are expected to provide suitable long-term recruitment potential.

Roads parallel to the channel can be a primary factor limiting riparian forests in many forested watersheds. The Freshwater basin has a legacy of roads constructed on old railroad grades that paralleled many of the main sub-basin streams. Although trees are absent from the active roadbed, the surrounding riparian areas are often fully forested with second-growth redwoods >24 in. dbh (RDW5D). Roads were not found to be a principal limiting factor for wood recruitment in the Freshwater basin.

Expected future trends in riparian forest condition were evaluated using CRYPTOS-(Wensel et al. 1987), which is a forest stand growth model. Left undisturbed, the total trees per acre is expected to decrease over time; however, basal area will expand as the remaining trees increase in size. Model results confirm what empirical observations and the key piece analysis had indicated; both near-term and long-term LWD recruitment potential is good for the majority of riparian stands in the Freshwater basin. The large tree (RDW5) and small tree (RDW4) riparian stands currently have approximately 38 tpa at ≥22 in. dbh. The number of trees per acre at ≥22 in. dbh will increase over time.

The young (CWHR 2/3) moderate to dense redwood dominated stands currently have a QMD of 15.7 inches. Immediate LWD recruitment potential is limited for RDW2/3 riparian stands (3.5%, 4.8%, and 11% of riparian area for Class I, II, and II streams, respectively). These stands currently provide key piece functional size LWD as defined by Fox (1994) to small Class II and III streams (bankfull stream width ≤15 ft). There are, on average, currently about 34 tpa at ≥12 in. dbh within these young stands (RDW2/3). These stands will achieve 43 tpa at ≥22 in. dbh within 40 years. This future stocking is sufficient to provide key piece LWD to all but the mainstem Freshwater Creek. In 40 years, these stands will achieve 8 tpa at ≥40 in. dbh.

Near-term recruitment potential for sparse and open redwood stands is poor; there are few trees of key piece size for LWD (≥22 in. diameter for all but headwater streams). These stands will only provide limited LWD recruitment opportunities for key piece LWD to stream channels with an average bankfull width of ≥ 20 ft during the next 20 years. The density of larger trees increases to 53 tpa at ≥22 in. dbh at 40 years. Therefore, long-term recruitment potential for these stands is good. These stands currently have only 1 tpa >40 in. dbh. and there is expected be only a slight increase of very large trees over the next 40 years assuming no silvicultural management.

Mixed redwood/hardwood and hardwood riparian stands have a QMD of 17.8 inches and the stocking of key piece size conifers will remain relatively low (<17 tpa at ≥ 22 in. dbh) for the next 40 years or longer. These stands contain few, if any, larger diameter (≥ 40 in. dbh) trees. These areas of poor LWD recruitment potential occur primarily in the lower Freshwater basin and uppermost upper Freshwater sub-basin outside of PALCO ownership.

The growth of a newly planted riparian stand was also simulated. Trees in the modeled plantation stand began reaching 24 in. dbh at 60 – 80 years. This finding is consistent with field observations for the Freshwater drainage.

4.4.3 Shade

Stream temperature dynamics have been widely studied, and the physics of heat transfer is one of the better-understood processes in natural watershed management. A stream's temperature is constantly adjusting to maintain equilibrium with its surrounding environment. Once a stream achieves this equilibrium temperature regime (typically occurring within a stream reach length of 2,000 ft or less for small to moderate streams), it will continue to follow the same daily temperature pattern until the channel or climatic variables affecting the heat transfer processes change. Larger streams have greater mass, and cool groundwater inflow provides a smaller portion of the total flow. Therefore, larger streams take longer to respond to changes in ambient conditions. While there are many specific climatic and physical variables accounted for in the stream heat energy balance, the four primary environmental variables are riparian canopy, stream depth, local air temperature, and groundwater inflow. Bartholow (1989) and Chapra (1994) rank air temperature as the most important variable influencing water temperature.

Most streams in the Freshwater Creek watershed currently meet properly functioning aquatic conditions for shade/canopy cover (Table 4-12). Canopy cover averaged 81% for streams with adjacent mature second-growth redwood stands (RDW5D and RDW5M). Young redwood stands (RDW3D) can still provide more than 85% canopy cover when the adjacent channel is small (<25 ft bankfull width). Canopy cover within mixed redwood/hardwood stands was slightly less, with an average 75% canopy cover. The lowest canopy cover occurred along the lower Freshwater Creek below PALCO’s ownership where riparian vegetation is often limited to shrubby growth along the banks. Cryptos modeling indicates that many of these areas will not achieve properly functioning aquatic conditions for shade/canopy cover for decades. In the absence of management, future canopy closure is expected to exceed 88% for most of the Freshwater riparian stands (Table 4-13).

Instantaneous and continuous recording water temperature data have been collected for numerous stream locations throughout the Freshwater basin. These temperature records are representative of Class I, II, and III streams within various sub-basins. Most of the maximum recorded water temperatures in the Freshwater basin during summer months were less than 16^{o}C. Temperatures up to 17^{o}C were measured in the lower mainstem reaches. Therefore, the majority of stream reaches within Freshwater, particularly those within PALCO’s ownership, meet properly functioning aquatic conditions for temperature. The riparian condition for the stream reaches where temperature data were collected reflect the distribution of riparian types in the basin. Most sites had dense redwood stands of >24 in. dbh trees; however, data are inclusive of sites with sparse stands, young plantation stands, and shrubby riparian vegetation. Even when canopy cover was as low as 70% and included only a narrow, shrub-dominated buffer, the maximum weekly average water temperatures ranged from 12.6°C to 17°C from early July through late October (see the Fisheries Assessment Module for a detailed discussion). The lack of differences in stream temperature regimes despite differences in riparian canopy cover suggests that stream temperatures in the Freshwater basin are strongly influenced by a cool maritime climate.

Table 4- 12: Canopy closure for consolidated riparian stand types.

Code	Description	% Canopy Closure
LC	Large/Medium Redwood: QMD 21.4 in.; >90%CC (RDW5d and RDW5M)	A & B plots 93% C plots 91%
SC	Small tree Redwood: QMD 20.3 in.; >90%CC (RDW4D and RDW4M)	86%
YC	Young Redwood: QMD 15.7 in.; 40-90%CC (RDW 2-3D/M)	90%
SP	Sparse to Open Redwoods: QMD 16.1 in; <40% CC for Dom/Co-Dominant (RDWS and RDWP)	62%
CH	Mixed redwood/hardwood: QMD 17.8 in, %CC variable (RDW/HWD, HWD/RDW)	94%
G	Grass	NA
H	Hardwoods	NA

Table 4- 13: Percent vertical canopy closure within riparian units estimated for the future using the CRYTOS model.

	Stand Type					
Year	**RDW5**	**RDW4**	**RDW2/3**	**RDW-SP**	**RDW/HWD**	**Plantation**
Current	77	79	71	43	42	35
10	80	82	78	50	49	
20	84	84	83	59	57	
30	87	86	87	65	64	
40	89	88	90	70	69	83

Summer climate regimes of the Freshwater basin are influenced by the inshore flow of coastal fog as inland temperatures rise. This phenomenon serves to maintain cool air temperatures and corresponding cool stream temperatures in the Freshwater basin. The entire Freshwater drainage lies within the coastal influence zone: thus, cool summer temperatures prevail. Hence, elevated summer temperatures due to riparian management within the Freshwater basin do not pose an adverse condition for salmonids and other cold water biota.

4.5 CHANNEL CONDITION

The Stream Channel Assessment Report evaluated the potential responses of streams channels to increases or decreases in flow, sediment inputs (coarse and fine), and large woody debris. Much of the analyses in the Stream Channel Assessment Report directly address the cumulative effects of management related inputs in that the interactions between sediment, wood, and flow effects are evaluated. Details of the assessment are found in the Stream Channel Assessment Module Report (Appendix E).

4.5.1 Channel Characteristics

Channel characteristics in the basin are highly affected by the underlying geology. Wildcat geology is soft and homogeneous, consisting of poorly consolidated mudstone, sandstone, and conglomerate. This makes for relatively simple channel forms in reaches overlying that geology. The longitudinal profile of channels overlying Wildcat geology are characteristically steep in their upper reaches and quickly transition to long, low gradient channels. Substrate in these channels is predominantly sand and silt, with local accumulations of gravel. Gravels derived from the Wildcat Group are typically very soft and can be broken between one's fingers. LWD is the dominant habitat-forming element in channels underlain by the Wildcat Group.

The Franciscan geology consists of greywacke, shale, chert, and schist. The geologic group consists of blocks of hard rock floating in a matrix of fine-grained materials (sand, silt, and clay). The hard rock provides a source of coarse material that can accumulate in channels, forming spawning habitat and providing rough components that enhance the formation of complex habitat within the channel. Relative to channels in the Wildcat areas, stream channels overlying the Franciscan geology are not as dependent on LWD as a habitat-forming element. Large landslides are more common in the Franciscan, and these features can dominate channel morphology.

The Yager geologic group is exposed in the bed of several channel segments. The sandstone and conglomerate units of this geologic group are relatively resistant and form good spawning substrate and amphibian habitat. The Yager outcrops are found primarily within the area dominated by the unconsolidated Wildcat geologic group. Yager sandstone and conglomerate clasts can travel down channels and not immediately crumble. However, the shale member of the Yager will crumble in one season on the gravel bars if exposed to more than a few wetting and drying cycles. For this reason, attrition in the Yager is bimodal: the sandstones are competent and the shales are weak.

Stream segments in the Freshwater Watershed were categorized into process groups that share certain key watershed characteristics, such as geology, channel gradient, and confinement. These process groups are referred to as Channel Geomorphic Units or CGUs (in the WDNR and revised PALCO Methods, CGUs are referred to as geomorphic map units [GMUs]). CGUs subdivide the stream channels into groups of discrete segments that are likely to respond similarly to different types of input or disturbance.

Stream segments were initially divided into two groups, reflecting the character of the underlying geology. These CGUs are referred to as “consolidated,” which are those overlying Franciscan geology and “unconsolidated,” which are primarily those overlying Wildcat geology. Within these groups, segments were further subdivided into groups reflecting changes in channel gradient, which is also an important factors influencing channel form and processes. Gradient classes that were used were adapted from Montgomery and Buffington (1993) and included 0 to 3%, 3 to 6.5%, 6.5 to 20% and >20%.

In addition to the eight CGUs that were defined by geology and gradient, several channel segments were identified that respond differently to inputs or have different channel characteristics. These include three channel segments that make up the lower mainstem of Freshwater Creek, Cloney Gulch, and Graham Gulch. A summary of the factors defining the various CGUs and the CGU designations used throughout the analysis is provided in Table 4-14.

Streams in all but the mainstem CGUs run through relatively confined valleys (5 24). Depths and widths of the CGUs tend to decrease as gradients increase and the streams approach the headwaters. Substrate size reflects the underlying geology. The substrates in the consolidated CGUs tend to be larger than the substrates in the unconsolidated and mainstem CGUs (Figure 26). Graham Gulch and Cloney Gulch have substrate sizes intermediate between the consolidated and unconsolidated CGUs. Each of these reflects local conditions. Cloney Gulch is underlain by a combination of Wildcat and Franciscan geologies and a large, deep-seated landslide influences Graham Gulch.

The mean size of sediments (d50) in the stream channels reflects the stream power (function of stream gradient and flow) of the various CGUs (25). Typically, those CGUs overlying Wildcat geology have a lower gradient and, hence, lower stream power than those overlying Franciscan geology. As a result, they also tend to have finer beds. The primary characteristics of each of the CGUs are summarized below. Detailed information regarding these units can be found in the Stream Channel Assessment Report.

Table 4- 14: Summary of CGU unit definitions.

CGU Code	Geology	Gradient
U1	Unconsolidated	0-3%
U2	Unconsolidated	3-6.5%
U3	Unconsolidated	6.5-20%
U4	Unconsolidated	>20%
C1	Consolidated	0-3%
C2	Consolidated	3-6.5%
C3	Consolidated	6.5-20%
C4	Consolidated	>20%
MS1	Mainstem	<1%
MS2	Mainstem	<1%
MS3	Mainstem	<1%
CG	Cloney Gulch	<1%
GG	Graham Gulch	<5%

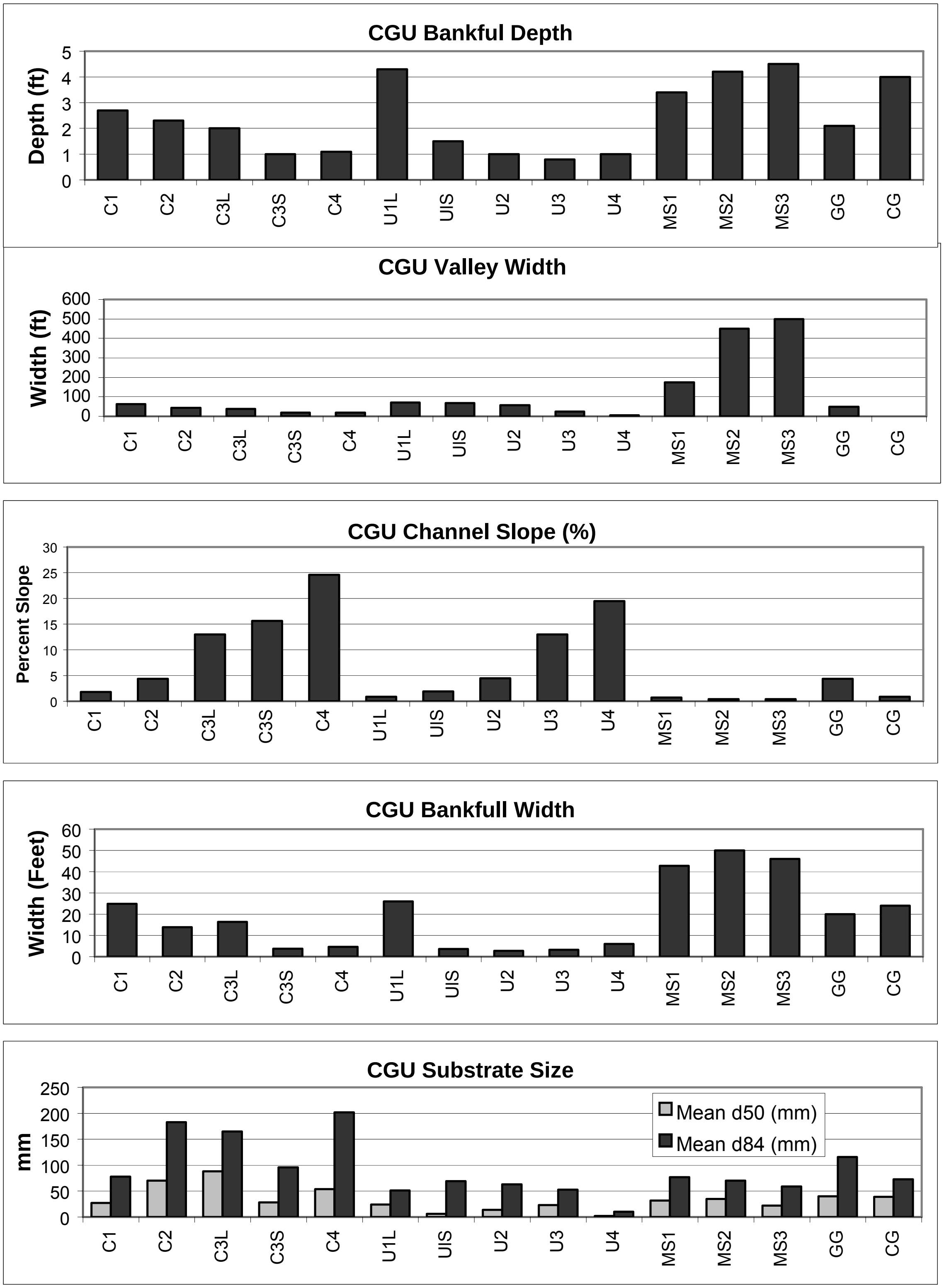


Figure 26: CGU Descriptions.

4.5.2 CGU Descriptions

Consolidated Units (CGUs C1-C4)

C1 - Low Gradient Reaches (0-3% in Consolidated Bedrock)

Most of the C1 reaches are located in the lower portions of Upper Freshwater Creek and the South Fork of Freshwater Creek. Shorter, less continuous C1 reaches are also found in portions of McCready Gulch (downstream of Horse Gulch) and in the middle mainstem of Little Freshwater Creek, where the channel has incised through the Wildcat sands to the underlying Yager Formation. CGU C1 streambeds are dominated by gravel and cobble with bedrock exposed in banks and occasionally in the bed. Gravel bars are abundant. Channel morphology in C1 reaches is predominantly pool-riffle, with some plane-bed reaches. Channel substrates vary considerably, depending in part on watershed lithology. Fine sediment is relatively abundant, and deposits of sand are generally present in pools. In Little Freshwater Creek, the C1 reaches provide some of the only competent rock in that tributary. The low-gradient nature of these reaches and the more competent nature of the substrate provide some of the best quality salmonid spawning and rearing habitat in the watershed.

C2 - Moderate Gradient Reaches (3-6.5% in Consolidated Bedrock)

C2 reaches are found in the middle and upper mainstem reaches of Upper Freshwater and the South Fork. Shorter, more isolated C2 segments are also found in the mainstem of Little Freshwater Creek and some of its tributaries, where the channel has incised through the overlying Wildcat sands.

CGU C2 is a moderately powerful channel, comparable to C1 but with a distinctly coarser substrate. It has cobble/gravel bed channels with bedrock commonly exposed in the banks and bed. Mobile gravel and cobbles are deposited on bars and in association with LWD, but bar abundance is lower than in C1. Average median grain size is much coarser than in C1. Channel morphology is predominantly pool-riffle and step-pool, with steps formed either by LWD accumulations, bedrock, or boulder accumulations in the channel. Roughly 1/2 of the stream segments in this CGU support fish. With the exception of a stretch in South Fork Freshwater where steelhead and coho are found, these fish-bearing segments contain only trout.

C3 - High Gradient Reaches (6.5-20% in Consolidated Bedrock)

CGU C3 was found to have two sub-groups differentiated as a function of drainage area and stream power. The sub-group C3-Large has an average drainage area of about

1,500 acres, while the sub-group C3-Small has an average drainage area of about 100 acres.

CGU C3-L is narrow and entrenched, and has boulder/cobble bed channels with bedrock commonly exposed in the banks and bed. Channel morphology is cascade and step-pool. Mobile gravel and cobbles are deposited in forced bars associated with LWD, boulders, and in regions of lower slope, but bar abundance is lower than in C1 and C2. CGU C3-S has the lowest stream power of consolidated CGUs. C3-S channels have gravel/cobble beds with some bedrock exposed in the banks and bed. Channel morphology is cascade and step-pool. Mobile gravel is deposited in forced bars associated with LWD, boulders, and in regions of lower slope. C3 channels with steep sideslopes have more frequent streamside landslides. Channel reaches in the vicinity of these landslides are often full of large boulders and coarse channel substrate.

With the exceptions of some short cascades in mainstem reaches, most C3 channels are found in the lower portions of tributaries to Upper Freshwater, South Fork, Graham Gulch, Cloney Gulch, and McCready Gulch. The majority of the C3 reaches lie outside of the distribution of the various fish species in the basin. Exceptions include a small segment (<800 ft) in Cloney Gulch, three small segments (about 3,000 ft total) at the lower end of tributaries to the upper mainstem of Freshwater Creek, and one small stretch on the lower end of a tributary to Little Freshwater Creek. The last of these supports coho. The others support resident fish populations. The upper extent of trout populations often breaks near the junction between C2 and C3 streams.

C4 - Very High Gradient Reaches (>20% in Consolidated Bedrock)

CGU C4 has a stream power index, similar to C1 and C2, and has gravel/cobble/boulder bed channels with some bedrock exposed in the banks and bed. Channel morphology is cascade with occasional step-pool forms. Mobile gravel is deposited in forced bars associated with LWD, boulders, and in regions of lower slope, but bar abundance is very low. C4 channels typically have a stepped profile due to the heterogeneous nature of the Franciscan formation. Boulders, clay-rich colluvial wedges, LWD, or roots from nearby trees or stumps can form steps and cascades in these channels. Banks in the C4 units are more cohesive than banks in U4 units due to the higher clay content in the Franciscan derived soils.

C4 reaches include the upper portions of the channel network in the northeast half of the Freshwater Creek Watershed. There are no C4 channels consisting of Yager bedrock because these smaller channels have not incised deep enough to penetrate overlying

Wildcat Group sediments. These channels contain no fish but are often important habitats for amphibians.

Unconsolidated Bedrock Reaches (CGUs U1 - U4)

Channels developed in the unconsolidated Wildcat Group tend to have a fairly uniform longitudinal profile due to the sandy, homogeneous parent material and easily weathered and eroded bedrock. The profile characteristically has a long low-gradient mainstem with a rapid transition to steep-gradient channel in the upper mainstem reaches. Ridges in the Wildcat Group tend to be narrow, especially where two channel heads approach each other from opposite directions. The landscape is generally more dissected in the Wildcat Group, with higher drainage densities and abrupt, steep headwall channels.

U1 - Low Gradient Reaches (0-3% in Unconsolidated Bedrock)

CGU U1 was found to have two sub-groups differentiated as a function of drainage area and stream power. The sub-group U1-Large has an average drainage area of about 2,300 acres, while the sub-group U1-Small has an average drainage area of about 160 acres. Similarly, the stream power index for U1-L is much higher than for U1-S. U1-L has gravelly sand bedded channels with Wildcat Formation bedrock commonly exposed in the banks and bed. Channels are not very entrenched, with relatively continuous floodplain surfaces extending along the channels. Channel morphology is pool-riffle and plane bed. Mobile gravel is deposited in sandy bars associated stream bends and LWD; bar abundance is high. The dominant substrate is sand. CGU U1-S channels are quite narrow relative to the valley, but the degree of entrenchment is greater. CGU U1-S has sand bedded channels with some gravel. Bedrock is not typically exposed in the banks and bed. Channel morphology is pool-riffle and plane bed. Mobile gravel is deposited in sandy bars associated with abundant LWD; bar abundance is low.

U1 reaches are found in the lower mainstem of Little Freshwater and McCready Gulch, which are both predominantly underlain by Wildcat Group sandstone and mudstone. They tend to be dominated by fine sediments, with fine alluvial bank material. Broad floodplains and terraces are common along many U1 channels, especially in Little Freshwater Creek. LWD can provide complex rearing habitat, but spawning habitat is very limited due to a lack of coarse substrate. Much of the habitat in McCready Gulch and Little Freshwater lies within U1 channels.

U2 - Moderate Gradient Reaches (3-6.5% in Unconsolidated Bedrock)

CGU U2 has very low stream power index, and the channel is narrow in comparison to valley width. CGU U2 has sand bedded channels with some gravel. Bedrock is occasionally exposed in the banks and bed. Despite low stream power index, channels are scoured to Wildcat bedrock in many places. Channel morphology is step-pool and pool-riffle. LWD accumulations create step-pool morphology. Mobile gravel is deposited in sandy bars associated with abundant LWD; bar abundance is high. U2 reaches are found in the upper mainstem of the Little Freshwater Creek, McCready Gulch, School Forest, South Fork, Graham Gulch, and Cloney Gulch, and in the lower reaches of the largest tributaries of these basins. Salmon are not known to be present in these channels and trout are known to be present in only a very small portion of them.

U3 - High Gradient Reaches (6.5-20% in Unconsolidated Bedrock)

CGU U3 channels have relatively low stream power index but greater than U1-S and U2. Channels are also more confined than U1-S and U2 channels, but channels are nevertheless relatively wide compared to the valley floor. U3 channels have some bedrock exposed in the banks and bed; mobile bed material in bars is sandy gravel. Channel morphology is cascade and step-pool. Mobile sediment is deposited in forced bars associated with LWD, boulders and regions of lower slope. Coarse substrates are often lacking due to an absence of resistant material in the underlying geology. Wood and roots from trees adjacent to the channels often play important roles in these channels due to the lack of cobble or boulder substrate or cohesive soil matrix.

U3 channels are found in the tributary basins to Little Freshwater Creek, McCready Gulch, School Forest, and portions of the South Fork. These channels generally have step-pool morphologies, and many of these channels show signs of channel incision, resulting in deeply entrenched or notched channels. This notching may be a result of rapid erosion following first cycle logging (PWA 1999). Within such notched channels, LWD is often ineffective in modifying channel morphology and processes because it cannot reach the active portion of the streambed.

U4 - Very High Gradient Reaches (>20% in Unconsolidated Bedrock)

CGU U4 channels have relatively abundant bedrock exposed in the banks and bed; mobile bed material in bars is sandy with little gravel. U4 has the highest stream power index in the unconsolidated CGU group. Channel morphology is cascade and colluvial. Mobile sediment is deposited in forced bars associated with LWD and in regions of lower slope, but bar abundance is low. U4 reaches are found in the upper reaches of all of each of the Wildcat-dominated basins. Many of these reaches also show signs of historic incision, resulting in deeply entrenched or notched channels similar to that seen in many U3 channels. Within such notched channels, LWD is often ineffective in modifying channel morphology and processes because it cannot reach the active portion of the streambed. The median grain size on the bed is anomalously low relative to stream power, and reflects largely the absence of coarse substrate in these headwater channels. Bedrock, however, is relatively abundant for a small channel, which probably indicates some degree of channel scour from first-cycle harvesting. These channels do not support fish and are not believed to support amphibians except possibly in isolated areas where larger substrates have accumulated.

Mainstem Reaches (CGUs MS1-MS3)

The lower mainstem of Freshwater Creek extends from the confluence of the South Fork and Upper Freshwater tributaries to Three Corners Market, near the Bridge at Myrtle Avenue. Channel gradient decreases gradually from 0.009 to 0.001, and bed material becomes finer in the downstream direction.

MS1 - Mainstem, Reach 1

CGU MS1 has intermediate stream power relative to other CGUs, but the highest by a small margin among the Mainstem CGUs. MS1 has gravel/cobble bed channels with bedrock exposed in banks and occasionally in the bed. Channel morphology is pool-riffle and plane bed. Mobile gravel and cobbles are deposited on bars and in association with LWD. MS1 includes the mainstem of Freshwater Creek, from the confluence of the South Fork and Upper Freshwater Creek to the confluence with Graham Gulch. The upper portion of this reach has incised into Yager terrane shale, forming a deep gorge with well-exposed fluvial terraces. Terrace heights decrease toward the lower end of the reach, but in general the channel in confined by fluvial terraces, with minimal floodplain development. In contrast to mainstem reaches of each of the tributary basins (primarily C1 channels), LWD accumulation is sparse in most of MS1. This is caused in part by relatively large channel width and depth that reduces the stability of LWD, but also due to historic management of riparian areas and residents that remove LWD from these channels. The lower reach of this CGU is one of the three primary salmonid spawning locations in the Freshwater Creek basin.

MS2 - Mainstem, Reach 2

MS2 extends from the confluence with Graham Gulch to the confluence with Little Freshwater Creek. The stream power index for CGU MS2 declines slightly relative to

MS1. Channel slope, confinement and entrenchment all decline in MS2 relative to areas upstream, making it prone to sediment deposition. It is also the upstream-most reach with a well-developed floodplain. CGU MS2 has gravel/cobble bed channels with bedrock exposed in banks throughout, and in the bed in the upper third of the CGU and in some localized areas further downstream. Wildcat bedrock is visible along the banks of much of this reach, except near Freshwater Park, where Yager terrane sandstone and shale are exposed. Exposed bedrock in these reaches indicates that there are limits to the amount of channel scour that can occur. There are accumulations of sand and fine sediment in pools. Channel morphology is pool-riffle and plane bed. There is very little LWD in this CGU. All species in the basin use this reach as spawning, rearing, or migration habitat.

MS3 - Mainstem, Reach 3

MS3 is a very low gradient reach (0.001-0.004), with a broad floodplain. MS3 has a sandy gravel bed with alluvial banks. Sub-reaches alternate between gravelly conditions and sandy conditions, apparently reflecting local variations in channel gradient. Channel morphology is pool-riffle and plane bed. MS3 extends from Little Freshwater Creek to the bridge on Myrtle Avenue (the downstream extent of the study area). The lower reach of MS2 is morphologically similar to upper MS3, but the contribution of fine sediment from Little Freshwater Creek influences channel morphology and provides a convenient place for a reach break. Below Little Freshwater Creek (and for a few hundred feet immediately above), the channel widens and the proportion of fine sediment stored in the bed and bars increases. There is very little wood accumulation in MS3, partly due to increased channel widths and flood discharges and partly due to historic management of riparian areas and removal of LWD by residents. For example, public scoping comments indicated that local residents have removed at least one large log jam in this reach in recent years. Spawning habitat in this reach is poor but there is some coho rearing habitat. Other species also are found rearing in the reach or during migration periods.

Small Mainstem Tributaries

There are numerous smaller tributaries to the lower mainstem that flow across the broad alluvial flats. With the exception of portions of the School Forest Watershed, these channels were not evaluated as part of this Watershed Analysis, since nearly all of these channels are on non-PALCO lands. These channels are probably similar to CGUs U1-S and U2.

Exception Reaches (CGUs GG and CG)

The middle and lower mainstem reaches of Graham Gulch and Cloney Gulch have unique channel morphological features and sediment transport processes. At least two faults bisect these channels, resulting in rapid changes in channel geology over relatively short distances. These channels therefore have characteristic of both unconsolidated and consolidated geologies. Both Graham Gulch and Cloney Gulch had railroad grades and/or corduroy roads constructed in the mainstem channel. The remains of these railroad grades are still found in portions of the channels today. These function as anomalous LWD accumulations.

GG - Graham Gulch

Graham Gulch is a unique CGU because of elevated sediment loads, the presence of remnant railroad features in the channel, and geologic complexities resulting from faulting and lithologic variability. CGU GG has a gravel bed with occasional bedrock outcrops in the banks. Gravel bars are abundant. Channel morphology is pool-riffle and plane bed. Reach average median grain size is about 30-40 mm. The lower mainstem of Graham Gulch is severely impacted by sediment due to remobilization of a large earthflow, and erosion of a remnant landslide dam deposit that introduced over 5,000 cubic yards of sediment to the channel. This earthflow and associated deposits appear to be of natural origin. The lower mainstem of Graham Gulch is likely to be severely impacted by sediment for at least a decade. Coarse bed material delivers directly to the upstream boundary of CGU MS2, where aggradation and flooding hazards are most significant in the watershed.

CG - Cloney Gulch

CGU CG has a gravel bed with occasional bedrock outcrops in the banks. Channel morphology is pool-riffle and plane bed. In most respects, it is probably similar to CGU C1. Cloney Gulch was designated as a CGU exception primarily due to geologic complexities and the presence of remnant railroad features in the channel. The mainstem of Cloney Gulch flows through all three dominant geologic formations found in the basin. The Freshwater Fault and Greenwood Heights Fault cut through the lower mainstem of Cloney Gulch, juxtaposing different lithologies. The high proportion of Franciscan Central belt terrane rocks contributes significant quantities of gravel and cobble to the mainstem of Cloney Gulch, creating more favorable habitat conditions than would otherwise be expected given the prominence of the Wildcat geology in this watershed. South Fork Freshwater has a somewhat similar mix of lithology. Some of the best-preserved railroad features are found in Cloney Gulch. These features continue to influence sediment transport and storage processes in a manner that does not occur in the other basins.

4.5.3 Channel Migration

The upper watershed, its tributaries, and the upper mainstem reach of Freshwater Creek have steep streamside slopes, are frequently bounded by bedrock, and have relatively narrow confined channels. Surveys of these channels revealed bank erosion processes but no significant lateral channel migration. Therefore, it was concluded there is little potential for significant channel migration except locally in CGU U1-L (see Stream Channel Assessment Report for details).

In lower Freshwater (MS2 and MS3), where channel confinement and the ratio between terrace heights and bankfull depth declines, a well-established floodplain exists. However, it is apparent that there have not been major changes in channel location since the 1940s. There are likely a few reasons for this lack of observed channel changes. First, the sediment delivered to these CGUs is primarily fine sediment. The quantities of coarse sediment needed to induce channel avulsion are not available to these channels. Second, there is a paucity of wood in these channels. In the presence of greater volumes of wood, the channel banks may erode or accumulate sufficient sediments to induce channel avulsion. Finally, there is evidence that residents actively intervene to prevent channel migration/avulsion. The absence of lateral channel migration in lower Freshwater suggests that erosion and sedimentation processes in the watershed are relatively modest.

4.5.4 Sediment Transport

Sediment inputs include a range of grain sizes. Those categorized as silt and clay (<0.075 mm) trend to transport in the suspended load. As a result, this size fraction is typically transported out of the basin quickly and does not accumulate appreciably in the streambeds. Note that these size fractions are not the same as those defined in other locations of this report as “fines” which are defined as <0.85mm, or up to an order of magnitude larger than the silt and clay particles that tend to remain in suspension. The paucity of this size fraction in the various bedload samples supports this assessment (see Stream Channel Assessment, Section 3.5). Some portion, roughly 50%, of the sand size fraction (<2 mm, including the portion of fines between 0.075 and 0.85 mm) is also transported in the suspended load, at least during high flow periods. (The sands and the larger components of the fines $\geq$0.075 mm are the size fractions that are often trapped in coarser sediments, affecting the quality of spawning substrates.) Other size fractions move through the watershed as bed load.

Approximately 70% of the cumulative sediments delivered to streams in the watershed are silt and clay (<0.075 mm) (Figure 22). While this size fraction does not accumulate appreciably in the beds, it does contribute to turbidity in the streams and may settle out seasonally in low velocity areas. Thus, most streams in this basin would naturally have higher turbidity levels than those draining areas with geologic formations that produce fewer fine sediments. The effects of turbidity are discussed further in Section 4.6 of this report. Roughly 60% of the remaining material ($\geq$0.075 mm) is sand. Material the size of fine gravel and larger makes up only 12% of the total sediment inputs. Sediment inputs were estimated at 386 tons/mi^2/yr, which is in close agreement with the data collected at the Salmon Forever gage, which yielded estimates ranging from approximately 375 t/mi^2/yr to 470 t/mi^2/yr. This agreement in the estimates of total cumulative sediment inputs substantially improves the confidence in the overall sediment budget.

Bedload transport varies with stream power; hence, the amount of sediment transported in any reach is a function of the stream gradient and the streamflow. Since streamflow is highly variable within and between years, the transport capacity also varies over time (Figure 27).

Attrition or break down of particles as they transport downstream can affect bedload composition. Attrition rates were qualitatively determined for the Freshwater. Field observations indicate that there are two primary attrition rate classes. Attrition classes are a function of bedrock strength. In the Freshwater Creek watershed, there are two distinct groups of geologic formations as described for Channel Geomorphic Units. One group is comprised of the relatively resistant rocks of the Franciscan formation and members of the Yager formation, collectively referred to as the Consolidated unit. The other group is comprised of the very weak rocks of the Wildcat Group, which comprises the Unconsolidated unit.

What little gravel is produced from Wildcat parent material has very high attrition rates. Hand samples of Wildcat gravel found on bars can generally be crushed in one’s hand. Based on field observations of the lithologic composition of gravel bars in Freshwater, Wildcat gravels typically do not persist as gravel for more than 100s of feet of transport. Hence, most of the material that enters channels from Wildcat bedrock or soils will be broken down to sand size particles or finer. Thus, these channels are naturally expected to have both high fine sediment and high turbidity levels.

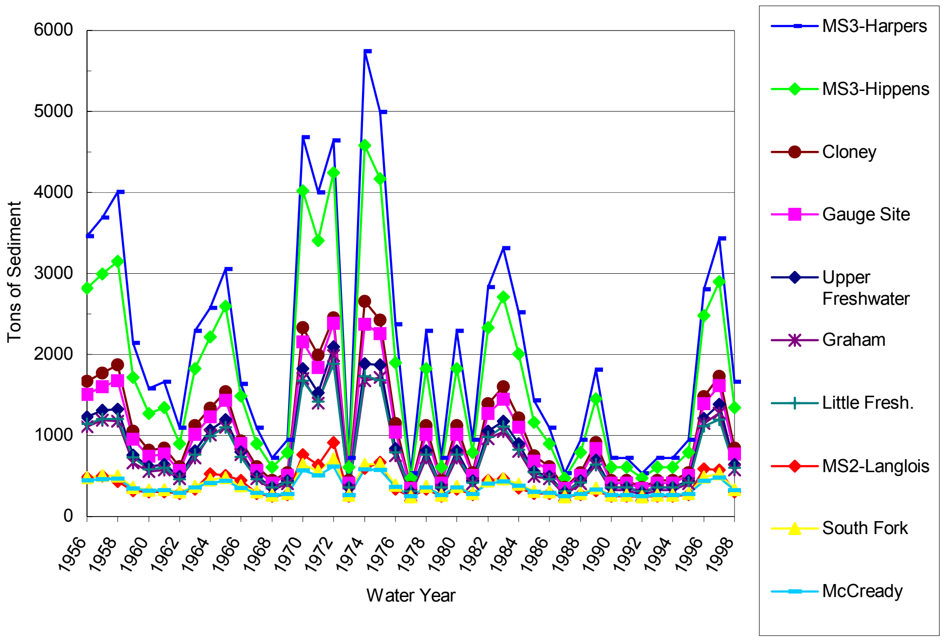


Figure 27: Modeled bedload sediment transport capacity over time for Freshwater subbasins and mainstem reaches (based on flow record at Little River).

Gravel produced from the consolidated bedrocks units has a wider range of attrition rates. Chert derived from the Franciscan is relatively resistant to attrition, while sandstones and conglomerates were less resistant than chert, but much more resistant than the Wildcat. The proportion of these gravel materials broken down to sand sizes or finer is not known. Estimates of attrition rates from other studies would suggest that roughly 25% of the larger material would be broken down in 6 km, the approximate length of the Class I channels linking Upper Freshwater and South Fork Freshwater to the bottom of GCU MS1.

4.5.5 Sediment Deposition and Channel Aggradation

Deposition of sediments is related to the transport capacity of the channel and the total inputs of sediment relative to the transport capacity. The grain size of existing and input sediment is also a factor in whether sediments deposit or are carried farther downstream. The unconsolidated CGUs tend to have smaller particle size than the consolidated units (Figure 28). In general, the mean surface d84 (mm) correlates with mean stream power index (Figure 29).

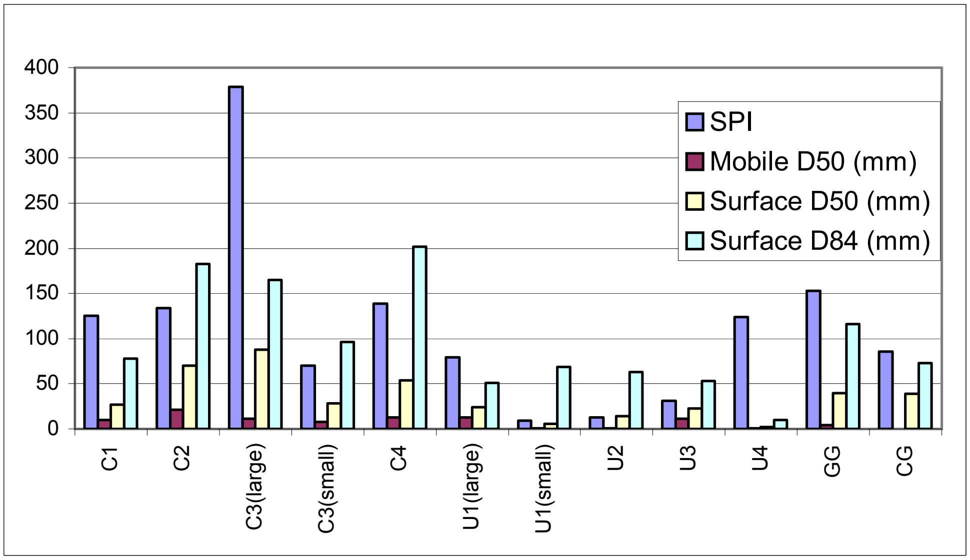


Figure 28: Summary of the range of values of d50 and stream power indices for CGU groups.

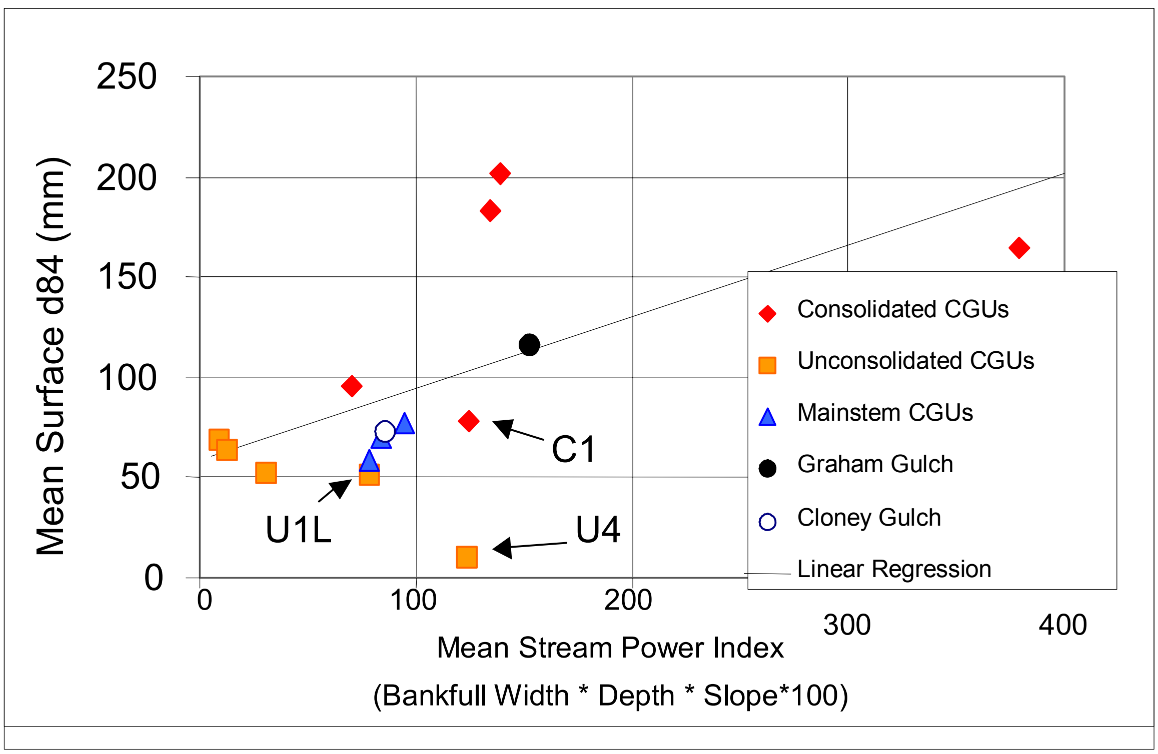


Figure 29: Plot of mean surface d84 for CGUs versus mean stream power index for each CGU.

Lower Mainstem Reaches

In general, the lowest gradient reaches ($\leq$0.5%) in the Freshwater watershed are expected to be most prone to aggradation due to simultaneous increases in valley width and floodplain width coincident with decreases in channel slope. Under these circumstances, stream energy typically decreases, allowing for deposition of coarser sediment delivered from upstream. In addition, the tidal influence of Humboldt Bay, which extends upstream to roughly ½ mile below the upper limit of MS3, creates a backwater effect during high tides. This causes a decline in water surface slope and creates a corresponding decrease in sediment transport. Therefore, sediment deposition is expected to increase during periods of high tide that coincide with peak discharge events.

Increases in cumulative bedload sediment from upstream that cause aggradation would typically be accompanied by adjustment of the channel to the changed conditions. Increases of bedload discharge may be expected to induce increases in channel width and stream meander, along with decreases in channel sinuosity. These changes, however, are not apparent in the lower Freshwater, suggesting that the channel has not been aggrading to a significant degree. In addition, field studies noted many areas in lower Freshwater where bedrock was exposed in the bed and banks, which indicates scour rather than aggradation. Finally, comparison of channel bed elevations to those recorded historically indicates either scour or limited aggradation over time (see Channel Assessment for more discussion of these data). Local residents, however, have reported up to 3 ft of aggradation; hence, an evaluation of sediment deposition within these channels was conducted.

Numerous approaches were used to evaluate the change in bed elevation over time in the lower mainstem Freshwater Watershed. These approaches included methods to factor in the cumulative effects of changes in sediment loads and changes in peak flows. The analysis methods are discussed in detail in the Stream Channel Assessment, Sections 5 and 6. One of the major potential cumulative effects of forest management in the Freshwater is downstream channel aggradation that could contribute to flood hazards in lower Freshwater Creek. The results of the various analyses presented in the Stream Channel Assessment are not always consistent; however, it appears that aggradation in at least some portions of the lower mainstem of Freshwater Creek (MS2 and MS3) is plausible. The most reasonable interpretation of the model results suggest that average aggradation in MS2 and MS3 combined over the period of 1942 to 1997 is about 0.6 ft.

Effect of Deposition on Flooding in the Lower Mainstem

Despite the evidence that aggradation in lower Freshwater Creek is both localized and limited to approximately 0.6 ft, analyses of the cumulative effects of aggradation and increased peak flows were conducted assuming 1.5 and 3 ft of aggradation at the Langlois cross-section in MS2, and 1 ft aggradation at the Hippen's cross-section in MS3. The methods used to evaluate these cumulative effects are described in the Stream Channel Assessment. The results of the analyses indicate that peak flows alone have a small effect on the frequency of flooding in the lower mainstem reaches (Table 4-15). Changes in bed elevation have a greater effect.

Assuming maximum aggradation and flow increases due to forest management, the analysis indicates that overbank flow will occur about four times more often at the Langlois reach than under estimated background conditions with a channel bed 3 ft lower than observed in 1999. If the presumed aggradation is reduced by half (1.5 ft), the annual probability of overbank flow is increased by about two times. At the Hippen's reach under the maximum aggradation of 1 ft and maximum flow increases, overbank flows are estimated to occur with a roughly two-fold increase in frequency.

Table 4- 15: Flood discharge and frequency for the Langlois and Hippen's cross-sections for 1999 channel bed elevations, elevations of 1.5 and 3 feet lower than 1999 elevations, and hypothetical baseline and 1999 runoff conditions.

Scenario	Channel Capacity (cfs)	Recurrence Interval (yrs)	Annual Probability (1/r1)
LANGLOIS CROSS-SECTION			
a – Baseline Flow, Bed Elevation 3 ft Lower	3960	8.3	0.12
a – Peak Flow Increase Only, Bed Elevation 3 ft Lower	3960	7.1	0.14
b – Baseline Flow, 1999 Bed Elevation	2540	2.7	0.37
b – Baseline Flow, Bed Elevation 1.5 ft Lower than 1999	3240	5.0	0.20
c – Peak Flow Increased, 1999 Bed Elevation	2540	2.2	0.45
c – Peak Flow Increased, Bed Elevation 1.5 ft Lower than 1999	3240	4.2	0.24
HIPPEN'S CROSS-SECTION			
a – Baseline Flow, Bed Elevation 1 ft Lower than 1999	4760	7.1	0.14
a – Peak Flow Increase Only, Bed Elevation 1 ft Lower	4760	5.6	0.18
b – Baseline Flow, 1999 Bed Elevation	4080	4.8	0.21
c – Peak Flow Increased, 1999 Bed Elevation	4080	3.8	0.26

Overbank flow as used above refers to flows that just top the streambanks, which is approximately equal to a 2-year event. Flows of this magnitude primarily involve flooding of unimproved properties, not of residences. Flooding of residences would most likely result from less frequent, higher magnitude floods (e.g., 10-year or 15-year events).

The effects of channel aggradation and harvest-related changes in peak flow on these less common events were also analyzed. For 15-year flood events, flood state is predicted to be in the range of 0.5 to 1 ft higher at the Langlois cross-section and 0.5 ft higher at the Hippen's cross section, presuming that the channel bed is aggraded 3 ft and 1 ft, respectively. For the 100-year flood, water surface elevation is predicted to be about 0.5 ft higher at both the Hippen's and Langlois cross-sections. The effect of an increase in the flood elevation of this magnitude is believed to affect only those residences constructed on the lower floodplain surface.

Tributaries and Upper Freshwater Creek

Tributaries and upper reaches of Freshwater Creek are significantly steeper than 0.5% and are entrenched with narrow floodplains. Relative to the lower reaches of Freshwater Creek, these reaches are unlikely to aggrade significantly in the long term. Current condition and changes in sediment loads over time were evaluated in these reaches using a wide variety of methods. These analyses are detailed in the Stream Channel Assessment, Section 5. Various indicators of current condition and trends were not always consistent. The overall conclusions regarding sediment deposition in the various reaches are summarized below.

Upper Freshwater: This area of the basin has a relatively coarse size distribution of bedload in storage, owing in part to the high proportion of Franciscan rocks delivered to the channel and in part to high stream power. Observed sediment storage in the channel is comparable to but less than predicted aggradation, suggesting that perhaps some aggradation has occurred in this sub-basin. The magnitude of the predicted increase in bed elevation is relatively small compared to the degree of entrenchment in this sub-basin, suggesting that major changes in channels potentially induced by avulsion are unlikely. Evidence of either stable or coarsening streambed sediment (d50, %< 0.85 mm, %< 4.7 mm) and bed fining (V*) are present. There is not a pattern providing consistent or strong evidence of sedimentation.

South Fork Freshwater: Most indicators suggest aggradation and/or fining. The South Fork has a relatively low drainage area and low stream power, which suggests relatively high sediment storage potential. The high volume of LWD and frequency of debris jams significantly enhance this potential. The high proportion of Wildcat parent material in the watershed suggests that a relatively high proportion of fines would be present in the channel even under natural conditions. Predicted bed aggradation is less than sediment storage, suggesting that high sediment storage conditions have existed for a relatively long period, possibly related to LWD accumulation in the channel following the first cycle of logging.

MS1: This CGU has a moderately coarse bed, relatively high stream power and drainage area, and is deeply entrenched in the valley floor with frequent bedrock exposures. There is limited evidence of aggradation. In addition, the low q* value is strongly suggestive of transport capacity in excess of sediment supply. The bedload routing model results are consistent with this interpretation.

Graham Gulch: This CGU has mixed indications of aggradation and degradation and bed fining. Both long-term and short-term indicators are consistent with episodic direct inputs of sediment by a large, persistent deep-seated landslide and relatively high transport capacity. Graham Gulch has a relatively coarse grain size distribution, in part owing to long-term inputs of relatively persistent gravel from the Franciscan terrane.

Cloney Gulch: Limited data were available for Cloney Gulch. The bedload routing model consistently indicates channel degradation. However, there is also evidence of bed fining suggesting deposition. Hence, analyses regarding deposition in this CGU are inconclusive.

MS2: As noted above, this CGU has mixed indications with signs of aggradation and fining locally present but interspersed with areas suggesting stable beds or scour. The bedload routing model consistently predicts bed aggradation; however, the relatively coarse grain size distribution in inconsistent with bed fining. Conditions in this reach appear to favor selective transport of sand and storage of gravel.

Little Freshwater: Little Freshwater has many indicators consistent with aggradation and bed fining. Due to the fine-grained character of sediment inputs in this watershed, high fine sediment concentrations would be expected even under natural conditions. The bedload routing model suggests that long-term channel degradation may be interspersed with periods of aggradation in response to increased sediment inputs. Sediment inputs are not expected to persist owing to high attrition rates of coarse sediment derived from Wildcat parent material.

McCready Gulch: McCready Gulch has consistent indications suggesting aggradation and fining. Predicted aggradation is consistent with observed sediment storage. However, given the degree of channel entrenchment, this may not have significant effects on channel processes. The fine-grained character of sediment inputs in this watershed partly accounts for indicators of bed fining in that high fine sediment concentrations would be expected even under natural conditions.

MS3: The lower mainstem downstream of Little Freshwater has consistent indications of aggradation and fining. The low gradient and low confinement of this channel, and many other factors described at the outset of this section, is consistent with these indications. However, the magnitude of aggradation observed and predicted in this reach is relatively small in comparison to channel depth.

4.5.6 Bedload Residence Time

Estimates of volumes of stored sediments were compared with estimated bedload transport rates to develop an estimate for bedload residence time. This assessment found that bedload is transported from the upper reaches of Freshwater Creek and its tributaries to lower Freshwater over a period of decades (Table 4-16). Thus, where aggradation is present, particularly in more downstream portions of the stream network (e.g., MS2, MS3), much of the sediment likely originates from natural and management-related sediment inputs from periods many decades in the past. This is less true for sand-sized particles. The residence time estimates do not distinguish differential rates of transport of sand and gravel. However, it is believed that the residence time of sand in these channel reaches is on the order of 10 years.

Table 4- 16: Estimated sediment storage, transport rate and residence time. "MS2 and MS3 Combined" is the scenario where the calculated bedload transport rate at MS2 is regarded as an anomaly.

Sub-basin or Reach	1999 Estimated Stored Sediment (tons)	Average Bedload Transport Capacity (t/yr)	Residence Time (yr)	Average Bedload Velocity (ft/yr)
Upper Freshwater	21,200	860	25	340
South Fork	51,400	200	260	42
Upper Mainstem (CGU MS1)	44,300	1100	40	300
Graham Gulch	30,600	720	43	150
Cloney Gulch	28,400	1290	22	510
Lower Mainstem (CGU MS2: Graham Gulch to Little Freshwater)	33,600	190	180	31
Little Freshwater	21,800	810	27	500
McCready Gulch	9,500	180	53	160
Lower Mainstem (CGU MS3: Below Little Freshwater)	69,900	2620*	27	460
MS2 and MS3 Combined	103,600	2620*	40	450

"*" denotes the MS3 transport rate, which is the average of two stations in the reach.

4.5.7 Potential for Scour of Redds

The increase in the probability of scour of redds as a result of increases in peak flows associated with forest management was evaluated using methods described in Haschenburger (1999). Details of that analysis are found in the Stream Channel Assessment, Section 6.2. The impact of flow change on stream scour was found to be relatively low for frequently occurring flow events (Figure 30). Since the effects of forest management decrease with increasing magnitude of flow, the expected increase in probability of scour will tend to decrease with increasing size of flow event. On the basis of these data, it is suggested that the effect of increases in peak flow on scour potential is sufficiently small as to be insignificant.

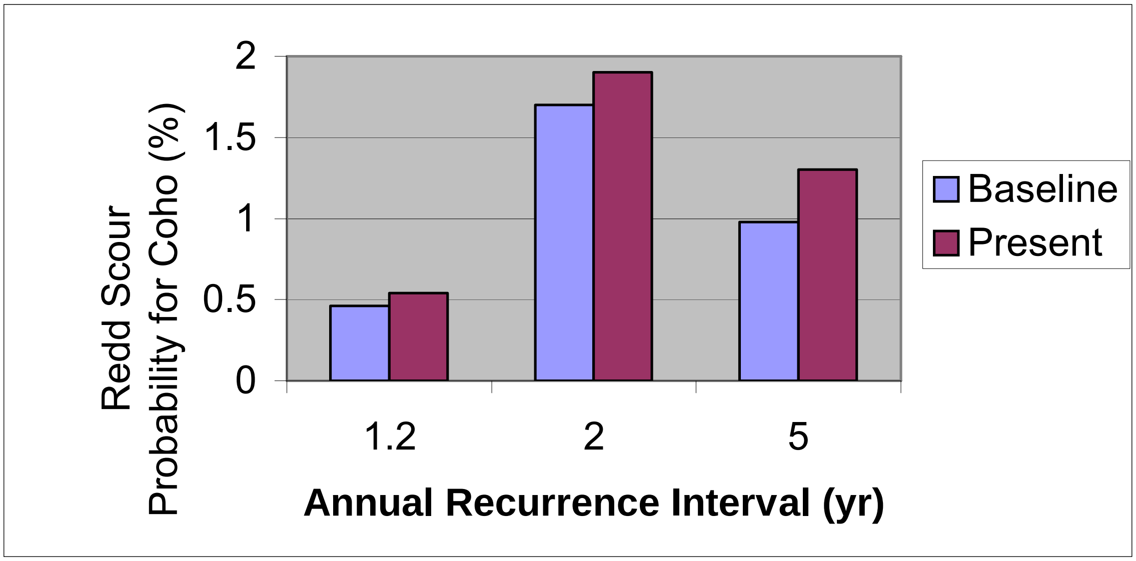


Figure 30: Comparison of the probability of critical bed scour under baseline hydrologic conditions and present managed conditions in MS1.

4.5.8 Large Woody Debris in Channels

The Channel Assessment Team completed inventories of wood in channels. In general, wood in the Freshwater Watershed is very abundant and meets criteria for properly functioning aquatic conditions (PFCs). The frequency of key pieces per 100 ft as described in the PFC matrix after Fox is exceeded substantially in all CGUs except the lower mainstem units located primarily outside of PALCO's ownership (Table 4-17).

Wood in the lower mainstem is often removed by residents, and these channels have reduced potential for future wood recruitment due to the narrow riparian zones along them that are dominated by hardwoods rather than conifers.

The dominant recruitment processes for LWD appear to be undercutting (bank erosion) and windthrow (Table 4-18). Together, these processes account for 65% of the pieces for which a recruitment process could be inferred from field evidence. Mass wasting resulted in additional wood delivery with the majority of such inputs coming from slides that originated from areas immediately adjacent to stream channels.

Table 4- 17: LWD key piece abundance in sample plots for each CGU. Underlined values in Column 4 indicate CGUs where the observed abundance is less than the PFC target abundance.

CGU	Plot Average Channel Width (ft)	PFC Key Piece Diameter-Fox (in)	PFC Target (Pieces per 100 ft-Fox)	Observed Key Pieces per 100 ft
CG	24	22	2-2.5	3.3
GG	31	25	1.4-1.7	5.5
U1	19	16	2.5-3.3	4.1
U2*	11	<16	<3.3	10
C1	38	25	1.2-1.4	2.3
C2	20	22	2.5	3.6
C3	24	22	2-2.5	8.5
MS1	28	22	1.7-2.0	0.5
MS2	45	25	1.1	0.0
MS3	38	25	1.2-1.4	0.3

Table 4- 18: Summary of LWD recruitment mechanisms for Freshwater Creek Watershed.

Input Mechanism	# of Pieces	Percent of Total
Undercutting	104	7.2%
Windthrow	179	12.4%
Mass Wasting	48	3.3%
Railroad	10	0.7%
Mortality	5	0.3%
Habitat Enhancement Structures	77	5.4%
No Entry	10	0.7%
Unknown	1005	69.9%
TOTAL	1438	100.0%

The distance in the riparian zone from which LWD has been recruited was also evaluated. Of the 1,438 LWD pieces surveyed, 158 (11%) could be traced to an origin point from which a recruitment distance could be measured. Over 80% of recent LWD recruitment originated from within 30 ft of the channel and nearly 100% is recruited from within 60 ft of the channel (Figure 31).

The effectiveness of wood in forming pools tends to increase with the size of wood (Figure 32). However, the majority of pools in the watershed were formed by wood that was 1.5 to 2.5 ft in diameter, indicating that wood this size is very functional in most of these streams (Figure 33). This size wood is similar to the minimum size defined by Fox in the PFC matrix, indicating that the Fox target for piece size is appropriate.

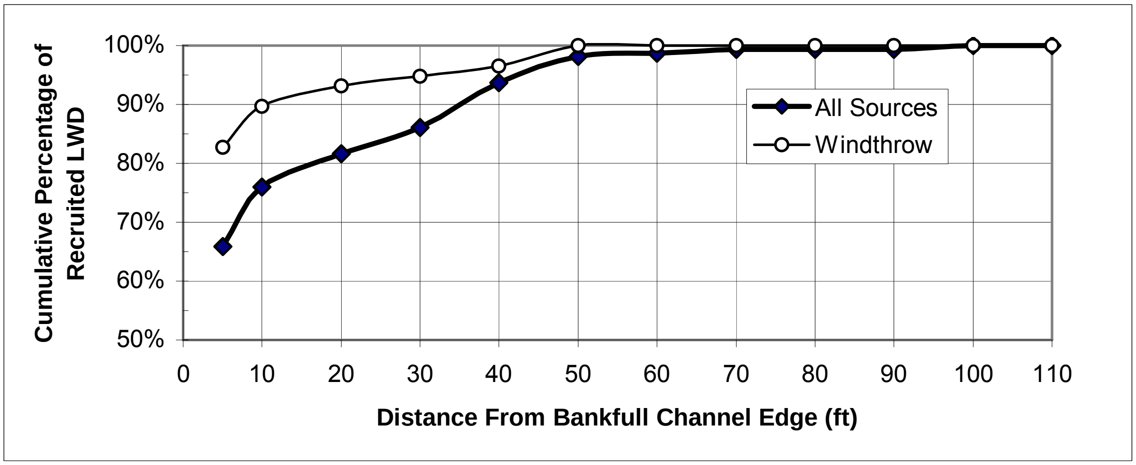


Figure 31: Cumulative percentage of LWD pieces recruited as a function of distance from the channel edge.

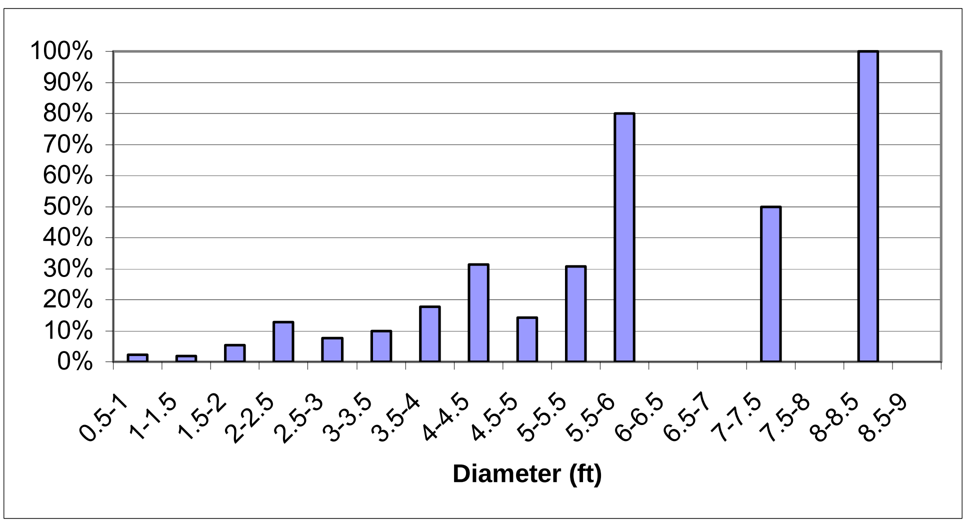


Figure 32: Percent of pieces of wood by size class that formed pools.

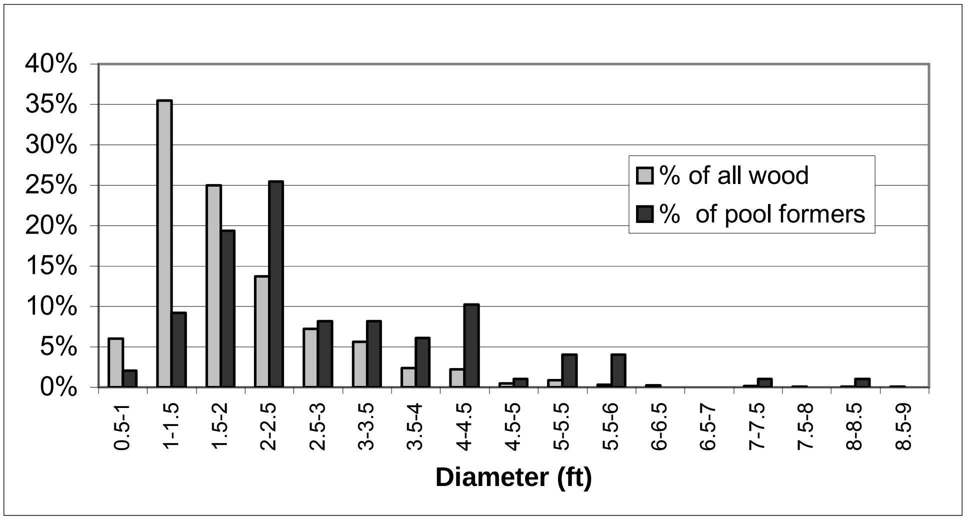


Figure 33: Percent of pieces of wood by size class present in the watershed and percent forming pools by size class.

4.6 FISH HABITAT

Salmonid rearing habitat is made up of several instream habitat characteristics including cover components (large woody debris, boulders, undercut banks, rootwads, bubble curtains, etc.), adequate streamflow, appropriate water temperature, substrate composition, pool depth, and pool area and frequency. Pool area and frequency, LWD function, and habitat complexity information from field surveys were used to determine summer rearing habitat conditions.

The data indicate that fair to good conditions exist for summer rearing by salmonids in the watershed. Pool area and frequency meet properly functioning condition target levels in most areas. Wood is the primary factor affecting the development of pools. Overall, a substantial number of the pools in the surveyed reaches were wood formed (Figure 33). A larger percentage of pools were formed in the moderate gradient channels (U2 and C2) than in the very low gradient and higher gradient channels (Figure 34). This is consistent with observations seen elsewhere. Pools in very low gradient channels often form at meander bends as a result of scour. Hence, some pools will form in the absence of wood (see MS1, which has very low wood abundance). In higher gradient channels, bedrock controls and rocks often serve as the roughness elements for pool formation. In these channels, however, larger pool forming boulders are scarce, particularly in streams flowing over Wildcat geology. Hence, wood plays an important role in habitat formation.

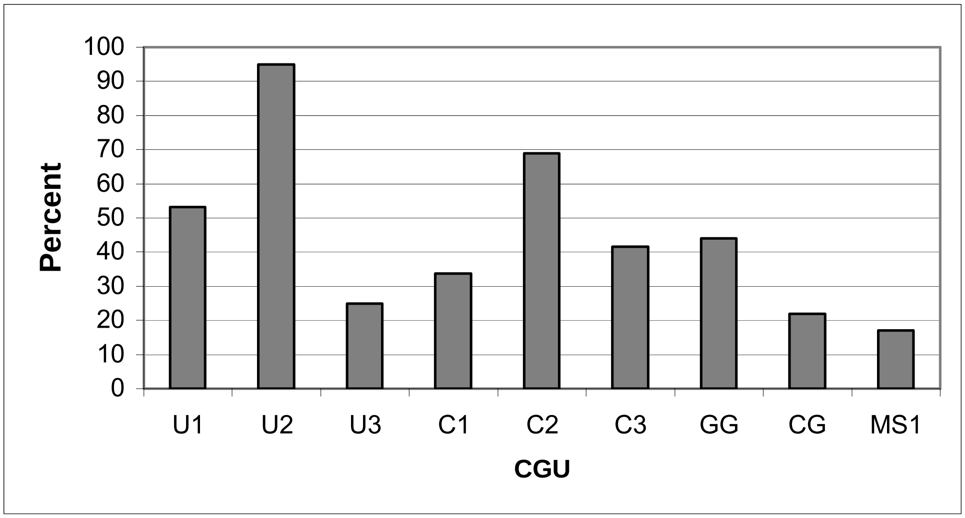


Figure 34: Percent of pools formed by LWD.

Only 4 percent of the pool forming wood was associated with deep pools (> 3ft depth). The low proportion of deep pools is believed to result from limits imposed by the depth of alluvial channel deposits above bedrock, which rarely exceed 3 ft (see channel condition report). The depth of alluvium may therefore play a role in determining whether APFC targets for pool depth are attainable in some streams.

Pool habitat cover complexity and LWD are at good levels in all CGUs except C1, U1, MS1, MS2, and MS3 (Table 4-19). These CGUs received a fair condition assessment and would be improved with an increased in the amount of complex LWD. The CGUs with the greatest percentages of pools deeper than two feet (measured at summer low flow not the higher winter spawning flows) are C-1, CG, MS-1, and MS-3. With the exception of MS-3 these CGUs also correspond to the areas with highest spawning use.

In general, spawning habitat conditions are poor in the unconsolidated CGUs and the lower reach of MS3. These include McCready Gulch, lower Little Freshwater, School Forest, non-PALCO portions of Freshwater Creek (MS3), and Graham Gulch (GG). The fine-grained nature and general absence of gravels in soils derived from the unconsolidated geologic formations (e.g., Wildcat) likely explains these observations. The best spawning habitat occurs in MS1 (South Fork to Graham Gulch), C1 (upper Freshwater and lower South Fork), and CG1 (Cloney Gulch). Better quality spawning habitat also occurs in mid-Little Freshwater, MS2, and the extreme upper portion of MS3. The data suggest that, overall, quality spawning habitat is spatially limited.

Table 4- 19: Summary of fish habitat ratings.

CGU Number	Pool Rating	Pool Cover Rating	Spawning Substrate Rating	LWD Rating
U1	Good	Good	Poor	Fair
U2	Good	Good	Poor	Good
U3	Good	Fair	Fair	Good
C1	Good	Fair	Fair	Good
C2	Good	Good	Fair	Good
C3	Good	Good	Poor	Good
GG	Good	Good	Poor	Good
CG	Good	Fair	Fair	Good
MS1	Good	Fair	Fair	Fair
MS3	Good	Fair	Poor	Fair

The success of emergence of swim-up fry begins to decline when the percentage of fine sediment (smaller than 2-6.4 mm) increases beyond 8 to 23% and survival of eggs drops rapidly as fine sediments (less than 0.84 mm) increase above 13% fines. The portion of fine sediment collected in substrate samples from the Freshwater basin ranged from 25 to 59% (Table 4-20). This suggests that salmonid abundance in the Freshwater Creek Watershed may be limited by substrate quality that reduces successful spawning. However, localized areas of good quality gravel were often observed within reaches containing generally poor conditions. This is likely due to localized hydraulic patterns that enable the flushing of fine sediments from the gravel. A good example of this is that coho in little Freshwater Creek spawn in a relatively small area containing suitable spawning habitat even though this tributary has, on average, poor spawning conditions. Thus, survival of salmonid eggs and fry is likely higher in many sites than the substrate data would suggest.

In most cases, summer water temperatures meet standards for properly functioning aquatic conditions. The maximum temperatures measured in the Freshwater Watershed ranged from 19.7°C measured in the mainstem of Freshwater in 1997 to 13°C measured in a headwater tributary the same year. The maximum weekly average temperatures ranged from 12.6°C to 17°C from early July through late October. Average summer water temperatures during all three sampling years ranged from 11.6°C to 16°C. The highest temperatures within these ranges generally occurred in downstream portions of the stream network. The aquatic properly functioning conditions matrix states the indicator range for temperatures is 11.6 to 14.5 °C. This is consistent with the preferred temperature range of 11.8°C to 14.6°C reported in Reiser and Bjorn (1979). The matrix identifies a maximum weekly average temperature (MWAT) of 16.8°C. The MWAT was only exceeded in one case during 1997 at the Mainstem Freshwater site, approximately 750 ft downstream of South Fork Freshwater. This area is below PALCO's ownership. The average water temperatures were within the preferred range of temperatures. This indicates that there are no chronic temperature problems in the Freshwater watershed.

Table 4- 20: Percentage of substrate composition less than 4.7 mm from PALCO shovel samples collected during late summer or early fall 1994 - 1999.[1]

PL Station #	Location	1994	1996	1997	1998	1999
15	Lower South Fork	49	43	40	39	46
18	Little Freshwater	-	51	41	55	59
19	Lower Graham G.	36	47	66	56	43
20	Upper Graham G.	39	47	50	-	-
32	Mainstem	35	28	30	25	36
33	Mainstem	19	27	33	-	-
34	Lower Upper Fresh	27	32	38	36	29
35	Lower Upper Fresh	33	48	40	-	-
36	Rd. 15 Upper Fresh	49	43	50	38	28
37	Lower South Fork	34	40	39	-	-
92	Cloney Gulch	-	-	-	37	46
135	McCready Gulch	-	66	60	59	53
165	Mid Upper Fresh	-	-	-	32	25

[1] all reported values are averages based on multiple samples.

The effects of turbidity in the basin were estimated using a risk modeling approach. Input data was limited to that collected at one site in the lower watershed. The assessment found that behavioral and mild sublethal stressful conditions likely occur at the data collection site during some peak flow conditions; however, no conditions measured in at the site have been of adequate duration or concentration to lead to direct mortality or deficits in growth. Exposure durations at that site have been generally less than 24 hours, and, at the concentrations realized, should not result in biological impairment. Most such exposures occur during periods of low water temperatures when the metabolic rates of fish are low and the likelihood of behavioral or physiological impairment is reduced. Analyses of turbidigraphs and hydrographs demonstrated that the conditions of greatest concern might be associated with early season storm events, when sediment loading into the stream will be disproportionately higher for a given rainfall and/or discharge event. Turbidity levels in other locations in the watershed are unknown.

No migration barriers were found on lands within the PALCO ownership. However, three County road crossings in the lower reaches of McCready Gulch, Cloney Gulch, and Graham Gulch constitute either seasonal or permanent migration barriers for salmonids.

4.7 AMPHIBIAN HABITAT

Amphibian habitat in the basin was inventoried and rated per several variables in the National Marine Fisheries Service Properly Functioning Condition Matrix (PFC) (Table 4-21). The habitat qualities in the headwater streams surveyed were found to vary with the underlying geology (Table 4-22).

The pool frequency met PFC standards everywhere in the basin except the steepest streams in the consolidated geology and the Graham Gulch area, which is affected by a large, deep-seated landslide. Wood loadings also met PFC standards in the streams flowing through consolidated geology, and fair to good wood levels were observed in streams flowing through unconsolidated geology.

Table 4- 21: PFC habitat diagnostics used for amphibian headwater habitat condition evaluation.

Habitat Component		Good	Fair	Poor
Pool Area	**<5% gradient**	>30%	20-30%	<20%
	>5% gradient	>40%	20-40%	<20%
Fine sediments (<0.84 mm)		<12%	12-17%	>17%
Embeddedness		<25%	25-40%	>40%
Large Woody Debris		>37.5	13.8- 37.5	<13.8

Fine sediment levels and substrate embeddedness varied with geology. The CGUs with unconsolidated geology (i.e., Wildcat) contain little or no coarse sediments and high volumes of fine sediment, which cover any coarse sediment and result in highly embedded substrates. This reduces the habitat quality for the headwater species by eliminating available coarse sediments and interstitial refugia spaces. However, these conditions are probably natural. Thus, unconsolidated geology types within the Freshwater basin may naturally have limited habitat suitability for headwater species of amphibians. The paucity of animals found during surveys tends to confirm this. There are, however, pockets of coarse material in some areas of unconsolidated geology where the Yager Foundation geologic unit has been exposed. Animals were found in one such unit along a stream that flows primarily through unconsolidated geology. Other such pockets may provide additional habitat.

Table 4- 22: Summary of headwater amphibian habitat by Channel Geomorphic Unit.

		Pool Area		Fines		Embeddedness		LWD	
CGU	# of Sites	Average Value	Rating[1]	Average Value	Rating[1]	Average Value	Rating[1]	Average Value	Rating[1]
C2	1	95%	Good	43%	Poor	23%	Good	111	Good
C3	12	43%	Good	17%	Fair	21%	Good	90	Good
C4	12	29%	Fair	11%	Good	25%	Good	116	Good
All Cs	25	38%		15%	Fair	23%	Good	103	Good
GG	1	26%	Poor	27%	Poor	5%	Good	100	Good
U1	1	69%	Good	15%	Fair	17%	Good	22	Fair
U2	1	56%	Good	33%	Poor	56%	Poor	28	Fair
U3	4	58%	Good	54%	Poor	33%	Fair	63	Good
U4	1	47%	Good	31%	Poor	14%	Good	32	Fair
All Us	7	58%	Good	42%	Poor	31%	Fair	47	Good

[1]The ratings are determined using the PFC matrix.

The CGUs with consolidated geologies (i.e., Franciscan) naturally produce more coarse sediments that provide interstitial spaces and form better quality habitat. In these areas, fine sediment inputs from management may have a real effect in reducing habitat quality for headwater amphibian species. However, fine sediments tended to decrease with increasing channel gradient, reflecting the increased stream power in these channels. Thus, even within consolidated geology areas, local stream conditions affect observed sediment levels. Embeddedness was rated good throughout the area dominated by consolidated geologies. The majority of the animals found during surveys were found in streams running through such geology, which provides further evidence that habitat is substantially better in these areas.

4.8 CONFIDENCE IN THE ASSESSMENT

Confidence in the assessments is highly variably. The quantity of data available in a basin was sometimes excellent. In some cases, however, the data available was limited. Where assessments rely on sparse historical data and/or require long-term records that were non-existent, confidence was lower and could not be rectified.

The tables 4-23 and 4-24 summarize the confidence discussions for various aspects of the analyses. In many cases, confidence was rated simply as high, moderate or low.

These rankings are in keeping with the Washington Department of Natural Resources' Watershed Analysis Methods. The high, moderate, and low reflect the degree of that the actual situation may vary from the estimates provided in the discussion. Generally, a high rating implies a reasonably high degree of confidence. Analysts reporting a high degree of confidence would not expect long term monitoring to provide significantly different results from the estimates reported. Low confidence is typically associated with situations where data were scarce or data was not available to properly calibrate models. Readers are referred to the individual resource reports for additional discussion of confidence in results.

Table 4- 23. Summary of confidence and sources of error in Freshwater Creek Sediment Input Budget.

Sediment Budget Inputs	Components to Input Estimate	Confidence in component	Influence on Overall Budget/ Comments
Background SE – Soil Creep	Stream Lengths	High – field checked in most areas	Upper Freshwater has a sizeable block of land that has not been recently field checked. It is likely that there is a higher stream density in this area, which would increase soil creep input a small amount.
	Soil Depths	High – soil testing results	
	Soil Creep Rates	Low/ Moderate	Used WDNR soil creep rates, which are similar to those measured in Redwood Creek. Creep rates in areas of active earthflows can be up to an order of magnitude higher. If actual creep rates in Freshwater Creek are higher, then the management impacts are less. [Note that areas of active deep-seated landslides are accounted for separately in the sediment budget.] Soil creep rates were used to estimate background sediment inputs for class II and III streams and for class I streams not on PALCO lands. Background sediment inputs from class I stream on PALCO lands were calculated using the class I stream sediment source survey data from PWA (Streambank slides and Bank erosion).
Streambank Slides Background & Management		High – PWA field work, actual measurements on Class I stream on PALCO lands.	Some questions in allocation over time, but overall volume estimate is good.

Sediment Budget Inputs	Components to Input Estimate	Confidence in component	Influence on Overall Budget/ Comments
Bank Erosion Background & Management		High – PWA field work, actual measurements on Class I stream on PALCO lands.	Some questions in allocation over time, but overall volume estimate is good. Management estimates are based on bank erosion caused by enhancement structures.
Shallow Hillslope Landslides Background & Management	Landslide inventory	Moderate – background Moderate/ High - Management	Smaller landslides (1,000-2,000 yd^2) in areas of advanced second-growth timber are difficult to identify on aerial photographs. Allocations of sediment inputs from background versus management landslides are approximate. Minor influence on budget from small landslides since rates/ inputs are low.
	Landslide Volume Contributions	Moderate overall – High within the correct order of magnitude.	Estimates of sediment introduced from hillslope landslides were made from aerial photographs. Depth estimates were made from landslide area-depth relationships derived from field measurements of a smaller set of road and hillslope landslides. From the standpoint of estimating sediment introduction to streams, this is not a major issue as smaller landslides contribute very little to both the cumulative volume of all landslides and the overall sediment budget. Even if estimates are off by 100% and the actual contributions are doubled, this would be one of the smaller sources of sediment inputs. Minor influence on budget since rates/ inputs are low.
Deep-seated Landslides Background & Management	Landslide inventory	Moderate/ High	Air photo interpretation with limited field checking. Lower confidence in dormant relict features which are more difficult to identify. However these features are not contributing.
	Landslide depths/ volume	na	Sediment budget only influenced by one or two features. Particularly the dominant deep seated landslide in Graham Gulch.

Sediment Budget Inputs	Components to Input Estimate	Confidence in component	Influence on Overall Budget/ Comments
SE associated with Timber Harvest	Relative contributions from tractor yarding, cable skyline, helicopter yarding, burning, herbicide application	High – field observation verified qualitative contributions	Field observations were consistent with other studies.
	Quantitative contributions – WEPP results	Moderate ± at least 50%	Three estimates of harvest-related erosion had up to a 5-fold difference between the lowest and highest estimates. However, even the estimate with maximizing assumptions resulted in erosion amounts that are small in comparison to other sources (including estimated background input). Important variables in WEPP calculations are hillslope, percent of vegetation and ground cover, and infiltration capacity. of the soils
SE associated with Roads	Identification of lengths of road contributing sediment directly to streams	High – 100% field survey on PALCO lands	
	Quantitative contributions – WEPP/ SEDMODL results	Moderate ± at least 50%	The different methods used to estimate road surface erosion were overall in fairly good agreement. Estimates of erosion rates from individual road segments differed from 20 to 200%,and averaged about 90%. SEDMODL results were consistent with field observations of erosion rates. Important variables include road surfacing and traffic levels.

Sediment Budget Inputs	Components to Input Estimate	Confidence in component	Influence on Overall Budget/ Comments
	Indirect delivery of sediment from roads	Moderate/ Low – due to little existing research on the effects of buffers on filtering fine grained soils, it is uncertain how much eroded sediment is trapped in buffers vs. delivered to streams.	Indirect delivery accounts for half of the total road surface erosion delivered to streams. If sediment transport distances are different than modeled, estimate of road related sediment inputs might be lower or higher. The WEPP model predicts 1.5 to 7 times as much erosion from individual indirect delivery segments, but this is primarily due to erosion from predicted gully development that is not supported by field evidence. This is one of the biggest sources of uncertainty in the overall sediment budget. Recommend monitoring on transport of eroded sediments. Make observations on how far sediment is carried across the forest floor in storm runoff at selected ditch relief culverts. This will increase confidence in the estimates of indirect delivery from roads and help determine how effective the current program of upgrading, improving, and disconnecting road drainage from streams is at reducing the delivery of road surface erosion.
SE-associated with shallow landslide scars	Direct or indirect delivery from landslide scars that intersect streams (landslide areas, rates of lowering, rate of re-vegetation)	Low to Moderate	Based on estimated landslide surface areas for landslides that reach streams and an assumed rate of lowering based on nearby studies of surface erosion rates on exposed soil surfaces and an assumption that landslide scars are revegetated and surface erosion ends within 5 years of the landslide event. A very minor amount of sediment is derived from this source so it has no effect on the sediment budget (i.e., about 1% of total shallow landslide sediment inputs).
Shallow Road Landslides	Location of Landslides	High – all landslides along PALCO roads were field checked	Some older very small landslides will not have been identified as they are well re-vegetated or reforested. However, these would make a miniscule contribution to the overall sediment budget.

Sediment Budget Inputs	Components to Input Estimate	Confidence in component	Influence on Overall Budget/ Comments
	Volume of Landslides	Moderate in general – High within correct order of magnitude – based on visual estimates and field measurements	Percent of landslide volume delivered is a visual estimate.
Legacy Fill		Low	Some field measurements, lots of extrapolation. Was likely a significant contribution after first cycle logging current influence. Minor influence on current budget since recent rates/ inputs are low.
Legacy Bank Erosion		Moderate – PWA field check all Class I streams on PALCO land	This input is a result of early harvest activities.
Sediment Size Classes		High – based on field data	
Overall Sediment Budget	**Total Volume Delivered**	**High**	**The total amount of estimated fine sediment input from all sources was very close to the amount measured at the community's Freshwater gage site (again, see sediment budget discussion in the Stream Channel Assessment)**

Table 4- 24. Summary of Confidence Calls and sources of potential error in Freshwater Creek Analysis Results

Module	Component	Confidence	Influence/ Comments
Mass Wasting	Landform Mapping	Moderate – due to mapping limitations	Landform boundaries reflect contour line spacing and morphology but not necessarily exact locations of change in slope. For example, the boundaries for incised units containing watercourses were digitized using a GIS query. This resulted in a standard polygon width of 200 to 300 ft for all incised units. For some of the field-checked map units containing Class 3 watercourses, however, the actual unit width was 50 to 100 ft. The actual field width for incised units containing Class 1 watercourses was usually wider than the 200-300 ft default used in the digitizing process. Actual boundaries are generally straightforward to identify in the field.
	Landslide sediment inputs	*See sediment budget summary*	
Surface Erosion		*See sediment budget summary*	
Hydrology	Flood History	High	Analysis based on two sources of information to provide a reasonable approximation of long-term flooding trends in the watershed at a decadal scale.
	Applicability of North Fork Caspar Creek equations to Freshwater	High/ Moderate	The two watersheds are similar with respect to relevant basin characteristics. Both are located primarily in the coastal redwood vegetation zone. Furthermore, using both systematic and random cross-validation techniques, Lewis et al. (in press) concluded that their model was not over-fitted to the developmental data. This ensures that its use in other similar areas is likely to yield accurate predictions of peak flows.

Module	Component	Confidence	Influence/ Comments
	Harvest information (location & extent)	High	From PALCO GIS system
	Residual post-harvest canopy cover	Moderate	From PALCO GIS system
	Soils data used to estimate runoff-coefficients for compaction modeling	Moderate	New soil surveys currently being completed by the NRCS will improve this information for future analyses
	Locations of road drainage ditches that deliver surface water to streams	High	100% survey of the PALCO road system
	Changes due to compacted areas and road drainage	Low	Due to an overall lack of confidence in the Rational Method model. However, the estimated effects are so low that it is unlikely true effects would appreciably alter the peak flow estimates based on interception and evapotranspiration losses alone. Results from these analyses are best used to prioritize road abandonment and "storm-proofing" activities among the 49 HAUs within the watershed.
	Regional equations used to estimate baseline peak flow magnitudes	Moderate	The lack of long-term streamflow records limit our ability to develop more accurate local equations. However, confidence in the baseline peak flow magnitudes affects the absolute value of a particular flow *but has no effect on the estimated percentage increases attributed to forest management.*

Module	Component	Confidence	Influence/ Comments
Riparian	Stand Conditions - Aerial Photo Analysis	High - due to field verification and plot data	Field verification by visual reconnaissance was completed for more than 85% of the Class I and II stream reaches. Aerial photo classification of stand size class is conservative relative to actual stand size in the Freshwater basin. Aerial photograph analysis underestimated density class; for 35 out of 92 riparian segments where riparian canopy closure was measured, aerial air photo call underestimated by at least one density class.
Stream Channel	General Channel Conditions	High – good field verification	
	Sediment Sources	*See sediment budget summary*	
	Sediment Routing Model	Moderate	Despite limited accuracy expected from sediment transport modeling, long-term predictions are in good agreement with data from Jacoby Creek, and proportions of bedload and suspended load are similar to Caspar Creek.
	Sediment Storage, transport & routing	High for Class I channels; moderate for Class II and III	High intensity of sampling and mapping in Class I channels; lower sampling intensity in Class II and III channels and LWD data is semi-quantitative.
	Channel erosion, stability and response to hydrologic change	Moderate	Hydraulic modeling of stream channels predicted flow resistance consistent with data from the Salmon Forever gage and with regional data for small rivers; two locations where residents reported more frequent flooding were modeled in lower Freshwater
	Woody Debris and channel relationships	High for Class I channels; moderate for Class II and III	High intensity of sampling and mapping in Class I channels; lower sampling intensity in Class II and III channels and LWD data is semi-quantitative.
Fisheries	Species List	High	

Module	Component	Confidence	Influence/ Comments
	Fish distribution	High	Due to the electrofishing and underwater and bank observation survey efforts during the analysis. However, additional rearing location information for MS1, MS2, and MS3 is desirable.
	Spawning Locations	Moderate	Due to inherent difficulties in completing spawner surveys
	Habitat Conditions	Moderate	Not all CGUs were sampled
	Substrate Quality as limiting factor	High	Consistent results in both fish and amphibian sampling.
	LWD	Low/ Moderate	Data not collected at all sites as part of the Fish Module – Stream Channel Module has additional information and did a more comprehensive analysis
	Temperature Analysis	High	Available data consistent among stations
	Turbidity analysis	Moderate/ Low	Based on a single stations data. However fine sediment inputs have been identified as a primary impact.
Amphibians & Reptiles	Species List	High	All species on the covered species list, except northwestern pond turtles and yellow-legged frogs were encountered either incidentally or in surveys
	Habitat Conditions	High - southern torrent salamander & tailed frog Moderate – other species	Based on headwater field surveys. Habitat conditions in Class I streams were evaluated in fish surveys which did not consider all aspects of habitat for other species.
	Distribution	High - southern torrent salamander & tailed frog Moderate – other species	Based on headwater field surveys – Due to mapping limitations the actual end of each Class II stream will be field verified during the THP review process. The distribution of non-headwater species was incidentally verified as part of the fish survey process.

4.9 CURRENT CONDITIONS RELATIVE TO THE APFC MATRIX

Table 4-25 summarizes the APFC matrix targets, the modules that provide evaluations of current conditions relative to the matrix values, and general comments regarding findings. The reader is referred to the cited reports as well as data provide earlier in this text for details on the conditions and places where the SPFC matrix targets are met.

Table 4- 25. Summary of interagency properly functioning conditions matrix targets and comparisons made in freshwater analysis

Parameter	APFC Target	Analysis Metrics/ Rational	Analysis Results
Temperature	11.8-14.6°C 16.8 MWAT	*Fish Module* – PFC targets *Amphibian Module* – PFC targets with additional comparisons to preferred temperature ranges of covered species.	Four years data 3 to 6 stations: The MWAT was only exceeded in one case during 1997 at the Mainstem Freshwater site, approximately 750 ft downstream of South Fork Freshwater. The average water temperatures were within the PFC range of temperatures.
Sediment			
% Fine <0.85 mm	Class I & II streams:	*Amphibian Module*- Good < 12%, Fair 11-16%, Poor > 17%	*Amphibian*: 32 Class II sites: 11 exceed PFC, 13 Meet PFC, 8 below PFC. Sites not meeting PFC are in C2, GG, U2, U3, U4. C4 was only CGU with good conditions.
Pebble counts	D_{50} of 65-95 mm	*Channel Module:* did pebble counts as part of scour and channel characterization analysis in Mainstem and lower tributary reaches.	The D50 sampled at all stations in Freshwater is below the minimum size of 65 mm.

Parameter	APFC Target	Analysis Metrics/ Rational	Analysis Results
Turbidity	No visible increase due to timber operations in Class I, II, or III streams	*Fish Module* – Data directly tied to timber harvest operations not available. Good time trend data was available from one station. Analysis of potential impacts completed using Newcomb & Jensen Risk Model.	The Freshwater Creek Watershed Analysis used a temporally extensive but spatially limited data to evaluate turbidity and TSS. The risk modeling demonstrated that behavioral and mild sublethal stressful conditions likely occur in Freshwater Creek during some peak flow conditions; however, no conditions measured at he sampling station were of adequate duration or concentration to lead to direct mortality or deficits in growth.
% Particles < 6.5 mm	<20-25% in Class I & II Streams	Not included in analysis	
Large Woody Debris			
Debris Pieces per 100' Channel Length >10 cm diameter and 2 m in length	15-20' wide- 12-16 pieces/ 100' 20-25' wide- 9-12 25-30' wide- 7-9 30-45' wide- 5-7	*Fish Module*: PFC	17116 ft of channel sampled: 45% exceed PFC, 21% Meet PFC, 37% are below PFC. Sites not meeting PFC are in U1 and MS1 & MS2
Key Pieces (Fox 1994)	See PFC table	*Fish Module*: PFC *Channel Module*: PFC, watershed specific data and regional comparisons for LWD loading	17116 ft of channel sampled: # of pieces: 57% exceed PFC, 43% are below PFC. Sites not meeting PFC are in MS1, MS2 & MS3. Vol/piece: 86% exceed PFC, 8 % Meet PFC, 6% are below PFC. Sites not meeting PFC are in MS2.

Parameter	APFC Target	Analysis Metrics/ Rational	Analysis Results
Pool Frequency	a-Stream gradient >3% & avg. width <10 m b-Stream gradient <3% & avg. width <19m		
Pool-to-pool spacing based on bankfull stream widths	a-1 pool per every 3 bankfull channel widths b-1 pool per every 6 bankfull cannel widths	*Fish Module*: Same as PFC *Amphibian Module*: not evaluated	*Fish*: 24 sites: 19 exceed PFC, 2 Meet PFC, 3 are below PFC. Sites not meeting PFC are in C3 and GG
Percent of stream surface area comprising pool habitat	a-Pool area >20% total stream surface area b-Pool area >25% of the total stream surface area	*Fish Module*: Same as PFC *Amphibian Module:* PFC modified to account for small class II stream characteristics Gradient <5%: Good > 30%, Fair 20-30%, Poor <20% Gradient > 5% Good >40%, Fair 25-40%, Poor < 40%	*Fish*: 24 Class I sites: 19 exceed PFC, 2 Meet PFC, 3 are below PFC. Sites not meeting PFC in C3 & GG. *Amphibian*: 32 Class II sites: 20 exceed PFC, 12 Meet PFC, 1 is below PFC. Site not meeting PFC in GG
Percent of number of pools associated with LWD	>90% of # of pools associated with LWD >50% of # of pools associated with LWD	*Fish Module*: Same as PFC *Amphibian Module*: not evaluated	*Fish*: 24 Sites: 12 exceed PFC, 11 Meet PFC, is below PFC. Site not meeting PFC is in C1.

Parameter	APFC Target	Analysis Metrics/ Rational	Analysis Results
Pool Quality			
Maximum depth	>3 ft maximum depth	*Fish & Amphibian Module* – not used	*Rational*: Most of the Class I channel network has relatively entrenched channels with bedrock exposed locally in banks and pool bottoms. The low proportion of deep pools is believed to result from limits imposed by the depth of alluvial channel deposits above bedrock, which rarely exceed 3 ft (see Figure 5-4 – Stream Channel Assessment). Depth of alluvium may play a role in determining whether NMFS PFC targets for pool depth are attainable in some streams.
Volume	V*=<.20	*Fish Module* <.20	Trend toward pool filling. South Fork Freshwater Creek had values 0.52 to 0.59. Graham Gulch increased 0.35 to 0.51 1992 - 1999. NF Freshwater increased 0.19 to 0.46 1992 - 1999.
Riparian Conditions			
Overstory tree canopy closure	Ave. of at least 85%	Riparian Module : PFC	94% of Class I and Class II stream meet PFC target. Factor reducing canopy cover: 1 - Pre-1974 clear cuts in the riparian area, 2 -Narrow buffers reduce average riparian canopy closure, 3- Development

Parameter	APFC Target	Analysis Metrics/ Rational	Analysis Results
Ave.# of large trees/ acre by dbh class	23.8 > 32 in. / acre 17.4 > 40 in. / acre	*Riparian Module:* Modified target	Riparian module presents information regarding old growth characteristics relative to the APFC matrix and suggests that the matrix values may not be attainable.
Ave. # and tons of large pieces of wood on ground/ acre	* no target for redwoods	29 pieces/acre downed wood within Douglas-fir stands	

**There is no PFC established for pieces or volume of redwood downed wood. The PFC does give a target of 29 pieces/acre downed wood within Douglas-fir stands. This compares with 14.3 pieces/acre within the Freshwater riparian redwood stands. Agee (1993) discusses the level of wood debris in redwood forests, and Bingham (1992) states the redwood forests contain 22 to 29 metric tons of wood debris per acre. Bingham and Sawyer (1988) report a volume of 957 m^3 per hectare with a log mass of 200 metric tons per hectare. However, Finney (1991) gives a log mass of from 10 to 280 metric tons/ hectare and Greenlee (1983) gives 186 metric tons per hectare as the mass of woody debris.*

5.0 SYNTHESIS

Through the Synthesis process, the information contained in the module reports is integrated to identify the resource situations of concern in the basin and identify linkages, if any, between the inputs affecting the resources and management activities. The questions that help establish these linkages include:

- Are resources being affected or could they potentially be affected by inputs of wood, energy (e.g., heat), coarse and/or fine sediment, or water (i.e., flows)?
- What are the inputs that have or could potentially affect the resources?
- Where are the potentially affected stream segments?
- What is the physical source of these inputs (where in the watershed are they originated)?
- What are the physical processes that trigger these inputs?
- What, if any, management practices contribute to these processes?
- What locations in the basin are subject to such management effects?

The process includes first identifying the resources and stream segments that have been or could potentially be affected by changes in inputs (development of habitat vulnerability calls). Once these are identified, the assessment team starts at the affected or potentially affected resource and works its way through the linkages to determine if management activities are influencing the situation and, if so, what the activities are and where they are of concern.

Management activities identified as potentially affecting resources are addressed in Causal Mechanism Reports (CMRs) that are tailored around each management activity identified in the process. These Causal Mechanism reports are then addressed during the Prescription process.

5.1 HABITAT VULNERABILITY CALLS

Vulnerability calls were developed for each of the CGUs that reflect the sensitivity of the units to changes in inputs of flow, coarse and fine sediment, turbidity, energy, and large woody debris. This information is used later in the Synthesis process to help identify areas potentially affected by management activities. The vulnerability calls that were developed are summarized in Table 5-1. The logic supporting those calls are detailed by CGU below.

5.1.1 C1: Low Gradient (0-3%), Consolidated Bedrock Units

Lower reaches of Upper Freshwater and South Fork, middle portions of Little Freshwater and McCready Gulch

Coarse Sediment: High in the South Fork, Moderate Elsewhere

CGU C1 has gravel/cobble bedded channels with bedrock exposed in banks and occasionally in the bed. Mobile gravel and cobbles are deposited on bars and in association with LWD. Reach average median grain sizes range from about 50 mm in Upper Freshwater to about 20 mm in McCready Gulch and South Fork Freshwater. Coarser material is relatively abundant in Upper Freshwater.

This CGU is heavily used by spawning fish. The potential for burial of redds by coarse sediment is of concern regarding spawning habitat. In addition, filling of pools as a consequence of channel aggradation is of concern regarding rearing habitat. Increased coarse sediment inputs could also cause the size distribution of gravel in the channel to change, potentially increasing the risk of streambed scour that affects salmon and steelhead redds. The scour issue is discussed in the peak flow discussion for this CGU.

Table 5- 1: Vulnerability calls for the Freshwater watershed CGUs.

CGU	Coarse Sediment	Fine Sediment	LWD	Peak Flows	Bank Erosion	Major Interactions
C1	High in South Fork, Moderate elsewhere	High	High	Moderate	Moderate	
C2	Moderate	Moderate	Moderate	Low	Moderate	
C3	Large: Low Small: Moderate	Large: Low Small: Moderate	Moderate	Large: low Small: Moderate	Moderate	
C4	Low	Moderate	Low	Moderate	Low to Moderate	
U1	Low	Moderate	High	Moderate	Moderate	
U2	Low	Moderate	High	Low	Moderate	
U3	Low	Low	High	Low	Moderate	
U4	Low	Low	Moderate	Low	Moderate	
MS1	Moderate	High	High	Low	Moderate	
MS2	High	Moderate	High	Moderate	Moderate	Peak flow X coarse sediment = Moderate
MS3	High	High	Moderate	High	High	Peak flow x sediment inputs = High
CG	High	Moderate	Moderate	Moderate	Moderate	
GG	High	High	Moderate	Moderate	Low	

The evidence for aggradation from coarse sediment is mixed (see the Stream Channels Assessment). However, field measurements of sediment storage suggest that aggradation is most evident in the C1 reaches of the South Fork where in-channel sediment storage is more than twice that found in other C1 channels. Most of the "excess" sediment storage in the South Fork is related to LWD jams.

The passage of pulses of coarse sediment through the channel has the potential to accelerate bank erosion and streamside landslide processes where the channel becomes congested with coarse sediment. These conditions can force peak streamflows to undermine banks, particularly where bank materials are weak. Within the channels in CGU C1, there is evidence of bank erosion and streamside landslides, but the magnitude varies between sub-watersheds (see the Stream Channel Assessment). The magnitude of these erosion processes is greatest in the South Fork where LWD is most abundant. The presence of alluvial terrace deposits in the South Fork probably contributes to this effect. Sediment inputs from bank erosion in Upper Freshwater, McCready Gulch, and Little Freshwater Creek are much lower than in the South Fork. Consequently, the effect of coarse sediment routing on near-stream erosion processes is probably of intermediate significance for all C1 channels, except the South Fork where these effects are potentially high.

Overall, conditions with respect to coarse sediment effects are severe only in the South Fork, and that appears to be caused largely by the abundance of wood in those channel segments. In addition, coarse sediment inputs in these watersheds are relatively small compared to fine sediment inputs, limiting the potential for significant increases in coarse sediment inputs. Consequently, despite high potential fish use and potential effects of aggradation, the overall vulnerability to coarse sediment inputs is moderate. Vulnerability in the South Fork to coarse sediment is high because of evidence for currently aggraded conditions.

Fine Sediment: High

This CGU is one of the prime spawning areas in the basin and moderate increases in fine sediment could have significant effects on spawning success. V* measurements in channel segments within CGU C1 (Upper Freshwater and South Fork) indicate that fine sediment is accumulating in pools to a significant degree. Sand is dominant or subdominant in the beds of some habitat units (see the Fisheries Assessment). Fine sediment (<1 mm diameter) in bulk samples of bar material from C1 reaches ranged from 3% (Upper Freshwater) to 20% (McCready Gulch).

Overall, fine sediment is not likely to have dramatic effects on channel morphology. However, the extent of fine sediment accumulations on the channel bed surface observed in the field observations and the relatively high sand concentration in channel deposits suggest intermediate physical channel sensitivity to fine sediment. The high vulnerability call was primarily due to the importance of these areas for spawning, locally high concentration of fine sediment in and on the streambed, and relatively high inputs of sandy sediment to these watersheds.

LWD: High

Wood plays a major role in formation of pools, velocity shelter, and sediment sorting in CGU C1. Current LWD loads are relatively high (see the Fisheries Assessment). Much of this wood was input during old logging activities. Significant changes in habitat and/or channel condition are not expected unless dramatic reductions in wood load occur. Nevertheless, this unit was given a high vulnerability call for LWD, which reflects importance of this unit to fish and amphibians and the potential habitat degradation if the long-term LWD supply was significantly reduced.

Peak Flow: Low

Peak flows are not expected to have a significant effect on scour of redds. The size of material that may be mobilized as a result of increases in peak flow is smaller than the grain size that fish normally spawn in. Increases in peak flow may mobilize finer particles, but this will have the effect of cleaning gravel rather than scouring redds. Hence, mobilization of fine material will tend to enhance the quality of spawning gravel.

Increased peak flows are expected to drive a small increase in near-stream erosion processes. In combination with coarse sediment increases, these peak flow increases may be somewhat more significant with respect to near-stream erosion. These considerations indicate that a moderate vulnerability to peak flow increases exists.

Bank Erosion: Moderate

CGU C1 has moderate vulnerability to bank erosion. Varying degrees of bank erosion and streamside land sliding were documented. In the overall sediment budget, bank erosion and streamside landslides are a significant, but not particularly large, source of sediment in this CGU. Therefore, its effect on fish habitat and biological processes is modest. Sediments from road-related surface erosion and landslides are much greater contributors. Nevertheless, reinforcement of streambanks and streamside slopes by tree roots and other vegetation is significant, and should be maintained within this CGU to reduce long-term erosion rates from streamside sources.

5.1.2 C2: Moderate Gradient (3-6.5%), Consolidated Bedrock Units

Mostly found in the upper reaches of Upper Freshwater and South Fork, with additional portions in each of the other tributary sub-basins.

Coarse Sediment: Moderate

CGU C2 has moderate overall vulnerability to coarse sediment. This unit has cobble/gravel bed channels with bedrock commonly exposed in the banks and bed. Mobile gravel and cobbles are deposited on bars and in association with LWD, but bar abundance is lower than in C1. Average median grain size is about 70 mm.

Channel geomorphic conditions indicate moderate vulnerability. The unit routes coarse sediment better than C1, based on coarser grain sizes and lower bar abundance, but it is narrower and possibly easier to overwhelm with coarse sediment inputs. Stream power is comparable or somewhat higher than in C1. There is little evidence that channels have been overloaded with coarse sediment, but the potential exists. The step-pool morphology found in these reaches is less prone to morphological change due to coarse sediment inputs than lower gradient reaches.

Use of the unit by fish could affect vulnerability. Steelhead and cutthroat spawn in CGU C2. Spawning is limited and occurs in localized pockets of spawning gravel. Increases in coarse sediment could benefit fish by providing more spawning gravel or harm fish habitat by burying redds and filling pools. Since this unit is not as critical as C1 in terms of spawning and rearing habitat, and the potential for harming habitat is indeterminate, the biological vulnerability was determined to be moderate.

Fine Sediment: Moderate

The overall vulnerability to fine sediment for CGU C2 is moderate. The channels in this CGU are steeper and have more transport capacity for fine sediment than segments in C1, reducing the potential for accumulation of finer sediment. Fine sediment was observed accumulating in a few of the fish habitat units. Fine sediment has the potential to accumulate in spawning gravels and may also accumulate in larger substrates, which may provide interstitial cover for overwintering juvenile salmonids. Overall, the potential for fine sediment to have a major effect on channel conditions or fish habitat is rather low, but evidence indicates that moderate potential exists, particularly in portions of the South Fork.

Peak Flows: Low

The C2 channels are typically confined, transport reaches of moderate gradient with step-pool morphology, relatively coarse sediment, and often bounded by bedrock. The expected magnitudes of increases in flows are not expected to significantly affect channel condition or habitat.

LWD: Moderate

In CGU C2, wood is currently abundant. Much of this wood appears to be debris from historic logging activities. In general, large wood is not very mobile in these smaller, steeper channels because of step-pool morphology and relatively narrow channel width. In these step-pool channels, wood and boulders together create pools and store sediment. Channels in this CGU are responsive to LWD, but less so than lower gradient reaches with finer substrate and pool-riffle or plane bed morphology (e.g., C1); hence, they were given a moderate vulnerability rating.

Bank Stability: Moderate

The vulnerability of CGU C2 for bank erosion is moderate. The passage of pulses of coarse sediment through the channel has the potential to accelerate bank erosion and streamside landslide processes where the channel becomes congested with coarse sediment. These conditions can force peak streamflows to undermine banks, particularly where bank materials are weak. C2 channels have more frequent bedrock exposures in bed and banks, and coarser substrate. These channels have somewhat more evidence of streamside landslides than C1, and somewhat less bank erosion. Overall, the vulnerability is probably less than in C1, but root reinforcement of streambanks and streamside slopes should be maintained in this CGU to minimize near-stream erosion.

5.1.3 C3: High Gradient (6.5-20%), Consolidated Bedrock Units

Primarily located in Class II channels in tributary and mainstem reaches of Upper Freshwater, South Fork, Graham Gulch, and Cloney Gulch. There are small and large sub-classes in this high-gradient CGU that are easily distinguished by drainage area and stream power. C3 "large" (C3-L) resembles C2, while C3 "small" (C3-S) resembles C4.

CGU C3-L

Coarse Sediment: Low

CGU C3-L has boulder/cobble bed channels with bedrock commonly exposed in the banks and bed. Channel morphology is cascade and step-pool. Mobile gravel and cobbles are deposited in forced bars associated with LWD, boulders, and in regions of lower slope, but bar abundance is lower than in C1 and C2. Average median grain size is about 90 mm.

CGU C3-L was found to have a low vulnerability to inputs of coarse sediment. Stream power is very high, bar abundance is low, bedrock is commonly exposed in bed and banks, and substrate is quite coarse. These conditions indicate low response potential to coarse sediment inputs, despite relatively common, large streamside landslides.

Coarse sediment provides good habitat for amphibians; habitat that could be limited by a lack of coarse sediment inputs. Overall, the aquatic organisms are likely to respond positively to coarse inputs given the low accumulation rate of fine sediment, and channel condition is not likely to be highly responsive to inputs.

Fine Sediment: Low

CGU C3-L has an overall vulnerability of low to fine sediment inputs. This CGU tends to transport fine sediment out of the unit to a greater degree than any CGU due to the relatively high stream power. Some fine sediment accumulations were found, but they were among the least abundant observed in the watershed.

Amphibians commonly use these channel segments, and the presence of larger clean substrate is believed to be an important habitat component. There appears to be minimal potential for accumulating fine sediment; hence, amphibian populations should not be significantly affected.

Peak Flows: Low

The vulnerability of channels in CGU C3-L to increases in peak flows is low. These channels are transport reaches that have beds and banks armored by bedrock and coarse substrate, large rock, wood, and roots. The roughness that these features provide helps prevent channel incision. There is little evidence of channel response to increases in peak flows. Increases in flow would, if anything, clean fine sediments from the coarse substrate, thereby improving amphibian habitat.

LWD: Moderate

CGU C3-L has moderate vulnerability to LWD reduction of inputs. LWD is currently abundant, in part due to inputs during historic logging. In general, wood is not very mobile in these channel segments. The relatively narrow channel width and high roughness of the channel promotes deposition rather than transport. In these channels, wood and boulders work together to create pools and store sediment. The channels in this CGU are not very responsive to wood, but LWD can be important in storing gravel that is used by amphibians.

Bank Erosion: Moderate

Bank erosion vulnerability in CGU C3-L is similar to that described for C2 in that the channels are relatively resistant to such erosion. Bedrock exposures in the banks of many

CGU C3-L channels indicate many such streams will be resistant to bank scour. Overall, the vulnerability of this unit to bank erosion was determined to be moderate.

CGU C3-S

Coarse Sediment: Moderate

CGU C3-S has gravel/cobble bed channels with some bedrock exposed in the banks and bed. Channel morphology is cascade and step-pool. Mobile gravel is deposited in forced bars associated with LWD, boulders, and in regions of lower slope, but bar abundance is lower than in C1 and C2 and comparable to C3-L. Average median grain size is about 30 mm.

CGU C3-S has moderate vulnerability to inputs of coarse sediment. Stream power is relatively low, bar abundance is low, bedrock is occasionally exposed in bed and banks, and substrate is relatively fine for channels in this slope class. These conditions indicate moderate response potential to coarse sediment inputs because coarse materials could potentially accumulate if the supply were high, inducing bank erosion or streamside land sliding.

Coarse sediment provides good habitat for amphibians—habitat that could be limited by a lack of coarse sediment. Overall, the aquatic organisms are likely to respond positively to coarse inputs; however, increased sediment inputs would be expected to increase accumulation of fines (in contrast to C3-L).

Fine Sediment: Moderate

CGU C3S has an overall vulnerability of moderate to fine sediment inputs. This CGU has some potential to accumulate fine sediment based on relatively low stream power. However, fine sediment accumulations are relatively low and intermediate between C3-L and C2.

Amphibians commonly use these channel segments, and the presence of larger clean substrate is believed to be an important habitat component. Although fine sediment accumulations are relatively low, there is some potential for accumulating fine sediment; hence, amphibian populations could be affected.

LWD: Moderate

CGU C3-S has moderate vulnerability to LWD reduction of inputs. LWD is currently abundant in part due to inputs during historic logging. Much of the LWD is relatively decayed. Wood is not very mobile in these channel segments since it tends to span or lay parallel to the channels. In addition, the small size and high roughness of the channel promote deposition rather than transport. In these channels, wood and boulders work together to create pools and store sediment. The channels in this CGU are moderately responsive to wood.

Peak Flow: Moderate

The vulnerability of channels in CGU C3-S to increases in peak flows is moderate. These channels are transport reaches that have beds and banks armored by coarse sediment, wood, and roots. The resistance to erosion that these features provides prevents channel incision. However, there are pockets of gravel-sized material that could be more frequently entrained or scoured, and bank erosion is relatively common. The extent of bank erosion may be related to the relatively high abundance and function of LWD. These local effects could reduce the stability of amphibian habitat and create sources of fine sediment. On the other hand, increases in flow would also tend to flush finer sediments from the coarse substrate, thereby improving amphibian habitat. Because of potential for accelerated bank erosion and the importance of this stream type for amphibian habitat, overall peak flow vulnerability is moderate.

Bank Erosion: Moderate

Bank erosion vulnerability is similar to that in C3-L. Thus, the vulnerability rating is moderate.

5.1.4 C4: Very High Gradient (>20%), Consolidated Bedrock Units

Coarse Sediment: Low

CGU C4 has gravel/cobble/boulder bed channels with some bedrock exposed in the banks and bed. Channel morphology is cascade with occasional step-pool forms. Mobile gravel is deposited in forced bars associated with LWD, boulders, and in regions of lower slope, but bar abundance is very low. Average median grain size is about 55 mm.

Channel segments in CGU C4 have a low vulnerability to coarse sediment inputs. They do not appear to be aggrading. Stream power and median grain sizes are comparable to C1 and C2, indicating relatively high transport capacity. This is consistent with the low abundance of gravel bars. These factors suggest low channel response to coarse inputs. Biologically, inputs of coarse sediment may actually improve amphibian habitat.

Fine Sediment: Moderate

The overall vulnerability rating to fine sediment for CGU C4 is moderate. Channel segments in C4 have some potential to accumulate fine sediment, based on stream power and observed accumulations. Like C3 channel segments, these segments can be important to amphibians, and fine sediment will be detrimental to habitat.

Peak Flows: Moderate

The vulnerability of CGU C4 to increases in peak flows was determined to be moderate for the same reasons described for CGU C3-S.

LWD: Low

The overall vulnerability to LWD in CGU C4 was determined to be low. LWD is currently abundant, in large part from historic logging debris. Wood is not mobile in these channel segments because much of the wood either spans or lies parallel to the channel and flows are too low to mobilize it. Roots from riparian trees and stumps and from understory vegetation are more important to the structural integrity of the channels than LWD lying in and spanning channels. Boulders and roots provide a lot of function in these channels.

Bank Erosion: Low

The vulnerability to bank erosion in CGU C4 was determined to be low to moderate. These channels tend to have low energy flows that reduce the potential for bank erosion. Bank erosion and streamside landsliding are relatively uncommon. Where present, streamside landslides can be relatively large owing to areas of unconsolidated material (Franciscan mélange) that are prone to failure. Potential for near stream erosion is higher in areas with steeper side slopes or Franciscan mélange. Many of these channels tend to be intermittent or ephemeral watercourses that do not support aquatic life, except in seep areas, reducing the extent of potential habitat. However, fine sediment would be routed from C4 to channels downstream with amphibian habitat.

5.1.5 U1: Low Gradient (0-3%), Unconsolidated Bedrock (Wildcat)

Most of Little Freshwater Creek, the School Forest sub-basin, and portions of McCready Gulch and Falls Gulch (a tributary of Cloney Gulch). There are small (U1-S) and large (U1-L) sub-classes in this low-gradient CGU that are easily distinguished by drainage area and stream power. U1 "small" resembles U2.

CGU U1-L

Coarse Sediment: Low

CGU U1-L has gravelly sand bedded channels with Wildcat Formation bedrock commonly exposed in the banks and bed. Channel morphology is pool-riffle and plane bed. Mobile gravel is deposited in sandy bars associated stream bends and LWD; bar abundance is high. Average median grain size on bars is about 25 mm, but the dominant substrate is sand.

The overall vulnerability to coarse sediment in CGU U1-L is low. The bedrock underlying the channels in this CGU is relatively soft and produces very little gravel. Most gravel in these reaches is derived from somewhat harder rocks upstream. Hence, there are limited sources of coarse sediment. There are some accumulations below logjams and on bars in the unit. In other areas, the limited coarse sediment present in these channels tends to be buried in fines. Delivery of coarse sediment from landslides in the past has not had much effect on channel condition or fish habitat. The vulnerability to coarse sediment is low because there are few sources. Moreover, spawning habitat would likely improve if coarse sediment inputs increased, and spawning habitat is limiting in these reaches.

Fine Sediment: Moderate

The overall vulnerability to fine sediment in CGU U1-L is moderate. These channels are naturally dominated by fine sediment, largely due to the dominant watershed geology (Wildcat Group). Significance of potential pool filling by sand is reduced by the relative abundance of low velocity summer rearing habitat. Reductions in fine sediment inputs may result in significant local improvement in habitat in some areas, but large improvements in habitat over the unit are not expected. In particular, if sediment inputs into these channels were reduced, the condition of existing gravel for spawning would likely improve in some areas.

Peak Flows: Moderate

The overall vulnerability rating to peak flows in U1-L is moderate. The bed and bars in these reaches, which support limited spawning, are expected to be easily scoured due to small sediment sizes. Marginal increases in peak flow frequency would not be likely to significantly affect the principal factor creating poor quality spawning habitat (lack of coarse sediment inputs), but could cause some erosion of the bed itself. The banks are moderately stable and are less likely to be affected by changes in peak flows.

LWD: High

The overall vulnerability rating for LWD in CGU U1-L is high due to the relative absence of coarse substrate and large roughness elements other than LWD. Wood plays a major role in both formation of pools and storage of sediment in CGU U1. Much of this wood was input during previous logging activities. The effect of LWD on channel morphology makes it very important to fish and amphibians.

Bank Stability: Moderate

The overall vulnerability rating for bank stability in CGU U1-L is moderate. There are very few streamside landslide features in this unit. The valley bottom is U-shaped and broad, thus buffering some hillslope and tributary sediment sources (i.e., such sources are trapped on the valley margins so that delivery to the active channel is reduced). The banks are composed of alluvial material dominated by sand and silt. Nevertheless, the extent of bank erosion is low. Vegetation plays a significant role in maintaining stable banks. There is modest potential for bank erosion.

CGU U1-S

Coarse Sediment: Low

CGU U1-S has sand bedded channels with some gravel. Bedrock is not typically exposed in the banks and bed. Channel morphology is pool-riffle and plane bed. Mobile gravel is deposited in sandy bars associated with abundant LWD; bar abundance is low. Average median grain size on bars is about 6 mm.

The overall vulnerability to coarse sediment in CGU U1-S is low for the same reasons as in U1-L.

Fine Sediment: Moderate

The overall vulnerability to fine sediment in CGU U1-S is moderate (see U1-L).

Peak Flows: Moderate

The overall vulnerability to peak flow increases is moderate. The bed and bars in these reaches, which support limited spawning, are expected to be easily scoured owing to small sediment sizes. Marginal increases in peak flow frequency in this low energy channel would not be likely to significantly affect the principal factor creating poor quality spawning habitat (i.e., lack of coarse sediment inputs). Bank erosion is relatively common; however, this is not the dominant source of fine sediment. Bank erosion conditions are attributed to narrow channel width, sandy/silty bank material, and high LWD abundance.

LWD: High

The overall vulnerability rating for LWD in CGU U1-S is high (see U1-L).

Bank Stability: Moderate

The overall vulnerability rating for bank stability in CGU U1-S is moderate. In this unit, there are very few streamside landslide features. The valley bottom is U-shaped and broad, thus buffering some hillslope and tributary sediment sources. The banks are composed of alluvial material dominated by sand and silt. The extent of bank erosion is high, attributable to narrow channel width and high LWD abundance. Vegetation plays a significant role in maintaining stable banks.

5.1.6 U2: Moderate Gradient (3-6.5%), Unconsolidated Bedrock (Wildcat)

Mostly located in tributaries or headwaters of Little Freshwater Creek, with some units in McCready Gulch, South Fork, and School Forest sub-basins.

Coarse Sediment: Low

CGU U2 has sand bedded channels with some gravel. Bedrock is occasionally exposed in the banks and bed. Channel morphology is step-pool and pool-riffle. Mobile gravel is deposited in sandy bars associated with abundant LWD; bar abundance is high. Average median grain size on bars is about 15 mm.

Overall vulnerability of channels in CGU U2 to coarse sediment is low. There is some evidence of channel response to coarse sediment, due to the abundance of bars. However, there is very little bank erosion or streamside mass wasting. Bar abundance may be attributed to relatively well-developed floodplain conditions and moderate LWD abundance. Moreover, most of these reaches are already deficient in gravel. Increases in gravelly coarse material would likely improve habitat in the unit.

Fine Sediment: Moderate

Like U1, reductions in fine sediment loads in CGU U2 may lead to winnowing of fine sediments, resulting in more exposed, less embedded gravel. Improvements are, however, expected to be local and relatively minor. Since some minor and/or local response is expected with decreases in fine sediment, the overall vulnerability of CGU U2 to fine sediment was determined to be moderate.

Peak Flows: Low

The overall vulnerability rating to peak flows in U2 was determined to be low. The bed and bars in these reaches, which support limited spawning, are expected to be easily scoured owing to small sediment sizes. Marginal increases in peak flow frequency would not be likely to significantly affect the principal factor creating poor quality spawning habitat (i.e., lack of coarse sediment inputs). The banks are moderately stable and are less likely to be affected by changes in peak flows. Channels have moderately abundant wood and relatively well-developed floodplains that help dissipate stream energy under high flow conditions. The response of the channel and substrate under increased peak flows is dependent to some degree on the abundance of LWD. Given the moderate to low use of the area for spawning and factors that limit responsiveness of the channels to changes in peak flows, the vulnerability of these channels to increases in peak flows was determined to be low.

LWD: High

The overall vulnerability rating to LWD in U2 was determined to be high. CGU U2 has moderately abundant LWD. Wood is more important in this CGU compared to CGU C2, since U2 channels do not contain boulders that contribute to pool development and fish cover habitat. LWD in this CGU is also important for sediment storage and grade control.

Bank Erosion: Moderate

The potential for bank erosion in U2 is similar to that described for U1. The vulnerability to bank erosion in this unit is moderate.

5.1.7 U3: High Gradient (6.5-20%), Unconsolidated Bedrock (Wildcat)

Most of Little Freshwater Creek tributaries, large portions of McCready Gulch, South Fork, and School Forest sub-basins. This unit is also found in the lower portions of Upper Freshwater, Graham Gulch, and Falls Gulch.

Coarse Sediment: Low

CGU U3 channels have some bedrock exposed in the banks and bed; mobile bed material in bars is sandy gravel. Channel morphology is cascade and step-pool. Mobile sediment is deposited in forced bars associated with LWD, boulders, and in regions of lower slope, but bar abundance is lower than in U1-L and U2, and comparable to U2-S. Average median grain size on bars is about 25 mm. The vulnerability of CGU U3 to coarse sediment was determined to be low. There is little evidence of channel response to coarse sediment; bars are not very abundant, bank erosion and mass wasting are not common, and bedrock control is locally significant. Additional gravel material is likely to improve habitat conditions.

Fine Sediment: Low

The vulnerability of CGU U3 to fine sediment was determined to be low. Stream segments in CGU U3 have somewhat higher gradient and stream power than those in U2. These reaches tend to transport fine sediment more effectively than U2 and U1-S. This CGU has a naturally high fine sediment load derived from the Wildcat Group. Reductions in fine sediment inputs are not expected to result in much change in channel conditions due to the geology type. These gravel-poor, sand rich substrates tend to have relatively limited amphibian use. There may be some local improvement in habitat but overall, little response is expected to changes in fine sediment.

Peak Flows: Low

The channels in CGU U3 have a low vulnerability to changes in peak flows. These channels contain patches of mobile sandy gravel overlying unconsolidated bedrock and have little resistance. Historic downcutting to bedrock is inferred to have occurred in these channels and is attributed to early logging in the watershed. Further downcutting is unlikely to be significant in the future due to bedrock control on bed elevation. Relatively abundant wood in these channels helps reduce the magnitude of the potential effect. In some channels, however, downcutting has created deep, narrow channels that limit the ability of wood to reach and modify the active bed. These reaches support few fish and amphibians, so the overall vulnerability rating is related less to the effect on habitat within the unit than the effect that peak flows has on the transport of material to downstream channel segments. The amount of sediment generated and transported due to downcutting and bank erosion affects the ultimate vulnerability call. Relative to the total sediment inputs to downstream channels from all sources, the amount of sediment generated through erosion of these channels and banks is low. The vulnerability of these channels to peak flows was therefore determined to be low, reflecting the potential for some channel modification, past downcutting, and limited downstream effect.

LWD: High

CGU U3 currently has abundant wood similar to that in C3. As noted, however, often this wood cannot reach the active channel due to deeply incised conditions. Where wood can reach the channels, it is important since these channels do not have abundant roughness elements such as cobbles and boulders in the channel. Hence, the overall vulnerability to large decreases in wood inputs for CGU U3 is high.

Bank Stability: Moderate

The vulnerability to bank erosion is moderate, owing in part to the interaction with potential peak flow increases and in part to past channel downcutting that has created steeper and taller streambanks. Somewhat more bank erosion and streamside landsliding has been observed within CGU U3 relative to other unconsolidated CGUs, but it is not extensive compared to Consolidated CGUs. The quantity of sediment that could potentially be delivered is not large in the sediment input budget. In addition, streamside slopes are somewhat steeper than in U2, but lower than in Consolidated CGUs. Root reinforcement of these banks from trees, stumps, and understory vegetation is thought to contribute to stability.

5.1.8 U4: Very High Gradient (>20%), Unconsolidated Bedrock (Wildcat)

Most of Little Freshwater Creek tributaries, large portions of McCready Gulch, South Fork, and School Forest sub-basins. This unit is also found in the lower portions of Upper Freshwater, Graham Gulch, and Falls Gulch.

Coarse and Fine Sediment: Low

CGU U4 channels have relatively abundant bedrock exposed in the banks and bed; mobile bed material in bars is sandy with little gravel. Channel morphology is cascade and colluvial. Mobile sediment is deposited in forced bars associated with LWD and in regions of lower slope, but bar abundance is low. Average median grain size on bars is about 2 mm

The vulnerability of CGU U4 to both coarse and fine sediment was determined to be low. The ability of these small streams to transport sediment is modest, despite moderate stream power induced by high channel gradient. Sediment generated in these small watersheds is dominated by fine material. Bars are not common, and fine sediment accumulations are abundant but relatively low for Unconsolidated CGUs. Channel enlargement and downcutting presumably occurred following initial clearcutting in the watershed. These channels can accommodate more sediment storage without impinging on banks; channels are oversized relative to streamflow. There is some tendency for sediment deposition in portions of these channels. The quantity and size of sediment that enters these channels are not expected to cause significant changes in channel conditions.

Peak Flows: Low

The overall potential effect of increases in peak flows in CGU U4 is low, similar to U3. These channel segments appear to have been subject to erosion and downcutting associated with early logging. Wood plays a minor role in moderating erosion because the channel is small or, as with some U3 segments, deeply entrenched conditions results in wood tending to overly the channel rather than reaching the bed. Roots in the bed and bedrock, rather than wood, provide the stabilizing element. These channels are little used by aquatic organisms, so the vulnerability is more related to downstream effects of channel erosion than to habitat modification within the channels themselves. Sediment generated through erosion processes within these channels is small relative to the total watershed sediment inputs. Therefore, the overall vulnerability to peak flows was determined to be low.

LWD: Moderate

The overall vulnerability to wood inputs for CGU U4 is moderate. CGU U4 currently has abundant wood. In comparison with CGU C4, wood is more important in U4 because these channels do not have cobbles or boulders in the channel. Many of these channels are deeply incised. It is hypothesized that there was an interaction between high flows and wood that caused downcutting and bank erosion in this unit in the past, but that process does not appear to be active under current conditions. In many of these channels, wood cannot reach the active channel due to deeply incised conditions. Where wood can reach the channels, it is important since these channels do not have abundant roughness elements such as cobbles and boulders in the channel. Hence, the overall vulnerability to large decreases in wood inputs for CGU U3 is moderate.

Bank Stability: Moderate

The vulnerability to changes in bank stability in CGU U4 was determined to be moderate. In this CGU, channel incision following first-cycle logging has lowered the base level of banks, causing increased bank erosion and streamside landslides. Under current conditions, few streamside landslides are seen. However, creation of a vertical bank increases the potential for bank erosion in this unit. Root reinforcement of these banks from trees, stumps, and understory vegetation is thought to contribute to stability.

5.1.9 MS1: Mainstem Freshwater, Between South Fork & Graham Gulch

Coarse Sediment: Moderate

CGU MS1 has gravel/cobble bed channels with bedrock exposed in banks and occasionally in the bed. Channel morphology is pool-riffle and plane bed. Mobile gravel and cobbles are deposited on bars and in association with LWD. Reach average median grain size is about 35 mm.

CGU MS1 is similar to CGU C1; however, it has relatively few direct coarse sediment sources. Coarse sediment supplied to MS1 originates in the Upper Freshwater and South Fork sub-basins. Sediment storage in MS1 is relatively low and analyses of bedload transport suggest coarse sediment inputs are relatively well balanced with transport capacity (see Stream Channel Assessment). CGU MS1 is used heavily by the anadromous fish species in the basin and provides good spawning habitat.

Increases in coarse sediment load are not expected to cause much response in the channel. Extreme increases in coarse sediment inputs would likely fill pools and tend to destabilize the channel. Rapid, large-scale increases of coarse sediment inputs are unlikely in this CGU, however, because coarse sediment is routed to this unit by fluvial processes from upstream, which tends to smooth out the rate of delivery. Gradual increases in coarse sediment load in excess of transport capacity are more plausible, and one possible manifestation of this would be a gradual decline in sediment sizes on the bed. This scenario has the potential effect of increasing bed scour and fill which could be detrimental to spawning habitat. Because of this potential effect, and the importance of this CGU for spawning, overall coarse sediment vulnerability was ranked as moderate.

Fine Sediment: High

The fine sediment situation in CGU MS1 is very similar to the situation in C1. Hence, the vulnerability to fine sediment was determined to be high for the same reasons that are described for C1. Although comparable V* monitoring data are not available, it is reasonable to assume that there has been or will be some increase in sediment accumulations in the pools, as well as increased concentrations of sand in spawning gravels. Increases in fines are not likely to have large effects on the channel characteristics; however, fines accumulating in the spawning gravels and pools could have significant effects on spawning success and the quality of rearing habitat. Therefore, CGU MS1 was given a high vulnerability call for fine sediment.

Peak Flow: Low

The vulnerability of CGU MS1 to peak flows is low. In this unit, the banks are often comprised of alluvial material and elevated river terraces. Bedrock exposed in the banks and bed is also characteristic of this CGU. The channel is entrenched and fairly stable, with relatively low rates of near stream erosion. The potential for physical changes in the banks due to changes in peak flows is low to moderate, with the higher potential in locations where alluvial bank materials predominate and there is little bedrock. The potential for peak flow increases to increase the frequency of scour was analyzed (Stream Channel Assessment), and it was concluded that peak flow increases have a relatively low potential to increase the frequency of bed scour to depths where egg pockets are typically found in redds. The average depth of egg pockets ranges from 8 to 12 inches, ranging up to 16 inches for larger fish and down to 3 or 4 inches for trout (Bjornn and Reiser 1991, Schuett-Hames et al. 1996). The predicted probability for bedload mobilization and scour to exceed the depth of the egg pocket in coho redds at MS1 is as follows:

Flood Return Interval	Baseline %	Present %
1.2-year	0.46	0.54
2-year	1.7	1.9
5-year	0.98	1.3

Although this CGU is one of the prime spawning areas in the watershed, the potential for effects due to increases in peak flows is low.

LWD: High

Large woody debris abundance in CGU MS1 currently does not meet wood targets, especially in that portion of MS1 downstream of PALCO's ownership. This CGU is confined in the upper reach and moderately confined in the lower reach. In these relatively wide channels with low abundance of key LWD, LWD is expected to be relatively mobile. Most pools are formed by scour in association with bedrock outcrops and stream bends. Under current conditions, LWD is a secondary habitat-forming feature. If LWD inputs increased, particularly longer, larger diameter pieces, it is expected that additional pools would be formed. In addition, LWD functions to sort spawning gravel and store sediment. Spawning and rearing habitat complexity and quality would improve if sufficiently large wood were recruited to the CGU. Large accumulations of LWD that could provide significant changes to the channel and habitats are not expected in the short-term due the inability of all but the largest wood to remain stable. Therefore, the overall vulnerability of the unit to large woody debris inputs was determined to be high.

Bank Stability: Moderate

There are a few large landslides on the outside bends of the channel. These features introduce both coarse and fine sediments into the CGU. Bank erosion, however, is not extensive and is a minor component of the overall sediment inputs. Since there is evidence of modest amounts of stream-driven bank erosion, the vulnerability to changes in bank stability processes was determined to be moderate.

5.1.10 MS2: Mainstem Freshwater, Between Graham Gulch & Little Freshwater

Coarse Sediment: High

CGU MS2 has gravel/cobble bed channels with bedrock exposed in banks throughout, and in the bed in the upper third of the CGU and locally in more downstream reaches. Channel morphology is pool-riffle and plane bed. Reach average median grain size is about 30 mm.

CGU MS2 is located at the upper end of the flood-prone reaches in lower Freshwater Creek. In at least localized portions of this CGU, coarse sediment appears to be accumulating, aggrading the channel, reducing channel capacity, and contributing to the flood hazards (see Stream Channel Assessment). The coarse fraction of the sediment load, rather than the fine sediment fraction, is the dominant fraction that is accumulating where indications of aggradation are strongest (see Stream Channel Assessment). In this middle portion of CGU MS2, aggradation has caused general channel simplification, replacing pool-riffle morphology with plane bed morphology. The low abundance of LWD in this reach contributes to the presumed reduction in pool frequency and volume. The effect of coarse sediment is nevertheless significant, independent of any interactions with other inputs, and, hence, has been given a high vulnerability rating. (See discussion of interaction of inputs below).

Fine Sediment: Moderate

CGU MS2 has relatively little fine sediment in the bed. In the bulk sediment sample (collected in the reach where indications of aggradation are greatest), only 8% of the material was finer than 1 mm and 12% was finer than 2 mm. Modeling of sediment routing and deposition (Stream Channel Assessment), however, suggests that sediment should tend to be deposited in this reach. A significant component of modeled sediment deposition should be sand. Although current levels of fine sediment in spawning gravels in this reach are low, the sediment budget and sediment routing analysis indicates that there is potential for deposition of sand. The potential for sand deposition, together with significant spawning potential, gives an overall vulnerability rating for fine sediment of moderate.

Peak Flows: Moderate

The vulnerability of CGU MS2 to increased peak flows is moderate when considering channel condition and aquatic habitat only, independent of interactions with other inputs (see discussion in following paragraph regarding interactions). The channel here is a relatively narrow, trapezoidal channel. The channel bed is composed of relatively mobile gravel with periodic bedrock outcrops. The banks are somewhat armored by bedrock in many of the streambanks. A moderate degree of vegetation is present on the banks; however, the banks are subject to erosion by peak flows because the density of bank vegetation is lower than in many other CGUs and is deficient in conifer species. This unit is used to some degree by spawning fish, so the potential for scouring redds could increase the vulnerability of the unit to increases in peak flows. However, the analysis of scour potential (Stream Channel Assessment) suggests that channel scour to egg pocket depth due to management-related increases in peak flow would likely be small. Overwintering habitat in this unit is limited because there are few areas to take refuge during high flow periods that do not overtop the banks. Ample winter habitat is available on floodplains once the water surface elevations provide access to them. Overall, the vulnerability of the unit as it affects channel conditions and aquatic habitat is moderate.

Interaction Between Peak Flows and Coarse Sediment: Moderate

There is substantial interaction between the peak flow and coarse sediment inputs in this reach. In some locations, accumulation of coarse sediment is raising the elevation of the bed, effectively increasing the potential for flooding, independent of changes in peak flows. Increases in peak flows would further increase the potential for flooding. Hence, there is a pronounced synergistic effect between coarse sediment inputs and peak flows in at least some portions of this CGU. Independent of this interaction, the vulnerability to coarse sediment was determined to be high and the vulnerability to peak flows was determined to be moderate. The combined effect of these inputs increases the vulnerability of resources, including private property, to changes in either or both of these inputs in those segments of MS2 where aggradation is present.

LWD: High

Currently, large woody debris abundance in CGU MS2 is quite low (see the Stream Channel and Fisheries Assessments). Owing to abundant coarse sediment in this unit, increases in the amount of LWD would cause scour and create pool habitat (which is currently limited in this unit) and provide cover. Debris jams might also form, which would increase the potential for channel avulsion and further development of rearing habitat in the form of side channels and pools. LWD distribution and longevity are directly influenced by human activities, such as log jam removal and modification. The overall vulnerability rating to large woody debris for this unit is high.

Bank Stability: Moderate

Riparian vegetation probably plays a substantial role in bank stability in this unit, owing to the generally fine texture of alluvial sediment that comprises the banks. There is little evidence of historic channel migration, but there is a moderate degree of small-scale bank erosion. The abundance of coarse sediment and the potential for bar growth to accelerate bank erosion suggest that there is significant potential for bank erosion. The vulnerability of MS2 to changes in riparian vegetation was determined to be moderate because of the limited extent of historic erosion, despite relatively low density of riparian vegetation and channel conditions that suggest substantial potential for bank erosion.

5.1.11 MS3: Mainstem Freshwater, Between Little Freshwater & Three Corners Market

Coarse Sediment: High

CGU MS3 has a sandy-gravel bed with alluvial banks. Sub-reaches alternate between gravelly conditions and sandy conditions, apparently reflecting local variations in channel gradient. Channel morphology is pool-riffle and plane bed. Reach average median grain size is about 15 mm.

CGU MS3 is expected to be a depositional reach owing to its low gradient, the influence of tides, and the sediment size distribution in the channel. The sediment routing analysis, however, suggests that sediment transport capacity is relatively high despite these factors (see Stream Channel Assessment) and appears to have adequate capacity to transport the sediment it receives. Despite mixed evidence, it was concluded that MS3 is prone to sedimentation and aggradation. Relative to MS2, a higher proportion of sediment deposited in this unit is sand. Nevertheless, the bulk sample for this reach indicated that two-thirds of the material is gravel (>2 mm diameter). Hence, the majority of sediment deposited in channels appears to be gravel. Consequently, to the extent that aggradation currently exists, it is driven to a significant degree by deposition of gravel. If the coarse sediment load were increased sufficiently, substantial changes in the channel characteristics would be expected. These changes might include pool filling, reduced diversity in channel morphology, bed fining, increased bank erosion, and channel avulsion. Therefore, the vulnerability to coarse sediment is high.

Fine Sediment: High

As mentioned above, fine sediment is relatively abundant in this CGU. This contributes to aggradation and increases flood hazards (see Stream Channel Assessment). In addition, the high concentration of fine sediment affects fish habitat. Sand is currently the dominant or subdominant particle type in 78% of the surveyed fish habitat units within this CGU. This unit has ample rearing habitat (particularly good for coho), with some evidence of limited pool filling. If fine sediment inputs were reduced, some improvement in spawning habitat would be expected; however, large quantities of sediment would still be expected due to the abundance of fine sediment produced in the watershed, the very low stream gradient, and the influence of tides. High fine sediment production is a function both of historic management practices and watershed geology.

Given the naturally high fine sediment loads in this unit, limited use for spawning, the current quality of rearing habitat, and the limited expected response of habitat conditions to changes in sediment loads, the unit would be given an overall vulnerability rating of moderate. This rating, however, does not reflect the potential to increase flooding in MS3. Fine sediment accumulating in this CGU increases the likelihood of flooding. Factoring in the flood hazard, the overall vulnerability for fine sediment for CGU MS3 was determined to be high. (See below for discussion of hydrology and the sediment/hydrology interaction that affect the flood situation.)

Peak Flow: High

CGU MS3 has poor spawning habitat but good winter rearing habitat. MS3 contains relatively little spawning habitat, but there are plenty of places for fish to seek refuge during peak flow events. Hence, the biological concerns regarding increases in peak flows are not great. Bank erosion is not as great a concern as in MS2 since the streambanks tend to be heavily vegetated, reducing bank erosion potential. On the other hand, the banks are comprised of unconsolidated alluvium and are not armored by bedrock outcrops, and are therefore potentially subject to some erosion. The overall vulnerability rating for this unit to increases in peak flows was moderate. This did not factor in synergistic effects of inputs or vulnerability of private property (both of which are discussed in the next paragraph). When these factors are considered, the vulnerability to peak flows is increased to high.

Interaction Between Peak Flows and Sediment Accumulation: High

There is substantial interaction between the peak flow and existing or potential channel aggradation (see Stream Channel Assessment). There is evidence that sediment accumulation has raised the elevation of the bed, effectively increasing the potential for flooding, independent of changes in peak flows. Increases in peak flows would further increase the potential for flooding. Hence, there is a pronounced synergistic effect between sediment inputs and peak flows in this CGU. Independent of this interaction, the vulnerability to each (sediment and peak flows) was determined to be moderate. The combined effect of these inputs increases the vulnerability of resources, including private property, to changes in either or both of these inputs. Hence, the vulnerability of the unit to changes in both peak flows and sediment is considered high.

LWD: Moderate

Currently, large woody debris abundance in CGU MS3 is very low. Since mobile sediment is abundant, increases in the amount of LWD would cause scour and create pool habitat and provide cover. There is evidence that LWD jams have historically induced channel avulsions, which would significantly increase channel and floodplain complexity. However, removal or modification of LWD jams through human intervention limits the future potential for such channel changes. LWD distribution and longevity are also directly influenced by human activities. Despite low LWD levels, MS3 currently has ample pool habitat; therefore, the increased LWD functionality would be less pronounced than would be expected MS2. The overall vulnerability rating to large woody debris for this unit is moderate.

Bank Stability: High

Riparian vegetation can play a substantial role in bank stability in this unit. Riparian fencing and other management changes along portions of MS3 have led to increased vegetation density on the floodplain relative to earlier periods in the aerial photograph record (e.g., 1940s-1970s). This increase in vegetation levels appears to accelerate sedimentation and the growth of natural levees in these areas. In reaches with dense riparian vegetation and relatively gently sloping streambanks, it appears that fine sediment is deposited. Such accretion of sediment on banks may further reduce channel capacity. This reach lies entirely within private residential areas and ranch lands, where banks have been treated with riprap and other materials to reduce erosion. Reductions in the density of riparian vegetation would probably reduce channel roughness to some extent and probably reduce bank accretion, thus reducing flood hazards to some degree. It might also increase the potential for bank erosion. Overall, the fine texture of alluvial banks and the potential for avulsion and bank erosion suggest that the vulnerability of MS3 to changes in bank stability is high.

5.1.12 Graham Gulch

Coarse Sediment: High

CGU GG has a gravel bed with occasional bedrock outcrops in the banks. Gravel bars are abundant. Channel morphology is pool-riffle and plane bed. Reach average median grain size is about 30 mm.

A large earthflow-landslide feature, believed to be of natural origin, and its remnant landslide dam over which the modern channel flows dominate channel conditions in Graham Gulch. This landslide feature is unusual in Freshwater tributaries in that about one-quarter of the sediment input is derived from a single “point source.” Sediment storage in Graham Gulch is among the highest observed in the watershed. Currently, the channel goes dry or subsurface in some areas due to the high accumulation of sediment. If coarse sediment inputs were increased, more of the channel would be buried and the intermittent nature of the stream would be more widespread. Therefore, the vulnerability of the reach to coarse sediment is high.

Fine Sediment: Moderate

Due to the landslide and sediment from other natural and management-related sources and the presence of Wildcat geology, this unit has abundant mobile sediment. Observations of fine sediment in channel surveys indicate low to moderate abundance on the channel bed. In contrast, field measurements of V_* values indicate substantial filling of pools by fine sediment. The bulk sediment sample for this tributary had about 22% sediment <2 mm. Ample pool habitat is available and rearing habitat is relatively good where the stream is not dry. Prior to reactivation of the landslide dam from the deep-seated landslide in 1997, this tributary supported some spawning habitat. The channel is relatively steep, and fine sediment should readily route downstream. At the present time, if management-related sediment sources were eliminated, the fine sediment situation in this unit would likely improve to some degree. Conditions are unlikely to improve significantly, however, until or unless the deep-seated landslide stabilizes. The overall vulnerability rating for fine sediment in this unit is moderate, recognizing that the sources of fine sediment are the deep-seated landslide, management influences, and other natural inputs.

Peak Flow: Moderate

The vulnerability of the Graham Gulch CGU to peak flow increases is moderate to high. The reactivation of the landslide dam from the deep-seated landslide occurred during the 1997 peak flow, which was a high magnitude, low frequency event. The magnitude of peak flow increases caused by timber harvest for relatively large floods is small. Hence, even if erosion of the landslide dam reactivated the slide, the management-related peak flow increases are thought to have a relatively small effect. Given current destabilized conditions, more frequent, lower magnitude peak flow events might slow the rate of stabilization and induce ongoing erosion of the landslide toe (moderate vulnerability).

LWD: Moderate

Currently, LWD in Graham Gulch is relatively abundant and meets PFC targets. This CGU is very similar to C1 in its responses to wood. The deep-seated landslide in this unit has been a significant source of LWD. A substantial component of LWD in this tributary is remnant railroad ties. At present, roughly 57% of the pools in the unit are wood-formed with 100% being associated with LWD. The channel is highly responsive to wood; pool development is highly dependent upon wood and the pools that form provide good rearing habitat. Given relatively high LWD abundance at present, the vulnerability to decreased inputs is moderate.

Bank Stability: Moderate

Bank erosion and streamside landslides produce relatively large inputs of sediment per unit channel length compared to other sub-basins. Nevertheless, total inputs attributed to this process are a small component of the sediment input budget. Hence, Graham Gulch was given a moderate vulnerability to changes in bank stability processes.

5.1.13 Cloney Gulch

Coarse Sediment: High

CGU CG has a gravel bed with occasional bedrock outcrops in the banks. Channel morphology is pool-riffle and plane bed.

Coarse sediment is tending to accumulate more in the upper reaches than the lower portions of this CGU. These accumulations of coarse material are providing spawning habitat for fish. The lower portion of the unit does not have the same quality of spawning habitat since less coarse material is present. Some reaches in the upper end of the CGU have intermittent or subsurface flow during the low-flow season, partially due to the buildup of coarse material. The buildup of sediments in these areas is enhanced locally by the presence of old railroad ties in the stream bottom. In areas not influenced by the railroad ties, developing bars or other evidence of aggradation has been observed in a few locations. This reach has very little bank erosion and few streamside landslides. While the accumulation of coarse sediment, particularly in the upper end of the unit, is providing good spawning habitat, additional input of coarse material would be expected to bury more of the stream, resulting in an increase of intermittent stream area. Therefore, the overall vulnerability to coarse sediment was determined to be high.

Fine Sediment: High

Fine sediment is currently found accumulating in some pools and is affecting the quality of spawning gravel in this unit. As in CGU GG, the presence of Wildcat geology is partially responsible for these fine sediment levels. Still, this area is heavily used for spawning; hence, degradation of spawning habitat is of particular concern. The unit was given a high vulnerability rating to fine sediment, reflecting the observed sediment situation and the sensitivity of the fish habitat.

Peak Flow: Moderate

In the upper reaches of this CGU, abundant LWD controls channel grade in many locations, reducing the potential impact of scour in response to increases in peak flows. The potential for scour in the lower reaches is higher owing to finer sediment sizes and lower LWD abundance. Analyses of scour potential in other CGUs with similar channel conditions suggest that the potential increase in scour affecting redds caused by peak flow increases is relatively small. Winter rearing habitat in the reach is fair to poor. Increases in peak flows in an area where little refuge habitat is available would potentially have an incremental effect on the fish populations. The magnitude of near stream erosion processes is low. Overall vulnerability of the Cloney Gulch CGU to peak flows is accordingly moderate.

LWD: Moderate

Currently, LWD abundance in this CGU meets PFC targets. Wood plays a major role in both formation of pools and storage of sediment in this unit. Approximately 23% of the pools in this CGU are LWD-formed with 79% associated with wood. The overall vulnerability to reduced LWD inputs for this CGU is moderate, owing to the relatively high LWD abundance under current conditions.

Bank Stability: Low

There are low rates of bank erosion and streamside landsliding in this CGU. Hence, this unit was given a low vulnerability to changes in bank stability processes.

5.2 HABITAT DIAGNOSTICS

The Properly Functioning Condition (PFC) matrix, which is used to guide the habitat targets and evaluate habitat condition within the watersheds covered under the PALCO HCP, was developed without watershed-specific data. The adequacy or applicability of the PFC matrix values was discussed during Synthesis by PALCO, the agencies, and scientists working on the Watershed Analysis relative to data available for the watershed. Discussions focused on sediment, wood, and shade measures. These discussions are summarized below.

5.2.1 Sediment

The discussion of sediment habitat diagnostics focused on bedload sediment. We discussed the sediment situation that was expected to be achievable in each CGU. All discussions were relative to the PFC matrix, which specified the measures summarized in Table 5-2.

Data collected in the Freshwater Watershed included bulk sediment data collected by PWA and additional site monitoring data collected under the SYP/HCP monitoring program. The SYP/HCP data differed somewhat from the parameters specified in the PFC matrix in that particle sizes were documented at a size break of less than and greater than 4.75 mm, rather than the 6.5 mm break used in the matrix. Data collected are summarized in Tables 5-3 and 5-4. The discussion that took place for each CGU is summarized below by CGU.

Table 5- 2: Sediment parameters specified in the PFC matrix.

Parameter	Target
1) Percent fines <0.85 mm	Class I and II streams: < 11-16%
2) Pebble Counts	d50 of 65-95 mm
3) Percent particles <6.5 mm	<20-25% in Class I and II streams

Table 5- 3: V* measurements in CGU C1.

Year	Upper Mainstem	South Fork
1992	0.18	0.52
1993	0.15	0.59
1999	0.46	0.59

Table 5- 4: Sediment data collected in the Freshwater watershed by CGU.

CGU	DATA SOURCE						
	PWA Data[1]			*SYP Data*[2]			*Bernard*[3]
	d50	Percent Fines	Percent <4.75 mm	d50	Percent Fines	Percent <4.75 mm	Percent Fines
MS1	32-37	21	35	48-81	13-24 avg 16	28-36 avg 32	5-6
MS2	28	8	23				7.9
MS3	15-16	22	48				8
CG[5]		25[6]		66	16 (1998) 25 (1999)	37 (1998) 46 (1999)	9
GG	31	17[7]	32	32-33	25-26	44-48 avg 46	8
C1	21-52 avg 42	3-20 avg 13	22-41 avg 32	44-72 avg 53	19-26 avg 23	30-48 avg 40	4-17 avg 40
U1	9[4]			15-42 avg 28	25-48 avg 39	54-64 avg 54	22

1/ PWA channel data are most representative of bars.
2/ SYP data are most representative of spawning gravels.
3/ Bernard collected substrate data using freeze cores.
4/ From patch mapping.
5/ Shovel sample data. Additional data: d84=110 mm, subsurface d50=11 to 12 mm.
6/ Sample taken in an area that is not believed to be very representative of the unit.
7/ Additional pebble count data found surface fines of 27 and 37% in Graham Gulch and subsurface fines at 6 and 10%.
8/ Defined as sediment less than 0.84 mm diameter.

C1 is a primary spawning area. It has outcrops of relatively resistant rock in the channel. The CGU includes significant variability in substrate size, reflecting the dominance of softer rock in the watershed interspersed with harder rock. The South Fork has a dense network of debris jams that tend to retain sediment; hence, fine sediment storage is much higher in the South Fork than in the upper mainstem. The geology in the South Fork subbasin includes a higher proportion of Yager (soft material), which contributes to the abundance of fines in the channel. V* measurements taken in the upper mainstem and South Fork are shown in Table 5-3.

Currently, the unit does not meet any of the PFC targets for sediment. The average particle sizes are smaller than the targeted d50. The analysts felt that the PFC targets might be attainable in the upper mainstem, although confidence in this conclusion was low. The sediment routing analyses indicate that a time delay of at least 10 years should be expected between reduction of sediment inputs and improved channel conditions. In the South Fork, PFC targets are not likely to be met as long as the debris jams are present. Some reduction in fine sediment, however, is likely over time.

U1 is underlain primarily by the Wildcat Formation. These weak rocks weather easily and tend to create channels with a high proportion of sand and silt. Gravel is limited and primarily found in accumulations below wood jams. Currently, none of the PFC values for sediment are met in this unit. The d50 is substantially smaller and the percent fines are high. Given the local geology and the current particle size distribution, there is a low probability of meeting the PFC matrix values in this CGU, except in pockets. The probability of meeting the PFC targets decreases with increases in the proportion of Wildcat geology present upstream of each stream segment in U1. The available data are not sufficient to support estimates of the attainable condition in these channels; hence, there is significant uncertainty regarding the expected response to changes in fine sediment inputs.

MS1 is an important salmon spawning reach. The portion of fines in the substrate is expected to be governed by sediment input from upstream. The current substrate in the spawning gravels meets or nearly meets the PFC targets. Hence, the PFC targets are assumed to be attainable. The bars, which may accumulate more fines, are currently finer textured and may not make the PFC targets. Differences in findings between years and sampling methods contribute to a degree of uncertainty regarding these targets. Inter-annual variability in sediment loads from upstream will likely result in years of unfavorable sediment from time to time. As sediment loads are reduced upstream, the portion of fine material in this reach may decrease. An approximate 10-year lag time between the reduction in sediment and channel response for fine sediment should be expected.

Sediment texture in **MS2** is relatively coarse. The underlying rock is weak and does not persist long. The gravel in the channel appears to be composed of persistent lithologic types that have accumulated in the reach. d50 collected in bars is relatively low although some areas in this unit are coarser. Generally, fines (sand) transported into this CGU are being transported farther downstream. Larger particles appear to be accumulating at least locally. The substrate appears to be coarser in the thalweg than along the margins of the channel, which contributes to the range of measured values in this CGU. Currently, the d84 is closer to the PFC matrix values than the d50; the percent fines, however, satisfy the PFC values. It is highly doubtful that the d50 will ever meet the PFC matrix since most of the material transported into this reach is smaller. The current size distribution supports this conclusion.

MS3 lies within the zone of tidal influence. It has areas that are slough-like with fine bed sediment, interspersed with gravelly areas. Salmon use this area primarily for rearing, although they spawn in the reach in low water years. Hence, pool filling is of greater concern than the quality of spawning gravel. The unit has the lowest overall gradient in the watershed; hence, it tends to be a depositional reach with substantial over bank deposition of fine sediment. Generally, the bed tends to fine from MS1 through MS3, with the larger particles depositing in the upper reaches of the mainstem and the finer particles depositing in MS3. The data on particle size reflect this. Reductions in sediment inputs are not likely to have a substantial effect on substrate composition but may reduce pool filling. Hence, the reach is not expected to meet PFC targets. It is expected to be sand rich with pockets of spawning gravel.

Cloney Gulch cuts across all the bedrock types. It tends to be gravel rich but with extensive fines. Coho use the CGU extensively. The data available to describe the current condition in this unit are not as extensive as that available for other units. Currently, the d50 is at the lower end of the range specified in the PFC matrix, and the percent fines are somewhat higher than the PFC matrix values. With reductions in fine sediment inputs, the PFC matrix values may be able to be met in most years. Confidence in this conclusion is fairly low. The upper reaches of this CGU have a higher proportion of consolidated geology than found in the lower reaches. Hence, the upper reaches are more likely to meet the PCF values in time than the lower reaches.

The **Graham Gulch** deep-seated landslide dominates the sediment loads in the Graham Gulch CGU. Aerial photos indicate the slide was active in the late 1940s and that the landslide jam at the toe reactivated again in 1997. The slide is not expected to stabilize very quickly, if at all, and may go through periods of relative stability followed by periods of active movement.

The substrate data in Table 5-5 indicate that the unit is currently dominated by small particles. The V* estimates were 0.34 in 1992 and 0.51 in 1999, suggesting an increase in fine sediment after the slide reactivated. The substrate reflects the particle size distribution of inputs from the slide.

Because the landslide controls the substrate characteristics in the unit, there is a low expectation for any short-term change in the substrate composition. Over time, the amount of fine material may decrease if the slide starts to stabilize but would increase again if the slide is reactivated. Hence, the PFC matrix values are not expected to be met in the near future.

In summary, none of the units currently meet all of the PFC matrix targets, although Cloney Gulch, MS1, and MS2 meet or come close to meeting the target values (Table 5-6). Sufficient data were not available to develop alternative targets for any of the CGUs however the descriptive expectations depict the anticipated trends. Since sand size particles take 10 years or more to move through the basin, and gravels and cobbles take 40 to more than 150 years, changes in bed load in response to changes in sediment inputs should not be expected in the near term.

Table 5- 5: Summary of current and expected bedload sediment conditions.

CGU	Current Sediment Conditions	Future Expectation
C1	Does not meet PFC targets.	May possibly meet targets, especially in the upper South Fork.
U1	Does not meet PFC targets.	Not likely to meet, even with reductions in sediment except in pockets.
MS1	Meets of nearly meets PFC targets except in bars.	PFC targets should be attainable although interannual variability in climate and sediment inputs will occasionally result in years where targets are not met.
MS2	% fines are met. d84 is close. d50 is not met.	Given the size of material that is delivered to this unit, it is doubtful that the D50 target will ever be met.
MS3	Does not meet PFC targets.	Unit is slough-like and is not expected to meet PFC targets. Expectation is that it will always be sand rich with pockets of gravel.
CG	Almost meets PFC targets.	Uncertain whether targets can be met. Upper reaches are more likely to meet them.
GG	Does not meet PFC targets.	Landslide will continue to dominate this unit. PFC targets are not expected to be met.

5.2.2 LWD

The Signatory Review Team and analysts discussed what constitutes Poor, Fair, and Good instream LWD levels. The PFC matrix only provides guidance on what constitutes good habitat. Since the watershed analysis methods require that poor and fair habitat conditions be determined, most of the discussion focused on what constitutes poor and fair conditions.

Through our discussion and review of the LWD inventory data analysis, it was agreed that pieces of LWD that were >1 ft in diameter and >1 bankfull width long were capable of functioning in all channel widths in the Watershed Analysis Unit (WAU). This is supported by the data (see Section 4.5.8). Therefore, it was agreed that the diameter and average length criteria in Fox (1994) would be modified to ascertain what might constitute a poor and fair LWD load. The Fox (1994) channel width and number of debris pieces per 100 ft would remain the same. Table 5-6 is the diagnostic table to be used in the analysis.

Table 5- 6: LWD diagnostic table for the Freshwater Watershed.

Channel Width (ft)	Debris per 100 feet	Poor		Fair		Good (Fox 1994)		
		Average debris diameter (inches)	Average Length (ft)	Average debris diameter (inches)	Average Length (ft)	Average debris diameter (inches)	Average Length (ft)	Average piece volume (ft^3)
15	3.3	<12”	<1 bfw	>12”	>1 bfw	16	27	35.3
20	2.5	<12”	<1 bfw	>12”	>1 bfw	22	32	88.3
25	2.0	<12”	<1 bfw	>12”	>1 bfw			
30	1.7	<12”	<1 bfw	>12”	>1 bfw			
35	1.4	<12”	<1 bfw	>12”	>1 bfw	25	59	211.9
40	1.2	<12”	<1 bfw	>12”	>1 bfw			
45	1.1	<12”	<1 bfw	>12”	>1 bfw			
50	1.0	<12”	<1 bfw	>12”	>1 bfw	28	78	317.8
55	1.0	<12”	<1 bfw	>12”	>1 bfw			
60	0.8	<12”	<1 bfw	>12”	>1 bfw			
65	0.8	<12”	<1 bfw	>12”	>1 bfw			

bfw = bankfull width

5.2.3 Shade

The PFC matrix states that at least 85% of overstory tree canopy closure shall constitute proper function. Confusion arises over where and how to measure canopy closure. There was agreement that as a stream channel widens, canopy closure decreases. This is due to the tree crowns being able to extend only so far over the channel. This pattern can be seen throughout the Humboldt Redwoods State Park along the South Fork Eel River. Through this natural process, it is possible to have old-growth conditions that do not achieve the PFC target. Generally, managers find it easier to measure canopy closure from within the riparian zone itself than in the stream, therefore, the SRT decided that canopy closure should be measured from within the riparian zone. The logic behind this is if you have a permanent 30-ft no-cut zone along a Class I watercourse (as PALCO's HCP provides) and good closure within this riparian zone, the over-stream canopy closure will be protected.

How should the riparian canopy closure be measured? It is very difficult to measure only the overstory canopy with the tools available today. In addition, other protocols in the HCP require the use of spherical densiometers. Spherical densiometers measure the amount of shade (or light) hitting the ground from an arc of sky through vertical and angular perspective. It was decided that measurements would take place within the riparian zone (30-50 ft from edge of channel) with a spherical densiometer.

Subsequent discussions have focused on the inadequacy of the 85% canopy closure target as a measure of shade. The stream does not "see" the 85% canopy closure within the riparian area. Other measures that reflect the amount of heating of the stream would be more desirable. The 85% target has also been discussed. Old-growth redwood forests seldom meet this target; hence, the target may reflect an unattainable condition in some redwood stands.

As is discussed at length in the Riparian Module Report, Freshwater Creek meets the PFC targets for stream temperature. Shade has little effect on this situation. The choice of preferred targets and the measures to be used to determine if those targets are met deserve further discussion prior to completing additional analysis for basins outside of the fog belt.

5.3 WATERSHED CONDITION ASSESSMENT

5.3.1 Resource Situation

The Riparian, Mass Wasting, Surface Erosion, Hydrology, and portions of the Stream Channel Module Reports provide information on the effect of management on the inputs of wood, heat or energy, sediment, and flow to various portions of the watershed. The Fish, Amphibian, and Stream Channel Module Reports provide information on the current condition of aquatic resources and the effects of sediment and flow changes due to management on channel condition. The vulnerability calls identify channel segments that are vulnerable to changes in inputs of wood, energy, sediment, and flow. Linkage of this information is necessary to determine which changes in inputs associated with management activities are having impacts on aquatic resources or have the potential to impact aquatic resources and where. Once these linkages have been identified, situations that are impacting aquatic resources can be identified and addressed. Each management effect that has been linked to an aquatic resource effect is summarized in a Causal Mechanism Report (Section 5.4) and will subsequently be addressed through the prescription writing process.

None of the effects of inputs act independently. For instance, LWD was determined to be of particular importance in the CGUs dominated by the Wildcat geologic group because an important function of wood in these channels is the storage and sorting of sediments. The effects of various inputs and the interaction between inputs are addressed in the discussion below. Pertinent interactions are included in the discussions of each input.

Fine Sediment in the Bedload

Evidence of excess fines in gravels and habitat simplification in areas of fine sediment accumulation (especially where LWD levels are low) were identified as the primary limiting factor affecting fish production (Fisheries Assessment Report). The abundance of fine sediment was identified as a probable effect on amphibian habitat as well. Fine sediment reduces the quality of spawning gravel and can also fill pools. Fine sediment can clog interstitial spaces that are important to these species. Excess accumulations of fine sediment were found in numerous locations in the watershed (Section 4.5). Several other channels that currently have good spawning habitat were also identified as potentially vulnerable to increases in fine sediment loads (Section 5.1).

Fine sediment may also be contributing to aggradation of mainstem reaches, resulting in increased potential for flooding within the floodplain area (Section 4.5). This flooding has the potential to affect private property on the floodplain.

Channel segments most vulnerable to changes in sediment loads are the lower gradient segments where sediments tend to deposit (Section 4.5). Such channels tend to be the primary salmon spawning and rearing areas (Section 4.6) and include the area of the mainstem where flooding is of concern. The segments that were given a high vulnerability rating to fine sediment inputs include MS1, MS3, C1, and Graham Gulch (Table 5-1). All others were found to moderately vulnerable to fine sediments, except the steeper segments in the unconsolidated CGU group (U3 and U4) and the larger C3 channels.

Given the fine-grained character of the bedrock in the watershed, both mass wasting and surface erosion inputs contribute large portions of fine sediment. The portion of the sediment input that is silt and clay (the very fine particles <0.075mm; roughly 70% of the sediment inputs during the period from 1988-1997) tends to transport as wash load and has little effect on the accumulation of fines. Some portion of the sand fraction (including particles ≥0.075 mm-0.85mm) also transports as suspended sediment. Approximately 50% of the remaining sediment inputs in the 1988 to 1997 period were fine enough to affect the quality of spawning gravels and potentially fill pools.

Due to the transport of sediment to downstream resources, channel segments vulnerable to changes in sediment loads can be impacted by sediment inputs anywhere upstream of those channel segments. Since the mainstem reaches are among the reaches that are vulnerable to inputs of fine sediment, sediment inputs from virtually anywhere in the basin have the potential to affect channel conditions and, therefore, aquatic resources in these areas.

The one possible exception is the School Forest subbasin. The vulnerability of stream segments in this subbasin to sediment inputs are low to moderate and sediment from this basin routes to the lower end of MS3, thereby affecting only a small portion of a highly vulnerable stream segment. Hence, sediment inputs would not be expected to have as great an effect on aquatic resources as in other subbasins where sediment inputs are routed to larger lengths of vulnerable stream reaches. MS3 is, however, one of the segments where flooding is of concern. The impacts of sediment inputs from School Forest, therefore, cannot be discounted.

Sediment inputs likely to have the greatest effect on aquatic resources are those that deliver to or are routed to not only the mainstem subbasins but also other channel segments that are highly vulnerable to changes in sediment inputs. These subbasins include the entire basin except McCready Gulch, School Forest, and the lower half of Little Freshwater.

Given that all sediment inputs eventually route to areas that were given high vulnerability calls for fine sediment, no differentiation in area of input was made. Inputs in all locations were assumed to eventually have the potential to impact vulnerable aquatic resources.

The primary source of sediment in the watershed is roads, both through surface erosion and road-triggered landslides (Section 4.5). These sources accounted for 88% of the total management inputs in the period from 1988 to 1997. Therefore, roads are the primary source of management-related effect regarding sediment inputs in the basin. The factors affecting inputs are discussed in Section 4.0.

Shallow landslides associated with harvest activities also contribute somewhat to the total sediment load. Where road surface erosion tends to be a continuous sediment input, varying primarily in response to rainfall, landslides tend to be episodic events that occur more frequently during major storm events and deliver locally larger volumes of sediment. Shallow landslides associated with roads accounted for 8.6% of the total sediment delivered to streams from 1988 to 1997. Areas with high to moderate landslide potential are scattered throughout the watershed (Mass Wasting Module Report).

Management activities did not affect any deep-seated landslides that delivered to streams in the watershed. Management activities may, however, have contributed to the remobilization of deep-seated slides that did not deliver to streams (Mass Wasting Module Report). Therefore, some potential for remobilizing deep-seated slides exists. Deep-seated slides tend to deliver very large quantities of sediment to streams and often persist for years. Once remobilized, a deep-seated landslide can have long-term effects on aquatic resources. Therefore, the potential to remobilize deep-seated landslides is also considered a potential source of sediment, at least locally. Locations of deep-seated slides are found throughout the basin (Mass Wasting Module Report). The primary management-related activity that can contribute to remobilization of these slides is cutting the toe of the slide (e.g., by road building), thereby reducing the physical support of the landslide material.

All of these potential sources of sediment either have or could potentially contribute to the fine sediment situation in the basin. Therefore, each of these mechanisms was forwarded for inclusion in the Causal Mechanism Reports (Section 5.4).

Coarse Sediment Inputs

Generally, inputs of coarse sediment in the basin were not found to have a significant effect on aquatic resources. Coarse sediment in the basin is limited by the paucity of large-grained material present in the local bedrock. This situation is particularly pronounced where Wildcat geology is dominant. There are, however, exceptions to this trend. Graham Gulch was identified as an area where coarse sediment is currently excessive and additional inputs would tend to further degrade habitat (Section 5.1). This is the area dominated by a deep-seated landslide. The C1 channels were identified as areas where additions of coarse material could potentially overwhelm habitat. These channels are heavily used by spawning fish and there is some evidence of localized areas of aggradation, particularly in the South Fork Freshwater. The upper reaches of Cloney Gulch are currently providing good spawning habitat, but potential to overwhelm that habitat with excess inputs of coarse sediment was also identified. Each of these areas was given a high vulnerability call for inputs of coarse sediment. C2 channels and the smaller C3 channels were given moderate vulnerability calls. The reasoning for the calls was similar, although the potential for effect was not felt to be as great since these channels are steeper and more efficient at routing coarse sediment.

Accumulation of coarse sediment was also identified as a potential factor that could lead to bed aggradation in MS2 and MS3 (Section 5.1). In MS2, localized sediment accumulation is potentially affecting flood frequency, which impacts private property on the floodplain. This effect is amplified by the interaction between increased peak flows and sediment deposition. There is also evidence that aggradation is contributing to the simplification of the channel, which reduces pool volume. This latter situation is further aggravated by the paucity of wood in MS2 and MS3, which contributes to the low pool counts and volumes. Independent of changes in peak flows, the coarse sediment inputs to this reach were determined to have a moderate effect on the potential for bed aggradation, but when the cumulative effects of fine and coarse sediment and the interaction between flows and sediment transport was considered, the potential effect is increased.

Inputs of coarse sediment originate in steeper areas dominated by Franciscan geology (Figure 5). The Wildcat geology contains only a very small portion of sediments of this size fraction (Section 2.3). Although bank erosion can mobilize sediments of the coarse size fraction, the primary source is landslides. Therefore, the primary sources of coarse sediment are the lands with higher probability of landsliding where Franciscan geology is present (Mass Wasting Module Report). These areas include the steeper portions of roughly the upper two-thirds of Graham Gulch, Coney Gulch, and Upper Mainstem subbasins, and the headwaters of the South Fork Freshwater subbasin (Figure 5). The areas of greatest concern are mapped and presented in the Mass Wasting Module Report. Also included in the areas of concern are deep-seated landslides in the Franciscan geology that could potentially be remobilized.

Management activities that could potentially contribute to landslides and/or the remobilization of deep-seated slides are the same as discussed under fine sediment in the previous section. The considerations discussed here are also recognized in the Causal Mechanism Reports that address activities potentially affecting landslide frequency. The concerns regarding the additional effects of coarse sediment could potentially be interpreted to mean that landslides in Franciscan geology have a greater overall effect on resources than those in Wildcat geology. However, the fine sediment effects in the basin are far greater than the coarse sediment concerns. Therefore, the additional potential coarse sediment effects increase the concern in Franciscan geology only slightly, if at all.

Peak Flows

In many areas of the western United States, increases in peak flows have been linked to scour of redds. In the Freshwater Watershed, several CGUs were given a moderate vulnerability rating to increases in peak flows. Increases in peak flows associated with management practices were not found to be of sufficient magnitude to significantly affect the frequency of redd scour (Section 4.5.7).

Additional potential avenues for effects of increased peak flow include increases in bank erosion (C3S, C4, MS2), erosion of fine beds (which may be offset by presence of abundant wood, U1, U2), effects on holding ability of fish during winter in areas with little winter habitat (CG), and erosion of the toe of the slide material in Graham Gulch. The effect of each of these additional avenues tends to increase with the magnitude of the flood event. Very frequent but small flow events (those that occur on average four times a year) are estimated to have increased in magnitude between 6 to 20% as a result of management activities. However, the magnitude of effect decreases rapidly with increases in the size of flow event. The 15-year event is estimated to have been increased by only 1 to 3%. Larger events will be increased by even smaller amounts. Since the effect on peak flows on the large events that are most likely to generate problems with bank and bed erosion and winter habitat is very small, it was concluded that a Causal Mechanism Report addressing peak flow effects on aquatic organisms was unnecessary.

Increases in peak flows also work synergistically with sediment inputs (Section 4.5.5) to effect flooding potential in the lower basin. Although the contribution of peak flow increases to the flooding situation in the lower mainstem is small relative to the potential effects of sediment aggradation, those increases can potentially have a significant effect on flood frequency on the mainstem floodplain. Aggradation in mainstem reaches is locally evident, and, as noted in the discussion on channels, appears to be a relatively modest 0.6 ft in the past 50+ years. In addition, natural sources have contributed to any such aggradation. Management activities have been identified that can contribute to peak flow increases including:

- Decreased channel capacity as a result of sediment inputs (primary factor).
- Forest harvest effects on canopy interception and evapotranspiration.

- Conversion of formerly forested areas to non-forest land uses. (Primarily applies to non-PALCO lands).
- Compaction of soils that reduce water infiltration rates.
- Road drainage features that transport water quickly to streams.

Given the potential management-related effects of changes in peak flows on lower mainstem flood frequency, it was determined that a Causal Mechanism Report should be written to address this situation. It may be possible that the long-term risks of flooding can be reduced by modifications of sediment inputs alone, but given the sediment transport times involved (a scale of decades – see Stream Channel Assessment) it is unlikely. The issue clearly cannot be addressed by modification of the peak flow situation alone.

Key factors that may affect the prescriptions that are written include:

- Recovery of hydrologic maturity occurs approximately linearly at the rate of 8% per year.
- Although changes in peak flow due to harvest are not permanent, they may persist long enough for the channels to adjust to the impacted regime. This would reduce the impacts on peak flows over time. Conversion of lands to non-forested land uses is relatively permanent in nature; hence, the impacts of these activities may decrease over time as the channels adjust to the modified flow regime.
- The limited extent to which the road system is connected to the stream system in the Freshwater Watershed has resulted in a relatively small increase in the effective drainage density (0-24% for any given HAU, median value of 6%). Estimated road drainage effects are therefore probably overestimated.

No Causal Mechanism Report was written for other areas of the watershed since no significant linkage was found between the magnitude of peak flow increases and resource effects.

Suspended Sediment (Turbidity)

An assessment of the effects of management on turbidity and subsequent effects on fish populations was conducted (Fisheries Assessment Report). The results of the analysis are applicable only to the point where data was collected on the lower mainstem. Assessments in other subbasins have not been conducted. The assessment found that behavioral and mild sublethal stressful conditions likely occur during some peak flow conditions; however, no conditions measured were of adequate duration or concentration to lead to direct mortality or deficits in growth. Exposure durations have been generally less than 24 hours and, at the concentrations measured, should not result in biological impairment. Most such exposures occur during periods of low water temperatures when the metabolic rates of fish are low and the likelihood of behavioral or physiological impairment is reduced.

Given this low level of effect, no Causal Mechanism Report was written to address this specific issue. The team noted, however, that reductions in sediment that may be brought about in prescriptions addressing the fine sediment issues described above will also tend to reduce turbidity.

Large Woody Debris

Large woody debris (LWD) is abundant throughout most of the watershed, with the exception of the lower mainstem (Table 4-16). The lower mainstem is among the most important salmon habitat areas in the watershed. The low abundance of LWD in these channels has contributed to simplification of habitat. These areas are the primary holding areas for upstream migrating salmon. Deep holding pools are important to these fish. Although a few deep pools were found in these reaches, the numbers are likely lower than would be present if wood was more abundant. Wood would also facilitate the sorting of sediments in these reaches and may improve the quantity of spawning habitat. Additionally, wood would provide cover for juveniles. Because wood depletion rates are higher in MS1 due to greater scour during peak flows, pool frequency and depth may degrade within the next 20 years due to depletion of LWD outpacing inputs (Section 4.4). The gradual reduction of LWD could also reduce spawning habitat due to the sediment storage and sorting function of LWD in MS1. Winter rearing habitat may also be reduced as complex LWD is depleted.

Because of the importance of these channels to salmon in the basin and the role that wood could potentially play in improving the habitat available to fish, the low abundance of wood in these channels was identified as the second-most important limiting factor to the production of salmon in the watershed (Fisheries Assessment Report).

PALCO does not own the riparian areas that would contribute LWD to these reaches; hence, the situation described cannot be addressed within the scope of the HCP. The Assessment Team decided to write a Resource Sensitivity Report for this situation to document this very significant land use affect. The Prescription Team does not address Resource Sensitivity Reports.

In the rest of the watershed, current wood loads are good. Vulnerability of various CGUs to wood inputs, however, is not equal throughout the watershed. In general, the unconsolidated units are more vulnerable to reductions in wood than consolidated units (Section 5.1). This situation arises because the unconsolidated units have few sources of boulders and other hard material that provide the structure that forces pools and helps sort substrate materials. These unconsolidated channels are also more dependent upon wood to maintain bed stability and reduce potential for bed erosion. In addition, wood plays an important role in the development of salmonid habitat. Hence, wood is of particular importance in channels that are important to fish.

CGUs determined to have the highest vulnerability to reductions in wood loads were C1 (important spawning and rearing habitat), U1, U2, U3, MS1, and MS2 (Table 5-1). The latter two are covered under the Resource Sensitivity Report described above. All other CGUs, with the exception of C4, were determined to have moderate vulnerability to changes in LWD. In CGU C4, roots from riparian trees, stumps, and understory vegetation were found to be more important to the structural integrity of the channels than LWD lying in and spanning the channels (Section 5.1). Boulders also provide a lot of the function that wood provides in other areas.

Short-term and long-term wood recruitment potential is also good along the majority of the streams. With the exception of mixed conifer hardwood stands and hardwood dominated stands, current conifer densities range from 80.7 to 163.6 trees per acre (tpa) which is roughly 1.5 to 3 times as many trees as are found in the old-growth forests of lower Redwood Creek (Tables 4-8 and 4-9).

The majority of the riparian stands in the Freshwater Watershed (73% of stands along Class I and II streams and 54% of the stands along Class III streams) currently provide good near-term and long-term LWD recruitment per the definitions of functional wood described by Fox (1994).

Three stand conditions were identified that will provide limited wood recruitment into the future. These include stands mapped as young riparian stands, sparse/open stands, and mixed redwood/hardwood and hardwood stands (Riparian Module Report).

Young riparian stands are found adjacent to approximately 4% of the Class I and II streams. Harvest in these areas within the last 30 years has resulted in moderate to dense redwood dominated stands with a quadratic mean diameter (QMD) of 15.7 inches. These stands will provide limited recruitment opportunities for key piece LWD to stream channels in CGUs with an average bankfull width of ≥20 ft during the next 20 years.

Near-term recruitment potential for sparse and open redwood stands is poor, but long-term recruitment potential is good. Past harvests that encroached on the riparian areas and residential development led to sparse and open redwood stands adjacent to 4% of Class I streambanks and 6% of Class II streambanks. Such stands had a QMD of 16.1 inches. These stands will provide reduced recruitment opportunities for key piece LWD to stream channels in CGUs with an average bankfull width of $\geq$20 ft during the next 40 years.

Mixed redwood/hardwood and hardwood riparian stands will have poor LWD recruitment potential in the next 40 years or longer. These areas occur primarily in the lower Freshwater basin and uppermost portions of the upper Freshwater subbasin outside of PALCO ownership. There are also several small areas on PALCO land in this condition.

Harvest within these three stand types will tend to further reduce future LWD recruitment potential. However, the Assessment Team recognized that stand densities could affect the rate of growth of redwood stands. Hence, opportunities may exist to enhance the growth rate of trees within these riparian areas that currently have limited recruitment potential by, for example, thinning. These three situations are described and treated within a Causal Mechanism Report. The report includes information on growth and recruitment to aid the Prescription Team.

The Assessment Team also recognized that future harvest in riparian stands that currently have good LDW recruitment potential could affect near-term and long-term wood recruitment. It was determined that these stands would also be addressed in a Causal Mechanism Report.

Finally, the Assessment Team recognized that wood function in Class III streams represented a unique situation. In these areas, roots, small shrubs, and branch fall may provide the needed structure to minimize bank and bed erosion and provide cover for amphibians. Therefore, Class III streams were treated in a separate CMR.

Important considerations for the development of prescriptions include the recruitment distance from the stream, the growth rates of trees as a function of species, size and density, and processes through which trees are recruited. This information is provided as supporting information in the Causal Mechanism Reports. The Assessment Team recognized that the Prescription Team might request additional information during the prescription development process.

Temperature

Temperature standards as described in the PFC matrix are currently being met throughout the basin. Shade along the streams may have local effects on temperature but is not affecting whether the temperature standard is being met. Hence, no Causal Mechanism Report addressing shade was determined to be warranted.

Migration Barriers

No migration barriers were found on PALCO’s land; hence, no need to write a Causal Mechanism Report was identified. There are, however, three barriers on County roads. These barriers are a potentially significant limitation on the distribution of fish, at least seasonally. In the interest of completeness, a Resource Sensitivity Report will be written covering this situation. The Prescription Team will not address this situation.

5.3.2 Summary of Cumulative Effects

Interpretation of the cumulative effects of inputs on aquatic resources in the Freshwater Watershed was fairly straightforward. Alternative hypotheses explaining observations were not identified for most situations regarding aquatic species. The two primary situations of concern regarding aquatic species in the Freshwater Watershed are: (1) the accumulation of fine sediment in gravels and pools, which reduces the quality and quantity of spawning and rearing habitat; and (2) the lack of LWD in the channel and the lack of LWD recruitment potential along MS1, MS2, and, to a lesser extent, MS3. The accumulation of fine sediments can be linked to several erosion processes that are cumulatively affected by management activities. The lack of LWD in MS1, MS2, and MS3 is due to activities of downstream landowners and is not related to forest management by PALCO.

Pool and wood frequency in the watershed upstream of the lower mainstem are in good condition. Wood recruitment potential is high in most areas. With the exception of the sediment situation, the quality of habitat was found to be unusually good relative to what is normally seen in managed forest watersheds in the Pacific Northwest. The riparian Causal Mechanism Reports were written toward maintaining the quality of habitat by ensuring a continuous supply of wood recruitment over time. One Causal Mechanism Report was written to address the small percentage of riparian areas that were not providing sufficient long-term LWD recruitment, and a second Causal Mechanism Report was written to ensure that the current good recruitment potential is maintained.

Interpretation of data regarding the cumulative effects of management on flooding potential along the lower mainstem of Freshwater Creek was less clear. In many cases, the data were found to be conflicting. Coarse sediment seems to be accumulating in at least localized areas of MS2, which is acting in concert with increases in peak flows to increase the likelihood of overbank flooding of the floodplain. Yet in other areas of MS2, bedrock outcrops are present, indicating scour rather than aggradation. Similarly, the sediment involved derives from both natural and management-related sources; determining the relative role of each is difficult, especially since much of the sediment is believed to have entered the stream network decades ago. The situation is also not clear in MS3. Due to the low gradient of the channel, sediment would be expected to accumulate in this reach. Sediment routing analysis, however, suggests that sediment transport capacity in this reach is relatively high and appears to have adequate capacity to transport the sediment it receives. Despite this mixed evidence, it was concluded that MS3 is prone to sedimentation and aggradation. Details of this are found in the Stream Channel Assessment Report.

5.4 CAUSAL MECHANISM REPORTS

Causal Mechanism Reports (CMRs) and Resource Sensitivity Reports (RSRs) were developed as part of the Freshwater Watershed Analysis. The CMRs address specific resource situations on PALCO land, while the RSRs address resource situations that are not within PALCO's ownership. The CMRs address the areas identified as creating significant effects on aquatic resources including mass wasting, surface erosion, hydrology effects, and riparian management. Section 6.3.2.2 of the HCP states:

"Watershed analysis may modify the following elements of the Aquatics Conservation Plan: hillslope management prescriptions; channel migration zone prescriptions; Class I, Class II, and Class III RMZ prescriptions; the disturbance index; and monitoring."

Given this language from the HCP it is possible not all the CMRs included in this document will be addressed in prescriptions.

5.4.1 Sediment-Related CMRs

A sediment input budget was prepared for the Freshwater Watershed to provide an indication of the relative magnitude of sediment inputs to streams from different management and background sources. The sediment inputs for the most recent period (1988-1997) provide an indication of the relative magnitude, as well as the grain size of sediment inputs from different sources under modern forest practices (Figure 35, Figure 19 and Table 4-3). It should be noted that forest practices during this period were governed by California Forest Practice rules; future actions in the watershed will be controlled by the HCP agreement, which is more restrictive and should reduce sediment inputs.

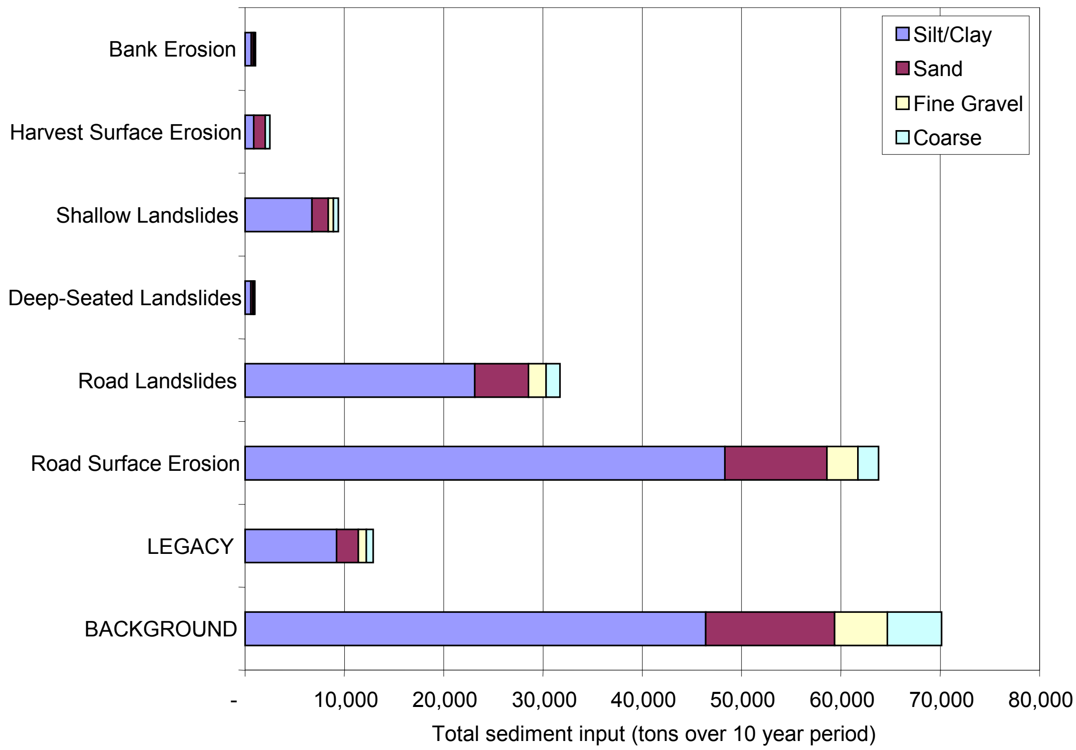


Figure 35: Sediment input to Freshwater Watershed from different sources, 1988-1997.

The majority of sediment supplied to the Freshwater Watershed is silt, clay, and sand-sized as a result of the very fine-grained nature of the underlying geologic units. Total input from background sources is an average of 7,000 tons/year; an additional 1,300 tons/year is contributed from ongoing erosion associated with pre-1974 "legacy" practices such as tractor yarding up streams that are no longer used. This legacy component would increase substantially if sediment from historically constructed roads was included within that category. Sediment sources from recent management activities are dominated by road-related sediment. Road surface erosion and road-related landslides provide an estimated average of 9,500 tons/year to the watershed. Harvest-related shallow landslides are the next largest contributor of management sources, although at 940 tons/year it is a relatively small input; harvest-related surface erosion is also a relatively minor component with 250 tons/year. Management-related inputs from large, deep-seated slides and bank erosion are relatively insignificant.

Based on the Surface Erosion, Mass Wasting, and Stream Channel Reports, as well as discussions with the fish and amphibian analysts during the Synthesis process, three surface erosion CMRs and five mass wasting CMRs were developed to address sediment inputs that had links to critical downstream channel or aquatic resources. These CMRs covered all management-related sediment inputs regardless of the magnitude of the input in relation to other sediment sources. The Prescription Team has kept the relative inputs from each source in mind when determining how to address each CMR. The ultimate goal of the prescriptions is to reduce sediment inputs that are affecting channel aggradation and fish and amphibian habitat. Or, to use the HCP's language, the prescriptions resulting from a watershed analysis must always be designed to achieve, over time, or maintain a properly functioning aquatic habitat condition. The Prescription Team found that this standard could be accomplished without developing unique prescriptions for all eight CMRs.

These CMRs also address the potential for increased flooding in the lower mainstem of the Freshwater Watershed. This potential is related to a combined influence of fine and coarse sediment inputs and peak flows. The Prescription Team kept these types of interactions in mind as they addressed the situations presented in the CMRs.

The Prescription Team was aware that the mapping of mass wasting hazard areas may not be precise. An on the ground review of any area may reveal areas of higher or lower hazard within any given mapped unit. For instance, there may be areas of moderate or high hazard within the mapped low hazard area. Thus, the mass wasting prescriptions incorporate a site specific checklist to ensure that local landslide hazards are identified and evaluated.

SURFACE EROSION 1: ROAD SURFACE EROSION AND ROAD GULLIES

Resource Situation: Surface erosion from road segments that drain to streams (Map B-8 in Appendix B: Surface Erosion Module Report) delivers sediment to streams and can increase turbidity and fine sediment loads. In addition, road gullies resulting from stream diversions or washouts at stream crossings deliver sediment to streams (noted on Map B-8; see also PWA Sediment Source Investigation for Freshwater Creek, Table 27 and associated database for road locations and more detail).

Resource Sensitivity: Fine sediment is accumulating in some channel segments, filling pools and clogging gravel. Pool filling reduces rearing habitat, and high fine sediment loads in gravel has been documented to reduce fish embryo survival from egg to emergence. Fine sediment may also accumulate in gravels and cobbles in amphibian habitat, filling interstitial spaces and reducing available habitat. Turbidity reduces feeding efficiency and may result in sub-lethal effects in fish, amphibians, and other aquatic organisms.

Management-Related Contributing Factors:

<u>Road Surface Erosion:</u>

- Length of road and portions of road prism (ditch, tread, cutslope) that drain to streams. This is the primary determinant of how much surface erosion from roads actually gets delivered to streams.
- Road use by log trucks, and to a lesser degree cars and pickups, increases sediment production. Higher traffic levels on mainline roads results in high sediment production.
- The type of road surfacing affects erosion rates - gravel surfacing reduces erosion by about 80% compared to native surfaced roads. Good quality (durable) gravel produces less sediment than softer gravel surfacing.
- Use when the road is wet increases erosion due to pumping of fines and disturbance of the road surface by traffic.

<u>Road Gullies and Washouts:</u>

- Undersized stream crossing culverts and those with a high plug potential can result in gullies or washouts during large storm events.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability
Vulnerability of spawning habitat:

High: CGUs C1, MS1, GG, MS3

Moderate: CGUs C2, C3S, C4, U1, U2, MS2, CG

Hazard Rating: High

Target Habitat Diagnostics: PFC matrix with caveats discussed in Section 5.2

Additional Comments:

Sediment inputs to streams in the watershed are the primary habitat concern. Surface erosion from roads is estimated to be the largest contributor to the management related sediment load (see Figure 34 and Table 4-3). Surface erosion is a chronic sediment source; it occurs every year during rainfall events (unlike mass wasting, which is more episodic).

All sediment eroded from road segments that drain directly to streams is delivered to that stream. Sediment from roads that drain to the forest floor via cross drains or driveable dips gets filtered by vegetation and does not all deliver to the stream. The percent of sediment delivered to a stream decreases with distance between the road drain and the stream, increased vegetation cover, and decreasing hillslope gradient. Thus, the length and location of road segments that deliver to streams are the primary determinant of how much surface erosion from roads actually gets delivered.

Sediment delivery from individual road segments has been estimated. A small portion of the road system is responsible for the majority of the sediment delivered to streams. Map B-8 depicts the relative contribution of each road segment to the total sediment inputs related to road erosion. The spreadsheet appended to the Surface Erosion Report provides detailed information for each road segment, indicating the specific contributing factors (traffic rates, surfacing, length) for each road segment.

The amount of sediment delivered to streams from road gullies and washouts is relatively small but is an episodic sediment source. The PWA Sediment Source Investigation details road crossings prone to plugging or gullying (Pages 76-85).

SURFACE EROSION 2: HARVEST UNIT SKID TRAIL EROSION

Resource Situation: Surface erosion from skid trails that deliver sediment to streams can increase turbidity and fine sediment loads.

Resource Sensitivity: Fine sediment is accumulating in some channel segments, filling pools and clogging gravel. Pool filling reduces rearing habitat, and high fine sediment loads in gravel has been documented to reduce fish embryo survival from egg to emergence. Fine sediment may also accumulate in gravels and cobbles in amphibian habitat, filling interstitial spaces and reducing available habitat. Turbidity reduces feeding efficiency and may result in sub-lethal effects in fish, amphibians, and other aquatic organisms.

Management-Related Contributing Factors:

- Blading skid trails removes the protective duff and organic soil layers; recent tractor harvest units have had approximately 15% of the harvest unit disturbed by skid trails (high density of skid trails).
- Tractor skidding compacts fine-grained soils.
- Tractor skidding on slopes over about 20% can result in rill and gully development.
- Waterbars constructed on fine-grained, erodible soils (particularly those derived from Wildcat) are easily eroded, then cease to function effectively to divert water.
- Direct delivery of sediment from a skid trail can occur where the skid trail drains to a stream (Class I, II, or III) or to a road ditch that drains to a stream.
- Fine-grained soils in the watershed contain high amounts of silt and clay (Wildcat 78% silt/clay and Franciscan 58% silt/clay) that remain in suspension in runoff during large storm events. These fine-grained sediments are not as easily filtered out by vegetative buffers as larger sand particles, so delivery of a portion of the sediment eroded from skid trails can take place through buffers, particularly on steeper slopes (over 30%).

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability:

Vulnerability of spawning habitat:

High: CGUs C1, MS1, GG, MS3
Moderate: CGUs C2, C3S, C4, U1, U2, MS2, CG

Hazard Rating: Moderate (low proportion of the total sediment inputs, high probability of occurrence).

Target Habitat Diagnostics: PFC matrix with caveats discussed in Section 5.2

Additional Comments:

- Sediment inputs to streams in the watershed are the primary habitat concern. Surface erosion from timber harvest is a small but widely distributed input source of sediment (Figure 34; Table 4-3). There is a fairly high degree of uncertainty in absolute amounts of harvest-related surface erosion, so despite the fact that it is predicted to be a relatively small source of sediment, it was forwarded as a CMR. See the Surface Erosion module for a detailed discussion of the sources of uncertainty.

- Skid trails revegetate fairly quickly in the Freshwater Creek Watershed, and surface erosion decreases with increasing vegetative cover. Most skid trails observed in the field had 90-100% revegetation 10 years after harvest (in-unit revegetation occurs more quickly).

- Skid trails observed on steeper (over 30%) slopes in Wildcat were eroded down to bare mineral soil after 3-4 years. Whether or not this sediment reached a stream, the loss of the productive portion of the soil profile from 15% of a unit during a single rotation should be considered from a site productivity standpoint during individual THPs.

SURFACE EROSION 3: SURFACE EROSION ASSOCIATED WITH BURNING HARVEST UNITS

Resource Situation: Surface erosion from intense broadcast burning or pile burning of clearcut units to prepare the site for regeneration can deliver sediment to streams and increase turbidity and fine sediment loads.

Resource Sensitivity: Fine sediment is accumulating in some channel segments, filling pools and clogging gravel. Pool filling reduces rearing habitat, and high fine sediment loads in gravel have been documented to reduce fish embryo survival from egg to emergence. Fine sediment may also accumulate in gravels and cobbles in amphibian habitat, filling interstitial spaces and reducing available habitat. Turbidity reduces feeding efficiency and may result in sub-lethal effects in fish, amphibians, and other aquatic organisms.

Management-Related Contributing Factors:

- Intense (hot) burns can remove most vegetative and litter cover that protects the soil from erosion and can occasionally result in hydrophobic soils.

- Raking for pile burning mechanically disturbs the soil; subsequent burning of the unit further reduces vegetative and litter cover, and the combined effect is 80-90 % soil disturbance.

- Tractor yarding paths in units that are subsequently burned provide compacted areas and additional bare soil (cumulative contributing factor).

- Fall burns allow little time for protective vegetation to grow prior to the fall/winter rains.

- Fine-grained soils in the watershed contain high amounts of silt and clay (Wildcat 78% silt/clay and Franciscan 58% silt/clay) that remain in suspension in runoff during large storm events. These fine-grained sediments are not as easily filtered out by vegetative buffers as larger sand particles, so delivery of a portion of the sediment eroded from intense burns can take place through buffers, particularly on steeper slopes (over 30%) or if runoff is concentrated by site topography or management practices.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability:

Vulnerability of spawning habitat:
High: CGUs C1, MS1, GG, MS3
Moderate: CGUs C2, C3S, C4, U1, U2, MS2, CG

Hazard Rating: Moderate

Target Habitat Diagnostics: PFC matrix with caveats discussed in Section 5.2.

Additional Comments:

- Sediment inputs to streams are the primary habitat concern. Surface erosion from burning is a relatively small input source of sediment.

- Although small relative to the total sediment budget, burning can create significant local effects. Accumulations of fine sediment have been observed in channels downstream of burned areas.

- Less intense burns result in more litter left on the ground to protect the soil, and less erosion; light broadcast burning of cable or helicopter yarded units results in minimal erosion and delivery of sediment.

- Spring burns allow a growing season for burned units to begin to revegetate prior to fall/winter rains.

MASS WASTING 1: LARGE, DEEP-SEATED LANDSLIDES

Resource Situation: Large, deep-seated landslides occur throughout the watershed and are associated with numerous landforms. The majority of these features are dormant (inactive) or relict. One large feature in Graham Gulch (this feature may consist of several smaller landslides) and another in the upper reaches of the mainstem of Freshwater Creek are the dominant active deep-seated landslides. There are also several smaller, active deep-seated landslides. The locations of and hazard rankings for these deep-seated landslides (about 241) are depicted on Map A5 (Appendix A-Mass Wasting Module Report).

Resource Sensitivity: Sediment inputs from stable, deep-seated landslides are small. If deep-seated landslides are reactivated, as is the case for the landslide mass in Graham Gulch, sediment can be delivered in a large “pulse” followed by persistent surface erosion and sediment delivery for a period of time until the landslide ceases to move and the face of the slide is revegetated. Within a valley floor, stream channels can be shifted by these landslides, temporarily damming or partially damming streams. Sediment inputs from deep-seated landslides can result in the following resource responses:

- Fine sediment accumulations fill pools and interstitial spaces in spawning gravel. Filling of pools reduces the available rearing and overwintering habitat. Accumulations of fine sediment in gravel potentially reduce survival of eggs to emergence. This sediment may also accumulate in gravels and cobbles in amphibian habitat, filling interstitial spaces and reducing available habitat.

- Coarse sediment contributes to channel aggradation but can also provide a source of gravel suitable for spawning habitat.

- Turbidity resulting from fine sediment introduced into streams reduces feeding efficiency and may result in sub-lethal effects on fish, amphibians, and other aquatic organisms.

- Coarse woody debris introduced into streams by deep-seated landslides contributes to channel and habitat complexity.

Possible Management-Related Contributing Factors:

Management activities with at least some potential to reactivate large deep-seated landslides include:

1. Road cuts or other excavations that intersect the toe of the slope may remove toe support for the upslope landslide mass and may initiate or accelerate movement in the landslide mass. This is a rare occurrence but can result in substantial inputs if the potential is not addressed.

2. Overloading the slope with very large quantities of material such as debris from quarrying activities. Small amounts of sidecast typically do not result in landslide reactivation or acceleration. This is a very rare occurrence but could result in substantial inputs should it occur.

3. Increases in the water content of the landslide mass related to roads or harvest, particularly at the head of the landslide area. This is a very rare occurrence but could result in substantial inputs should it occur.

Delivered Hazard Rating and Vulnerability:

<u>Resource Vulnerability</u>:

Vulnerability to coarse sediment:
High: C1 in South Fork, MS2, MS3, GG, and CG
Moderate: CGUs MS1, C1 channels except those in the South Fork, C2, C3S

Vulnerability to fine sediment:
High: CGUs C1, MS1, GG, MS3
Moderate: CGUs C2, C3S, C4, U1, U2, MS2, CG

<u>Hazard Rating</u>: High for the active landslides in Graham Gulch and Upper Freshwater; Moderate elsewhere.

Target Habitat Diagnostics: PFC matrix with caveats discussed in Section 5.2.

Additional Comments:

- Deep-seated landslides are rarely influenced by normal forest management activities. As far as can be determined, all the mapped deep-seated landslides in Freshwater are natural features with the exception of the landslide that was remobilized by overloading a slope with quarry material.

- Most deep-seated landslides in the watershed are dormant or relict features. There is very little evidence that many of the deep-seated landslides in the watershed have reactivated during the last 50 to 60 years. This holds true for areas that have been intensively managed as well as for areas where little management has taken place.

- The faces of reactivated slides will continue to input sediment through surface erosion until the slide area is revegetated sufficiently to stop that erosion.

- It is possible that temporary increases in soil moisture following harvest will slightly increase the susceptibility of the hillslope to sliding in wet years.

- The boundaries of these landslide features have been determined from aerial photos, they have not been mapped in the field, nor can they be mapped precisely in the field; the boundaries of these features on the map should be considered approximate.

MASS WASTING 2: VERY HIGH HAZARD MORPHOLOGIC LANDFORM UNITS

Resource Situation: Morphologic landform units 3 and 6 (Appendix A: Mass Wasting Module Report, Attachment A-1) have a very high hazard rating for road failure and road-related shallow landslides (see the Empirical Landslide Delivery; Road Landslides, Map A-8). These map units include all planar steep and headwall landforms with potential to produce road-related shallow landslides that will deliver to streams (0.18-0.23 landslides/100 feet of road). There are no map areas classified as a very high hazard for shallow hillslope landslides in the Freshwater Watershed.

Resource Sensitivity: Sediment inputs are delivered in a "pulse" followed by persistent erosion for a short period of time (generally less than 5 years) until the landslide surface revegetates. Sediment inputs from landslides can result in the following resource responses:

- Within valley floors, short sections of stream channel can be infilled and/or very occasionally shifted by these landslides. Temporary damming of streams can occur. These effects are most common in first and second order stream reaches rather than valley floor streams.

- Fine sediment accumulations can fill pools and interstitial spaces in spawning gravel. Filling of pools reduces the available rearing and overwintering habitat. Accumulations of fine sediments in spawning gravels can reduce survival of eggs to emergence. This sediment may also accumulate in gravel in amphibian habitat, filling interstitial spaces and reducing available habitat.

- Coarse sediment contributes to channel aggradation but also provides a source for gravel suitable for spawning habitat.

- Turbidity resulting from fine sediment introduced into streams reduces feeding efficiency and may result in sub-lethal effects in fish, amphibians, and other aquatic organisms.

- Where coarse woody debris is introduced into streams through landslides, it contributes to channel and habitat complexity, and also retards erosion of the landslide mass and transport of sediment downstream.

Possible Management-Related Contributing Factors:

- Surface and subsurface water concentrated by the road network and diverted onto adjacent slopes may contribute to the initiation of shallow landslides within harvest units by saturating native soils (this is a generalized field observation and is not specifically documented in the data set).
- Oversteepened fill slopes (>55%).
- Overloading of native slopes and soils by road fill materials.
- Loss of toe support at road cuts or where streams undercut road fills.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability:

Vulnerability to coarse sediment:
High: C1 in South Fork, MS2, MS3, GG, and CG
Moderate: CGUs MS1, C1 channels except those in the South Fork, C2, C3S

Vulnerability to fine sediment:
High: CGUs C1, MS1, GG, MS3
Moderate: CGUs C2, C3S, C4, U1, U2, MS2, CG

Hazard Rating: Very High.

Target Habitat Diagnostics: PFC targets with caveats discussed in Section 5.2.

Discussion and Recommendations:

- See the Freshwater MLU descriptions in Attachments A-1 and A-2 of the Mass Wasting Module for details on the various landforms.

- Delineation of landform boundary and landslide locations is dependent on the resolution of the topographic maps used for this purpose. Hence, there will likely be minor inclusions of high, moderate, and gently sloping areas or other terrain within some of these map units. Accurate delineation of landform types and boundaries should be determined in the field. Similarly, accurate determinations of likely landslide runout distances and delivery potential require site specific review.

- Landslides can result in site loss or at least some short- to medium-term degradation of soil productivity.

- The faces of reactivated slides will continue to input sediment through surface erosion until the slide area is revegetated sufficiently to stop that erosion.

- Road fills built on slopes steeper than 55% within these very high hazard areas are not likely to be stable in the long-term. Full bench construction or designed fills will likely be required for >55% slopes to maintain stable roadways within these very high hazard areas. The choice of full bench and end haul or engineered structures will be dependent on the soils and stability conditions upslope and downslope of individual road design sections.

- On-site geologic assessments for road locations and older roads within areas mapped as having a very high road landslide hazard may be advisable. These on-site geologic assessments should follow the procedures outlined in the CDMG's note 45 for engineering geologic assessments.

MASS WASTING 3: HIGH HAZARD MORPHOLOGIC LANDFORM UNITS

Resource Situation:

Hillslope Landslides

High hillslope landslide hazard map units (hillslope units 1, 3, 6, 8, and 9) have a high hazard rating for hillslope failure. The Empirical Landslide Delivery; Hillslope Landslides Map (Map A-9, Appendix A: Mass Wasting Module Report) shows expected delivered landslide densities of 0.08 to 0.09 landslides/acre for high hazard units. These map units include planar steep and convex steep landforms, as well as limited numbers of headwall, convex moderate, and incised steep landforms.

Road Landslides

High road landslide hazard map units (road units 1 and 9) have a high hazard rating for road failure. The Empirical Landslide Delivery; Road Landslides Map shows expected delivered landslide densities ranging from 0.11-0.17 landslides/100 feet of road. These map units include incised steep and convex steep landforms.

Resource Sensitivity:

Sediment inputs are delivered in a “pulse” followed by persistent surface erosion for a period of time until the landslide surface revegetates. Sediment inputs from landslides can result in the following resource responses:

- Within valley floors, short sections of stream channel can be infilled and/or very occasionally shifted by these landslides. Temporary damming of streams can occur. These effects are most common in first and second order stream reaches rather than valley floor streams.

- Fine sediment accumulation fills pools and interstitial spaces in spawning gravel. Filling of pools reduces the available rearing and overwintering habitat. Accumulations of fines in gravel potentially reduce survival of eggs to emergence. This sediment may also accumulate in gravel in amphibian habitat, filling interstitial spaces and reducing available habitat.

- Coarse sediment contributes to channel aggradation, but it also provides a source for gravel suitable for spawning habitat.

- Turbidity resulting from fine sediments introduced into streams reduces feeding efficiency and may result in sub-lethal effects in fish, amphibians, and other aquatic organisms.

- Where coarse woody debris is recruited to streams through landslides, it contributes to channel and habitat complexity and retards downstream movement of sediment.

Possible Management-Related Contributing Factors:

<u>Hillslope Landslides</u>

- Loss of root strength following harvesting can reduce apparent soil shear strength, primarily in Douglas-fir dominated stands and to a lesser degree in redwood dominated stands.

- Short-term increases in growing season soil moisture contents following harvesting or due to loss of canopy may contribute to increases in pore water pressure.

<u>Road Landslides</u>

- Surface and subsurface water concentrated by the road network and diverted onto the adjacent slope may contribute to the initiation of shallow landslides within harvest units by saturating native soils (this is a generalized field observation and is not specifically documented in the data set).

- Oversteeped fill slopes (>55%).

- Over loading of native slopes and soils by road fill materials.

- Loss of toe support at road cuts or where streams undercut road fills.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability:

Vulnerability to coarse sediment:
High: C1 in South Fork, MS2, MS3, GG, and CG
Moderate: CGUs MS1, C1 channels except those in the South Fork, C2, C3S

Vulnerability to fine sediment:
High: CGUs C1, MS1, GG, MS3
Moderate: CGUs C2, C3S, C4, U1, U2, MS2, CG

Hazard Rating: High

Target Habitat Diagnostics: PFC Matrix with caveats discussed in Section 5.2

Additional Comments:

- See the Freshwater MLU descriptions in Attachment A-1 and Appendix B of the Mass Wasting Module for details on these landforms.

- In general, about 40% of the total volume of landslides reaching streams is injected into stream channels or is deposited in the riparian zone alongside streams. In smaller first and second order streams, much of this material is deposited in the riparian zone adjacent to the channel and may or may not be entrained and transported downstream. The incorporation of wood into the landslide material helps reduce the amount of sediment that is transported downstream.

- Delineation of landform boundary and landslide locations is dependent on the resolution of the topographic maps used for this purpose. Hence, there will likely be minor inclusions of moderate and gently sloping areas or other terrain within some of these map units that will have a lower potential for landslides that can be delineated during field geologic engineering assessments. Accurate delineation of landform types and boundaries should be determined in the field. Similarly, accurate determinations of likely landslide runout distances and delivery potential require site-specific review.

- Landslides can result in site loss or at least some short- to medium-term degradation of soil productivity.

- The faces of reactivated slides will continue to input sediment through surface erosion until the slide area is revegetated sufficiently to stop that erosion.

Hillslope Landslides

- Clearcut stands on some high hazard landforms will be more susceptible to hillslope landslides during very wet years with normalized rainfalls of 0.3 or greater (see the deterministic slope stability analysis section in the Mass Wasting Module Report).

- Data analyses suggest that landslide frequencies in partial cuts are similar to the background frequencies seen in older second-growth stands.

Road Landslides

- Road fills built on slopes steeper than 55% within these high hazard areas are not likely to be stable in the long-term. In these areas, full bench construction or designed fills will likely be required to maintain stable roads. The choice of full bench and end haul or engineered structures will depend on the soils and stability conditions upslope and downslope of individual road design sections.

MASS WASTING 4: MODERATE MORPHOLOGIC LANDFORM UNITS

Resource Situation: Road landslides that deliver to streams occur at a moderate rate (ranging from 0.04 to 0.08 landslides/100 ft of road) and hillslope landslides in these units that reach streams occur at a moderate rate (0.02 to 0.07 landslides/acre).

The road landslide hazard units include the convex moderate and incised moderate landforms where the maximum DEM slope exceeds 32 degrees and all planar moderate landforms (Units 2, 5, and 8). Refer to the map entitled Empirical Landslide delivery; Road Landslides (Map A-8, Appendix A: Mass Wasting Module Report).

The in-unit landslide hazard units include the majority of headwall, convex moderate, and incised steep landforms as well as complex moderate, planar moderate, incised moderate, and convex gentle landforms where average map unit DEM slope angles exceed 22 degrees (Units 2, 5, 7, 11, and 12). Refer to the map entitled Empirical Landslide delivery; Hillslope Landslides.

Resource Sensitivity:

Sediment is delivered in a "pulse" followed by erosion of exposed surfaces for a limited period of time until landslide surfaces revegetate. Sediment inputs from landslides can result in the following resource responses:

- Within valley floors, short sections of stream channel can be infilled and/or very occasionally shifted by shallow landslides. Temporary damming of streams can occur. These effects are most common in first and second order stream reaches rather than valley floor streams.

- Fine sediment accumulation fills pools and interstitial spaces in spawning gravel. Filling of pools reduces the available rearing and overwintering habitat. Accumulations of fine sediments in gravel potentially reduce survival of eggs to emergence. This sediment may also accumulate in gravels in amphibian habitat, filling interstitial spaces and reducing available habitat.

- Coarse sediment contributes to channel aggradation but also provides a source for gravel suitable for spawning habitat.

- Turbidity resulting from fine sediment introduced into streams reduces feeding efficiency and may result in sub-lethal effects in fish, amphibians, and other aquatic organisms.

- Where coarse woody debris is recruited to streams through landslides, it contributes to channel and habitat complexity and can inhibit downstream transport of introduced sediment.

Possible Management-Related Contributing Factors:

Road Landslides

- Surface and subsurface water concentrated by the road network and diverted onto the adjacent slope may contribute to the initiation of shallow landslides within harvest units by saturating native soils (this is a generalized field observation and is not specifically documented in the data set).

- Oversteepen fill slopes.

Hillslope Landslides

- Factors contributing to landslides may include loss of root strength and increases in soil saturation.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability:

Vulnerability to coarse sediment:
High: C1 in South Fork, MS2, MS3, GG, and CG
Moderate: CGUs MS1, C1 channels except those in the South Fork, C2, C3S

Vulnerability to fine sediment:
High: CGUs C1, MS1, GG, MS3
Moderate: CGUs C2, C3S, C4, U1, U2, MS2, CG

Hazard Rating: Moderate

Target Habitat Diagnostics: PFC Matrix with caveats discussed in Section 5.2.

Discussion and Recommendations:

Hillslope Landslides

- Hillslope landslide rates in these units are only slightly higher than those mapped in the low hazard units. Inputs of sediment arising from shallow hillslope landslides in these units are therefore relatively low.

- Areas within these units that are identified in the field to have characteristics of the high and/or very high hazard landforms can be expected to exhibit higher landslide frequencies if logged. Due to map resolution, inclusions of high and very high hazard landforms are likely to be found in the mapped areas. Such areas must be identified in the field during harvest unit layout and review (i.e., by site-specific).

Road Landslides

- Road related landslides are the primary concern within these units. Road landslide rates in these units are roughly 50% lower than in the high hazard units. Road landslides are most commonly observed on slopes greater than 55%.

MASS WASTING 5: LOW HAZARD MORPHOLOGIC LANDFORM UNITS

Resource Situation:

Hillslope Landslides

Low hillslope landslide hazard map units have a low hazard rating for hillslope failure (the Empirical Landslide Delivery Hillslope Landslides Map depicts expected landslide delivery densities ranging from 0.0 to 0.01 landslides/acre for low hazard units).

Road Landslides

Low road landslide hazard map units have a low empirical and stochastic hazard rating for road failure (the Empirical Landslide Delivery Road Landslides Map depicts expected landslide delivery densities varying from 0.00 to 0.03 landslides/100 ft of road for low hazard units).

Resource Sensitivity:

The input of sediment from landslides in these areas is very low. No appreciable effects on resources occur as a result of the few slides that occur.

Possible Management-Related Contributing Factors:

Management-related activities that contribute to landslides in these areas are very rare.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability:

Vulnerability to coarse sediment:
High: C1 in South Fork, MS2, MS3, GG, and CG
Moderate: CGUs MS1, C1 channels except those in the South Fork, C2, C3S

Vulnerability to fine sediment:
High: CGUs C1, MS1, GG, MS3
Moderate: CGUs C2, C3S, C4, U1, U2, MS2, CG

Hazard Rating: Low

Target Habitat Diagnostics: PFC matrix with caveats discussed in Section 5.2.

Discussion and Recommendations:

- There are a limited number of landslides occurring in this hazard class. It is likely that a number of these landslides occur on minor inclusions of steeper slopes within the low hazard map units that were too small to map or recognize at the map scale utilized for the study. These areas will be visible in the field and can be recognized by foresters during harvest unit layout.

5.4.2 LWD Related CMRs

The primary limiting factor for salmon populations in the Freshwater Watershed is the high levels of fine sediment in the basin and their effects on spawning and rearing habitat in the basin. This situation is addressed in the sediment related CMRs. The next most important limiting factor if the paucity of wood in the lower mainstem of the river. The riparian areas along the affected stream segments are not owned by PALCO; hence, this situation will not be addressed. A Resource Sensitivity Report (RSR) was, however, written to document this situation.

In addition to the RSR, three Causal Mechanism Reports have been written. These address: (1) situations where riparian stands meet the PFC target, (2) sparse/open and young riparian stands, and (3) LWD in Class III streams. Wood in virtually all the streams adjacent to stands addressed these three CMRs meets or exceeds the Fox criteria in the PFC targets.

LWD RECRUITMENT 1: RIPARIAN STANDS PROVIDING TARGET LWD

Resource Situation: Riparian areas within 100 ft of Class I and II streams are moderately to densely stocked with redwood-dominated conifers with a QMD $\geq$20 inches for 54% and 84% of the Class I and Class II stream length, respectively (Riparian Situation 1 (RWD5) and 2 (RWD4): Map 4: Appendix D: Riparian Function Module Report). The total LWD and key piece LWD in the adjacent channels currently meets or exceeds that necessary to maintain properly functioning conditions for aquatic habitat for fish and amphibians.

Resource Sensitivity: In Class I streams, LWD is important for salmonid fisheries due to its role in sorting sediment, stabilizing spawning gravel, and formation of pool and cover habitats. Complex LWD provides high flow velocity refugia, which is a critical element of winter rearing habitat. LWD maintains amphibian habitat directly by providing habitat and indirectly by allowing sediments to sort, providing the coarse substrates necessary for amphibian species in Class II streams. Adequate LWD directly provides habitat in the form of interstitial spaces used by amphibians as shelter. More indirectly, LWD affects the channel habitat as sediment particle size sorts around the obstructions provided by individual pieces and debris jams.

Bank stability is partially dependent upon root strength within 0-30 ft of the bankfull channel. Streambank vegetation reduces the size and frequency of small landslides triggered by bank erosion in geomorphic units with consolidated geology (bedrock also contributes to bank stability in C1). Within unconsolidated geomorphic units, root strength is an important factor in minimizing bank erosion. Roots from trees, stumps, and understory vegetation can also provide channel structure in smaller streams (CGU C4, U4).

Triggering Mechanisms:

Management including harvest that maintains sufficient stocking of conifer at a key piece size. Future management scenarios have the potential to affect stocking densities of target size wood.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability:	High (C1, U1, U2, U3)
	Moderate (C2, C3, U4, GG, CG)

Low (C4)

Delivered Hazard Rating: Currently low. Future scenarios could affect call.

Target Habitat Diagnostics: Equal or greater than target piece size as described in Fox (1994).

Additional Comments:

See Attachment B and Section 4.5.8 for summary discussion of LWD processes in the watershed.

LWD RECRUITMENT 2: SPARSE/OPEN & YOUNG RIPARIAN STANDS

Resource Situation:

A. **Young Riparian Stands -** Harvesting adjacent to approximately 4% of Class I and II stream riparian stands within the last 30 years resulted in moderate to dense redwood-dominated stands with a QMD of 15.7 inches. These stands will provide limited recruitment opportunities for key piece LWD to stream channels in CGUs with an average bankfull width of ≥20 ft during the next 20 years. Roughly 3-8 trees per acre >40 inch diameter will typically occur in these stands during the next 40 years; existing pieces of very large wood (>40 in. diameter) in the channel and riparian zone are expected to remain for at least a century, at which time these stands will contain redwoods within larger size classes.

B. **Sparse/Open Stands -** Partial and clearcut harvests that encroached on the riparian areas adjacent to 4% of Class I streambanks and 6% of Class II streambanks throughout the basin as well as residential development in the lower Freshwater Watershed resulted in redwood-dominated stands with a QMD of 16.1 inches. These stands will provide limited recruitment opportunities for key piece LWD to stream channels in CGUs with an average bankfull width of ≥20 ft during the next 40 years. Opportunities for recruitment of very large wood (>40 in. dbh) will remain limited by less than 5 trees per acre in this size class for at least the next 50 years or longer assuming no silvicultural management.

C. **Mixed Redwood/Hardwood and Hardwood Riparian Stands** are present locally on PALCO lands and dominate in many of the stream zones downstream of PALCO's ownership; these stands have a QMD of 17.8 inches, and the stocking of key piece size conifers will remain relatively low (<17 tpa at >22 in. dbh) for the next 40 years or longer. These stands contain few, if any, larger diameter (>40 in. dbh) trees.

Resource Sensitivity: Large woody debris is critical for providing quality fish habitat in Class I streams and quality amphibian habitat in Class II streams. LWD in sufficient abundance in these areas influences the development of pools that provide summer and winter rearing habitats and the step-pool habitat preferred by amphibians. It also influences the sorting of bedloads and directly provides amphibian habitat in the form of interstitial spaces.

Bank stability is partially dependent on root strength within 0-30 ft of the bankfull channel. Streambank vegetation reduces the size and frequency of small landslides triggered by bank erosion in geomorphic units with consolidated geology (bedrock also contributes to bank stability in C1). Within unconsolidated geomorphic units, root strength is an important factor in minimizing bank erosion. Roots from trees, stumps, and understory vegetation can also provide channel structure in smaller streams (CGU C4, U4).

Triggering Mechanisms:

<u>Young stands (RDW 2/3: Riparian situation 3)</u> – past clearcut harvest adjacent to or near Class I and II channels.

<u>Sparse/Open stands (RDW SP: Riparian situation 4)</u>
Class I streams: Percent of total streambank length

- Pre-1974 clear cuts in the riparian area; (0.7%)
- Buffers less than distance measured: (2.7%)
- Partial Cut: (0.5%)
- Other harvest: (1.7%)

Class II streams: Percent of total streambank length

- Buffers less than distance measured; (5%)
- Partial cut; (0.8%)

<u>Mixed and Hardwood Stands (RDW CH and H and G -no trees)</u>

- Historical harvesting along stream sections 502 and 503 (see Riparian Module Report) favored hardwood regeneration on moist terraces.
- Small streambank slides and channel disturbance at the confluence of some headwater channels.
- Large earthflow on Graham Gulch.

Delivered Hazard Rating and Vulnerability:

<u>Resource Vulnerability</u>:	High (C1, U1, U2, U3)
	Mod (C2, C3, U4, GG, CG)
	Low (C4)
<u>Delivered Hazard Rating</u>:	High

Target Habitat Diagnostics: Equal or greater than target piece size as described in Fox (1994).

Additional Comments:

1. For streams adjacent to young redwood stands, sparse/open redwood riparian stands, and hardwood-dominated stands in the upper Freshwater sub-basin, the rate of recruitment of trees to the channel will likely be less than in-channel LWD depletion rates until future stand growth provides increased recruitment opportunities.

2. Graham Gulch is representative of this riparian situation on PALCO lands. Although the current riparian stands may not be sufficiently stocked with key pieces diameter trees, the channel LWD rating is good. Approximately 65% of the pools in Graham Gulch are wood formed, and 100% of the pools have wood associated with them.

3. Within the mixed stands (RDW/HWD), conifers (redwood and some Douglas-fir) comprise an average of 23% of the trees per acre and 64% of the basal area. Vine maple and shrubby willows were not included since they do not contribute to LWD.

4. See additional comments in Section 4.5.8 and Attachment B.

LWD RECRUITMENT 3: LWD FUNCTION FOR CLASS III STREAMS

Resource Situation: Riparian condition adjacent to approximately 83% of the Class III channels is comprised of redwood-dominated stands with a QMD >20 inches [riparian situation 1 (RWD5) and situation 2 (RWD4)]. Elsewhere, riparian areas along Class III streams have an average QMD of 16 inches [11% in riparian situation 3 (RWD2/3 – young stands) and 7% in riparian situation 4 (RWD WP – sparse to open stands)]. Current and future LWD recruitment potential is good for all these situations since the functional size of woody debris in these small streams is smaller. Larger pieces of wood tend to span small channels and therefore provide less immediate function.

Resource Sensitivity: Wood of all sizes and roots provide a roughness element, especially in unconsolidated channel geomorphic units where boulder roughness is lacking. Wood may temporarily store sediment in some channel segments and can minimize headcutting/downcutting, especially in CGUs C4 and U3. Deeply incised channels, particularly in U3 and U4 channels, can limit wood access to the active channel, reducing wood function. Roots from trees, stumps, and understory vegetation can provide sufficient armoring to prevent cutting in many such channels. Bank vegetation is important for bank integrity of unconsolidated CGUs. Low-growing bank vegetation also provides filtration of sediment eroded from uphill slopes.

Triggering Mechanisms:

- Future equipment causing ground disturbance on streambanks.
- Future clearcut harvesting adjacent to streams.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability:	High (C1, U1, U2, U3) Moderate (C2, C3, U4, GG, CG) Low (C4)
Delivered Hazard Rating:	Low

Target Habitat Diagnostics: Good to excellent streambank stability as measured by streambanks that are less than 10% unvegetated.

Additional Comments:

1. Branch fall and streambank roots from trees, stumps, and streamside vegetation provide functions of wood in these small channels. The root diameter for conifers is approximately equal to the crown diameter (i.e., 30 ft or less).

2. Low growing vegetation (e.g., grasses and low shrubs) is sufficient to filter sediment. The distance required to provide adequate filtration is dependent upon the slope adjacent to the stream and the amount of sediment to be filtered.

RESOURCE SENSITIVITY REPORT LWD RECRUITMENT 4: HARDWOOD & MIXED HARDWOOD RIPARIAN STANDS IN LOWER FRESHWATER

Resource Situation: Hardwood riparian stands and predominantly shrub vegetated riparian reaches in lower MS1, MS2, and MS3 lack conifers >28 in. dbh that can provide recruitment of key piece size LWD to the channel. The channel is capable of transporting even large wood pieces. LWD is currently below target levels.

Resource Sensitivity: Lack of LWD in the lower mainstem reaches was identified as the 2nd most important factor limiting salmon production in the Freshwater Watershed.

An increase in wood would help to trap and sort gravels, thereby improving spawning habitat. Increases in the amount of wood would cause scour and create pool habitat (which is currently limited in MS2 but not MS3) and provide cover in the form of jams. Jams would tend to result in avulsion and further development of pools. Riparian vegetation can play a substantial role in bank stability in this unit; however, there is little evidence of historical bank erosion. Winter rearing habitat may be reduced as complex LWD jams are depleted.

Triggering Mechanisms:

- Residential development in MS1, MS2, MS3.
- Physical removal of wood from streams.
- Tidal lands downstream of Three Corners in MS3 naturally have a limited ability to support trees.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability: High for MS1 and MS2; Moderate for MS3
Delivered Hazard Rating: High

Target Habitat Diagnostics: Equal or greater than the target piece size: 25 in. diameter in MS1 and 28 in. diameter in MS2 and MS3. 1-2 key pieces per 100 ft stream length.

Additional Comments:

1. LWD volume is relatively low in MS1 due to the high flows flushing pieces out of the CGU, the lack wood recruitment potential in the form of large trees in the riparian areas, and removal and modification by residents. Most pools are the result of corner or bedrock scour. The LWD that is large enough to remain stable provides valuable habitat for spawning and rearing salmonids.

2. Streambank slides are not a wood recruitment mechanism in lower Freshwater, but bank undercutting and flooding are relatively more important recruitment mechanisms in this sub-basin.

3. Because depletion rates are higher in MS1 than in other stream segments, pool frequency and depth may degrade within the next 20 years due to depletion of LWD outpacing inputs. The gradual reduction of LWD could also reduce spawning habitat due to the sediment storage and sorting function of LWD in MS1. Winter rearing habitat may be reduced as complex LWD is depleted. Elsewhere, the amount of wood existing in the channel can be expected to maintain spawning and pool rearing habitat until the adjacent stands are capable of providing an ongoing source of key piece size LWD.

HYDROLOGY 1: FLOODING

Resource Situation: The magnitude of flood-producing peak flows (i.e., peak flows of a magnitude large enough to cause over-bank flooding, generally having a recurrence interval of 2 years, and often greater) has increased along the mainstem of Freshwater Creek in the Lower Freshwater due to forest harvesting (both clear- and partial-cut) over the past 14 years and other land use activities in all portions of the watershed. Increases in the 2-year recurrence interval event are on average approximately 10% (increases vary from 7-21% for any given storm event dependent on antecedent wetness conditions), while the 15-year recurrence interval event has increased on average approximately 2% (varying from 1-3% for any given storm). These increases are likely conservative (i.e., high) given the analytical approaches used. Although these increases in flood magnitude may not be significant in and of themselves, the combination of increased flood magnitudes and localized areas of channel aggradation has decreased the recurrence interval of overbank flooding in some areas of Lower Freshwater Creek.

Resource Sensitivity: Increased flood magnitudes and decreased channel capacity result in an increased probability of flooding of some residential property located on the Freshwater Creek floodplain in the Lower Freshwater Creek sub-basin. The peak flow effects work synergistically with bed aggradation related to sediment inputs.

Management-Related Triggering Mechanisms:

1. Decreased Channel Capacity (see supporting information for details)

2. Forest Harvest:

Forest harvesting (both clear- and partial-cut and clearing for roads) over the past 14 years, both within the Lower Freshwater sub-basin and in upstream sub-basins, has resulted in reduced canopy interception during storm events and reduced evapotranspiration during the growing season (resulting in relatively higher soil moisture levels in harvest areas at the start of the storm season).

Future harvest has the potential to further reduce canopy interception during storm events and reduce evapotranspiration during the growing season. However, any impacts from future harvest may be mitigated or totally offset by recovery of older harvest units (recovery occurs approximately linearly at the rate of 8% per year).

Although changes in peak flow due to harvest are not permanent, they may persist long enough for the channels to adjust to the impacted regime. This would reduce the impacts on peak flows over time.

3. Conversion of Formerly Forested Areas to Non-Forest Areas:

Past conversion of formerly forested areas to other non-forested land uses (agricultural, residential, powerline right-of-way, and roads) has also resulted in reduced canopy interception during storm events and reduced evapotranspiration during the growing season. Due to the relatively permanent nature of these conversions, the impacts on peak flows may decrease over time as the channels adjust to the impacted flow regime.

Future conversion of currently forested areas to other non-forested land uses has the potential to further reduce canopy interception during storm events and evapotranspiration during the growing season. Over time, the impacts on peak flows may decrease as the channels adjust to the impacted flow regime; however, in the short term any additional land conversions will impact peak flows.

<u>Other land uses</u>: Modeling results indicate an approximate 3% increase in the magnitude of the 2- to 15-year peak flow events in the Lower Freshwater sub-basin due to past conversion to other land uses (agricultural, residential, powerline right-of-way, and roads) within and upstream of the sub-basin. Future conversions may result in further increases.

4. Compaction:

Forest lands: The methodology used to assess forest harvest effects on peak flows includes the effects of ground-based yarding on soil compaction, as this methodology was adapted from the North Fork Caspar study where the amount of area tractor yarded ranged from 2 to 39% of the area among the ten treatment sub-watersheds.

5. Road Drainage:

Only limited analysis was done on the possible effects of road drainage (i.e., road drainage ditches having a surface water connection with streams). These results indicate that road drainage has only a minor effect on peak flows. Modeling results are complicated by the simplifying assumption that must be made that road drainage ditches capture 100% of the water moving from upslope areas (this assumption is probably wrong given the relatively deep soil profiles in the Freshwater Watershed). The limited extent to which the road system is connected to the stream system in the Freshwater Watershed has resulted in a relatively small increase in the effective drainage density (0-24% for any given HAU, median value of 6%) as compared to other areas such as the HJ Andrews forest in the Oregon Cascades where Wemple et al. (1996) found an estimated 21 to 50% increase in the drainage density, or portions of the Deschutes River basin in the Washington Cascades where Bowling and Lettenmaier (1997) found the effective channel network density to have increased by 64 and 52% due to road construction.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability: High: CGUs MS2, MS3 Moderate: MS1
Delivered Hazard Rating: High

Target Habitat Diagnostics: N/A

Additional Comments:

- Decreased channel capacity due to aggradation is the greatest concern in evaluating potential impacts on downstream flooding; increased flow magnitudes due to harvest are secondary.

- An analysis of sediment routing indicates that much of the sediment present in areas of aggradation resulted from natural and management-related inputs 40 or more years ago. The corollary of this is that regardless of contemporary changes in sediment inputs, aggradation from historic sediment inputs could increase in the future. Similarly, the routing analysis indicates that sediment in lower Freshwater Creek may have long residence time, that is, may not be removed quickly. For these reasons, solutions to address flooding concerns in Freshwater may require active modification to the affected stream channel segments (e.g., spot dredging).

- The recent wet-weather storm cycle in the Freshwater Watershed has influenced to some extent the perception of increased flooding in the Lower Freshwater sub-basin.

- Note that with respect to this CMR, it does not matter how harvest units are arranged within a given sub-basin (e.g., all of the harvest within the Cloney Gulch sub-basin could be concentrated within one of the HAUs or distributed evenly among all 4 HAUs, and it would have the same effect on what comes out the bottom of the sub-basin). This has implications for any possible prescriptions (i.e., gives the landowner more flexibility to operate within a given sub-basin).

RESOURCE SENSITIVITY REPORT: MAN-MADE SALMONID MIGRATION BARRIERS

Resource Situation: Three road crossings in the lower reaches of McCready Gulch, Cloney Gulch, and Graham Gulch constitute either seasonal or permanent migration barriers for salmonids. The McCready Gulch crossing is located on an abandoned County road on non-PALCO private land. It is constructed of a perched concrete box culvert with a natural bottom and may block upstream juvenile migration. The Cloney Gulch County road crossing is constructed of a half-arch with a concrete floor. It is a partial barrier for adults and a complete barrier for juveniles. The Graham Gulch County road crossing is constructed of a sectional steel pipe. It is a partial barrier to adults and a complete barrier for juveniles. See Map Fisheries 1: Salmonid Distribution Map.

Resource Sensitivity: Insufficient or too high of flow through the culverts may result in denial of access to sub-basins for migrating adults and subsequently affect salmonid spawning opportunities.

Triggering Mechanisms:

- Road built prior to understanding of salmonid migration needs.
- Crossings targeted for eventual upgrading by the county, which should improve passage.

Delivered Hazard Rating and Vulnerability:

Resource Vulnerability: Moderate

Hazard Rating: High

Target Habitat Diagnostics: Any man-made barriers present in the watershed allow upstream and downstream fish passage at all flows (NMFS 1997).

Additional Comments:

- McCready, Cloney, and Graham Gulches have been given upgrade prioritization rankings of 35, 12, and 29, respectively, by the Humboldt County Culvert Inventory and Fish Passage Evaluation project.
- Each culvert has either Washington-style baffles or inlet and outlet beams to aid fish migration.

- The migration barriers lie outside of the PALCO lands. Effects are primarily related to non-forestry land uses. No prescriptions to be written.

5.5 DISTURBANCE INDEX

The California Department of Fish and Game, NOAA Fisheries, U.S. Fish and Wildlife Service (collectively the "Wildlife Agencies") and The Pacific Lumber Company ("PALCO") reached agreement on the procedures for calculating and tracking the Disturbance Index of PALCO's Habitat Conservation Plan (HCP) within the Freshwater Creek Basin. These procedures are outlined below.

5.5.1 ASSUMPTIONS:

The disturbance index, as used here, includes estimates of sediment production and delivery from a variety of natural, and anthropogenic sources. There are areas of uncertainty associated with some of these estimates. A monitoring program for Freshwater developed by PALCO and the Wildlife Agencies has been designed largely to address these areas of uncertainty. Pending the results of such monitoring efforts, the following critical assumptions are used in the calculation of the disturbance index:

- A 20 year period was chosen for modeling harvest surface erosion because the WEPP model and field observations during the Freshwater analysis indicate that after 20 years, the forest provides 100% cover (vegetation, duff, litter, etc), and the potential, or lack of potential, for surface erosion is similar to that in an undisturbed forest.
- We chose to apply an exponential decrease to harvest surface erosion during this 20 year period because many studies have shown an exponential decrease in sediment production following disturbance. In addition, this is the type of decrease in sediment discharge shown by the WEPP modeling of the observed revegetation patterns in Freshwater following harvest.
- The rate of surface erosion discharge per unit of disturbed area over time was based on the average rates under the range of harvest methods and hillslopes modeled in the Freshwater watershed.
- After reviewing the watershed specific data and relevant literature no good models for prediction of road failures was apparent. Pending the results of the monitoring efforts noted above, we chose an even distribution of sediment savings from potential road landslides/washouts because: 1) there is an equivalent risk of a triggering storm occurring in any given year 2) it was the same period as the inputs from harvest surface erosion, and 3) a 20-year storm was a conservative

estimate of the size of storm required to initiate a potential road landslide or culvert washout. It is likely that a larger storm would be required to initiate many of the inventoried sites, since the inventory was completed in 1997, after the large storms of 1996. However, some of the sites could be initiated by smaller storms, particularly sites that are deteriorating, and therefore have increasing risk of failure over time (e.g., Humboldt Crossings).

5.5.2 DISTURBANCE INDEX CALCULATION:

A new Disturbance Index (DI) value will be calculated annually for each sub-basin using the following formula:

$$\mathrm{DI} = \left[\frac{\mathrm{DI}_{\text{Road Surf Eros}} + \mathrm{DI}_{\text{Harvest Surf Eros}} + \mathrm{DI}_{\text{Road Landslides/Gullies}} + \mathrm{DI}_{\text{Harvest (shallow) Landslides}} + \text{Legacy Inputs}}{\text{Background Sediment Input}} \right]$$

Specific details on methods/inputs for each of the factors in the above equation are as follows:

Background Sediment Input = constant based on long-term (1942-1997) average annual inputs. Values for these inputs in Freshwater are shown in Table 5-7.

Legacy Input = constant based on long-term (1942-1997) average annual inputs. Values for these inputs in Freshwater are shown in Table 5-7.

Table 5- 7. Background and Legacy Inputs (average tons/yr)

Sub-basin	**Background**	**Legacy**
Cloney Gulch	456	79
Graham Gulch	449	74
Little Freshwater	858	247
Lower Freshwater	243	139
McCready Gulch	201	82
School Forest	53	0
South Fork	861	166
Upper Freshwater	1,564	158

Total	4,685	945

Harvest Landslides = constant each calendar year, based on tons remaining from past harvest + current year

Average annual input from past harvest is assumed to decrease on a linear trend for 15 years since harvest on high hazard areas ceased. Input remaining from past years is calculated as:

Remaining from past years = (average ‘42-‘97) x Y/15

where Y = 15-# of years since 1997

(in 2002, Y=10; in 2003 Y=9)

It is anticipated that future harvest will avoid areas prone to landsliding, so that future inputs from newly harvested areas will be limited to 5 percent of the long-term (1942-1997) average. The total input from harvest landslides (past plus current year’s input) is shown in Table 5-8 and Figure 36.

Table 5- 8. Total Harvest Landslide Inputs (average tons/yr)

Sub-basin	**Average Tons/yr (1942-1997)**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**Future** (5 % of long-term average)
Cloney Gulch	22	16	14	13	11	10	8	1
Graham Gulch	212	152	138	124	110	95	81	11
Little Freshwater	208	149	135	121	107	94	80	10
Lower Freshwater	36	26	23	21	19	16	14	2
McCready Gulch	3	2	2	2	2	1	1	0
School Forest	3	2	2	2	2	1	1	0
South Fork	413	296	268	241	213	186	158	21
Upper Freshwater	480	344	312	280	248	216	184	24
Total	1,377	987	894	804	712	619	527	69

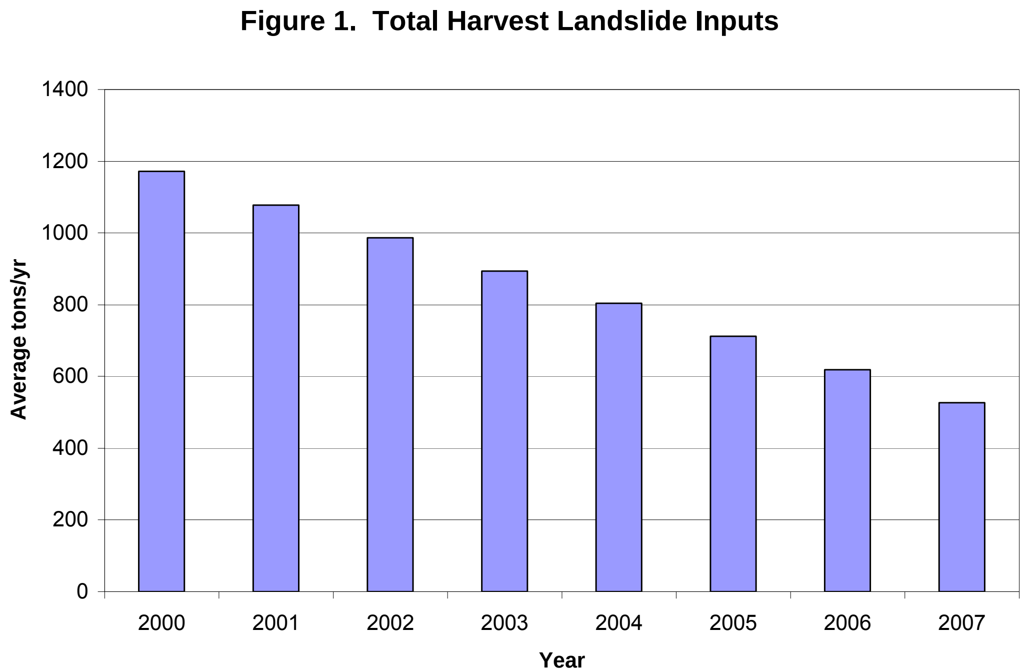


Figure 36. Total Harvest Landslide Inputs.

Harvest Surface Erosion = input remaining from 1989-99 harvest + accumulated new THPs

The amount remaining from 1989-99 harvest in Freshwater, based on the "Initial WEPP Run" calculations, is shown in Table 5-9 and Figure 37.

Table 5-9. Harvest surface erosion inputs remaining from 1988-99 harvest (average tons/yr)

Sub-basin	2000	2001	2002	2003	2004	2005	2006	2007
Cloney Gulch	61	34	19	17	17	17	17	17
Graham Gulch	40	31	22	19	14	7	7	7
Little Freshwater	52	39	31	30	29	24	24	19
Lower Freshwater	7	4	2	2	1	1	1	1
McCready Gulch	17	8	4	4	4	4	4	4
School Forest	4	2	1	1	1	1	1	1
South Fork	40	29	27	23	23	23	23	16
Upper Freshwater	50	32	21	18	17	16	16	15
Total	271	179	127	114	107	93	93	80

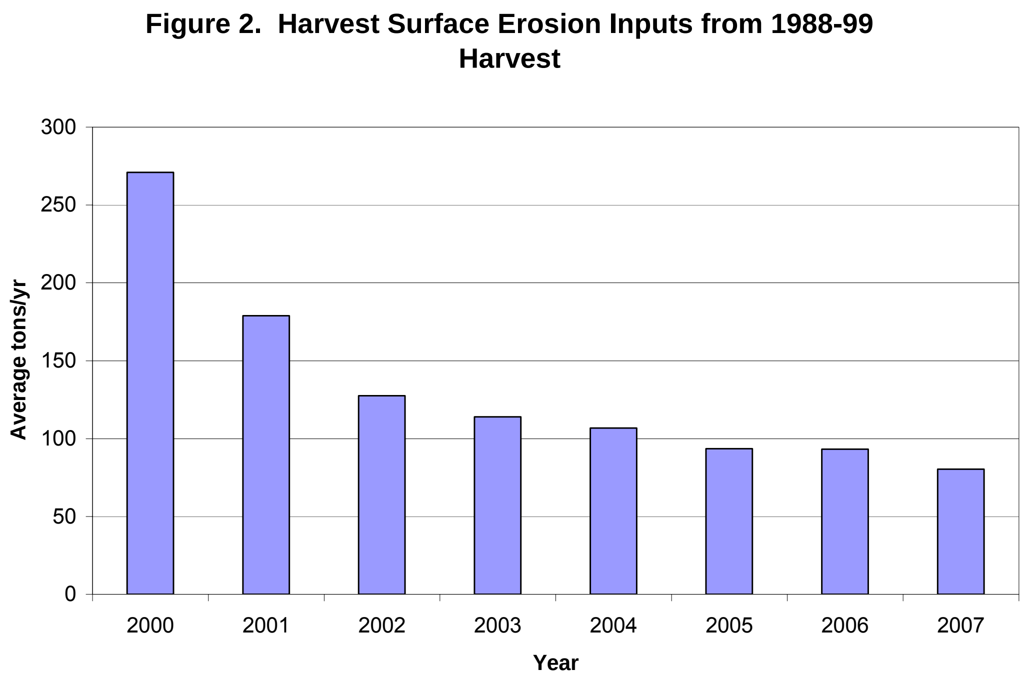


Figure 37. Harvest surface erosion inputs from 1988-99 harvest.

Harvest surface erosion from new/proposed THPs will be calculated using a GIS-based WEPP analysis similar to that used for the watershed analysis. The total input will be distributed over 20 years using a distribution similar to the average annual distribution from the watershed analysis computations (Table 5-10 and Figure 38).

Table 5-10. Distribution of Total Harvest Surface Erosion

Years after Harvest	Percent of Total Input
Year 1	20%
Year 2	14%
Year 3	9%
Year 4	7%
Year 5	5%
Year 6	4%
Year 7-20	3%

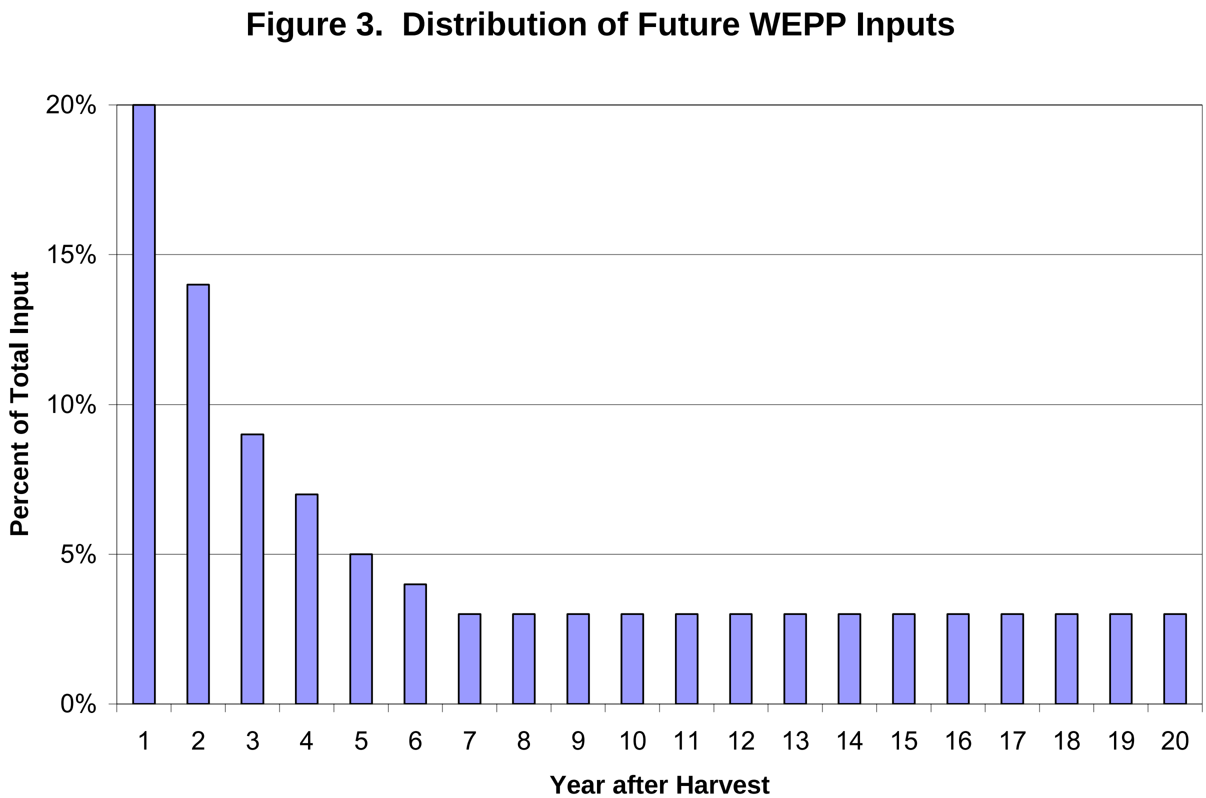


Figure 38. Distribution of future WEPP inputs.

On an annual basis the input from each harvest unit will be accumulated and added to past harvest surface erosion input. At the end of each calendar year, the DI database will be updated, and units that have been harvested will be advanced to the next year's status.

Road Landslides/Gullies

There are several challenges associated with analyzing the future sediment inputs from road landslides and gullies. In order to include the road landslides/gullies in the DI, we need to determine how much road landsliding will occur on an average annual basis. PWA identified the total potential road failure inputs during their road inventory of Freshwater. However, road landsliding is episodic, with little to no landslide input during most years followed by a large input during years with large storm events. It is not possible to know when a particular site will fail in the future. PALCO and the Wildlife Agencies agreed to initially use a procedure that distributes future road landslide inputs evenly over 20 years. However, they also agreed that this temporal allocation can be modified during that annual meeting to review/discuss the Disturbance Index.

Calculation of the 1997 (past) DI values is based on dividing the total volume of documented past input by the total time period over which those inputs occurred. A similar approach will be used for future inputs:

$$\text{Road Landslides/Gullies} = \frac{\text{Potential future inputs - }\left(\text{tons saved x 80\% effective}\right)}{\text{assumed recurrence period for landslide}}$$

In this method, the total input will be annualized by dividing it by an assumed 20-year recurrence interval. The volume associated with each road improvement (e.g. fixing PWA sites) will be subtracted from the total annualized potential input for each sub-basin. Road improvements are assumed to be 80 percent effective, so the total potential sediment savings is multiplied by 80% to get net savings. Road improvements assigned to a THP will be tracked with that THP; improvements not assigned to a THP (e.g., stormproofing activities) would be analyzed at the end of each calendar year as discussed above.

Table 5-11 shows the total potential inputs identified by the PWA inventory, with the past delivery (based on actual road landslides from 1942-1997). The average annual potential input in each sub-basin based on the assumed 20-year recurrence interval is also shown along with the past long-term average delivery (from 1942-1997) for comparison.

Table 5-11. Potential Future Inputs from Road Landslides and Gullies.

Watershed	Total Potential Future Yield (tons)	Past Delivery '42-97	Potential Future Average tons/yr*	Past Delivery Average tons/yr
Cloney Gulch	39,884	10,780	1,994	196
Graham Gulch	21,005	10,120	1,050	184
Little Freshwater	24,094	19,415	1,205	353
Mainstem Freshwater	8,280	4,400	414	80
McCready Gulch	45,754	12,925	2,288	235
School Forest	9,857	7,040	493	128
South Fork Freshwater	17,405	18,975	870	345
Upper Freshwater	23,124	28,930	1,156	526
Grand Total	189,402	112,585	9,470	2,047

* Assuming 20-year recurrence interval

The past inputs in all sub-basins are much smaller than the potential future inputs. In these sub-basins, the DI values for future calculations could be larger than "actual" DI values based on the 1997-status sediment budget if no stormproofing efforts have taken place. In fact, in Cloney and McCready Gulch the potential future inputs are so large that even if all sites identified by PWA are stormproofed, the future DI value would still be larger than the 1997 DI value that was based on actual sediment inputs (PWA identified some sites that are not treatable – these sites remain in the potential category).

6.0 REFERENCES

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ATTACHMENT A: CUMULATIVE EFFECTS ISSUES MATRIX

ATTACHMENT B: RIPARIAN CMRS SUPPORTING INFORMATION