Appendix F

Freshwater Creek Watershed Analysis

Fisheries Assessment

Review Draft

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EXECUTIVE SUMMARY

This Fisheries Assessment contributes significantly to the understanding of salmonid species distribution, instream habitat conditions, and factors limiting salmonid production within the Freshwater Creek Watershed. To develop this understanding it was necessary to collect and analyze current field and historic data from a variety of sources.

The study's findings show Freshwater Creek basin contains coho and chinook salmon, steelhead and coastal cutthroat trout. Although there is substantial overlap, chinook tend to occupy the mainstem of Freshwater Creek, with steelhead and coho in the larger tributaries and cutthroat in the smaller headwaters. In some cases cutthroat trout are located upstream of natural anadromous migration barriers, which would indicate at least some individuals of this species have residualized into a residential life history. The distribution of juvenile salmonids may be hindered by the presence of county and private road culverts downstream of PALCO land.

An analysis of the in-stream habitat data showed pool area, pool frequency, and water temperatures are at good levels. Limited large woody debris (LWD) inventory data indicated fair to good amounts of in-stream wood. Substrate shovel samples and embeddedness data analysis revealed generally poor to fair spawning habitat conditions in the WAU although there were locations with good quality gravel. The poor habitat tended to be associated with the Wildcat Geologic Formation with the fair substrate in areas influenced by Franciscan rocks. Data analysis also showed evidence of pool filling in sample reaches.

Suspended sediment conditions measured over an extended period in 1999 at the Redwood Sciences Laboratory (RSL) monitoring station in the upper Freshwater Creek mainstem exceeded modeled sublethal, principally behavioral, thresholds for salmonids during some discrete storm events. Suspended sediment conditions did not exceed lethal thresholds in any storm event modeled at this station during the period analyzed. The modeling discussed in this report suggests that suspended sediment conditions during storm events could alter behavior, although paralethal effects on growth were not predicted by the model. Further, since the majority of storm events occur during the late fall to early spring, when salmonids are not actively growing, effects of suspended sediment on feeding behavior are likely minimal.

Substrate conditions represent the primary limiting factor for salmonid production in Freshwater Creek, by affecting spawning and rearing habitat quality. Secondary factors may include the reduced amounts of LWD in some of the larger order reaches both on and off PALCO land.

RECOMMENDATIONS

Fine sediment tends to be the most detrimental fraction in stream substrate affecting salmonid production. Much of this is generated from the skid and haul road system in the watershed. Continuation of the PALCO road erosion control program should reduce the deposition of fines sediment into streams.

Consider placement of unanchored wood in streams reaches shown to be deficient in LWD to enhance that being supplied by riparian zones. These activities could be conducted during logging operations that utilize skyline cable systems, thereby avoiding heavy equipment operations in riparian zones. The Forest Practice Rules may have to be modified to accommodate projects of this type.

Continue the collection of downstream migrant trapping data especially in the mainstem Freshwater Creek to generate a better understanding of chinook spawning and rearing location.

Conduct post-watershed analysis monitoring to ascertain the effectiveness of established and proposed mitigation and enhancement measures. Such monitoring efforts could include: (1) channel cross sections and longitudinal profiles; (2) co-located turbidity and suspended sampling at multiple stations in the watershed to reflect a range in the geological, topographical, and hydrological conditions; (3) large woody debris surveys; and (4) bulk sediment samples.

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1.0 INTRODUCTION

The Fisheries Assessment of the Freshwater Creek Watershed includes the School Forest, McCready Gulch, Cloney Gulch, Graham Gulch, Upper Freshwater, South Fork Freshwater, and Little Freshwater subbasins. This analysis followed the methods and procedures outlined in Version 2 of the Methods to Complete Watershed Analysis on Pacific Lumber Company Lands in Northern California (PALCO 2000a). Some deviation from these procedures occurred where the habitat diagnostic target criteria were not applicable to the types of field data collected and/or were different from the PFC Matrix. In some cases, the PFC Matrix targets were not applicable or appropriate for use in this watershed. Therefore, watershed-specific habitat diagnostic targets that included some PFC Matrix criteria were developed through consultations with the Signatory Review Team (SRT).

The Fisheries Assessment process is designed to identify fish species present in the watershed, summarize the status of the fish populations, identify typical habitats and habitat areas of concern, discuss habitat conditions, and summarize vulnerability of habitat within the channel geomorphic units to changes in inputs that may be the result of forest practices. The following critical questions were developed to address these objectives:

Population Status and Distribution

- What is the distribution and relative abundance of salmonid fish species in the Watershed Analysis Unit (WAU)?
- Is there any evidence of change in distribution or relative abundance from historic conditions?
- What are the location and nature of migration barriers?
- Do non-native salmonids and/or exotic species that may adversely affect native salmonids occur within the watershed?

Habitat

- What are the existing habitat conditions in the WAU?
- Where are the areas of degraded fish habitat in the WAU?
- What are the potential limiting habitat factors for each life phase and each salmonid species in the WAU?
- Where are the existing or potential spawning, rearing, and holding habitat areas in the WAU for each species?

Water Quality Parameters

- Do recorded water temperatures approach or exceed stressful levels for any salmonid species or life stage?
- What information is available on the spatial and temporal distribution of turbidity and/or total suspended solids in the watershed?
- How are salmonids in the watershed likely to respond to increasing levels of turbidity/total suspended solids (TSS)?

The above critical questions that relate to water quality recognized the following assumptions:

- The ability of a waterbody to support all life stages of salmonid fishes is predicated upon water quality parameters that are within the nominal ranges tolerated by each life stage of salmonids within that waterbody.
- Water quality conditions can exhibit high natural variability between and within a watershed on the basis of local geomorphic characteristics, climate, and precipitation.
- Fish native to specific watersheds have evolved to tolerate the natural water quality conditions of the watershed prior to European settlement.

1.1 TOTAL SUSPENDED SOLIDS AND TURBIDITY ASSESSMENT OVERVIEW

One concern expressed during the development of the Watershed Analysis methods for PALCO is the potential for forestry practices to contribute sediment into the stream network above a background rate considered "normal" for the parent geology, topography, and climate within the basin of interest. Aquatic habitat can be indirectly affected by such sediment contributions through the filling of pools, the resultant widening of channel width, and the turbid conditions that may result from the sediment in suspension. Sediment may also cause direct impacts to aquatic biota through a variety of means (e.g., smothering of eggs, impaired feeding, etc.).

Some of the critical questions first posed in the Watershed Analysis Methods Manual (PALCO 2000a) were developed to frame investigations of the potential biological impacts of suspended sediment within the Freshwater Creek Watershed (see previous section). The analysis reported here attempts to address the critical questions related to suspended sediment by characterizing the frequency and magnitude of stressful or lethal suspended sediment conditions to salmonids over the period of record. This preliminary analysis represents a "first look" at the existing conditions within the basin, as measured through approximately one year of data collected by the Redwoods Sciences Lab (RSL), and modeled using a conservative risk assessment model developed initially by Newcomb and McDonald (1991). The Newcomb and McDonald model integrates exposure concentration and duration to calculate a risk number that is reflective of a range of effects endpoints that span the “no effect” to “lethal” range. By considering the annual or seasonal frequency with which suspended sediment conditions in the water column impart a risk number, it may be possible to characterize whether suspended sediment conditions within a basin have the potential to affect fish populations.

Because suspended sediment data available from the RSL monitoring station did not span the entire year for which flow and turbidity measurements were taken by the deadline for this report, the modeling results are temporally limited. As more data undergo complete quality control processing, additional evaluations will be considered. Notwithstanding, the data analyzed provide a thorough assessment of suspended sediment exposure and risk conditions over an 8-month period during hydrologic year (HY) 1999. As such, the analysis represents a significant advancement over all previous watershed analyses conducted that have attempted to address impacts to fish populations from suspended sediment.

Conclusions from the risk modeling exercise can be used to reflect general conditions of suspended sediment in the portion of the watershed where the sampling was conducted only. Although these results may also reflect conditions elsewhere in the watershed, they cannot be extrapolated to reflect the entire range of suspended sediment to which salmonids might be exposed in Freshwater Creek or its tributaries. Further, these results model effects during storms that occurred principally during winter months, when direct negative effects from suspended sediment have been shown to be reduced due to lowered metabolic rates (Sullivan references). No in-situ studies were done to directly examine fish health or behavior during the storm events for which risk endpoints were modeled. Findings of such studies might confirm or refute the findings of this modeling exercise.

Additional evaluations of turbidity were conducted in the watershed to generally characterize the conditions over the entire period of record at the RSL monitoring station. Turbidity data were not specifically used for the quantitative risk assessment, but were considered acceptable to evaluate the general relationships between: (1) turbidity and flow at the RSL monitoring station, and (2) turbidity and total suspended sediment.

2.0 METHODS

2.1 FISH POPULATIONS AND HABITAT

The analysis consisted primarily of compiling and summarizing results of fish and habitat surveys completed within the watershed. Fieldwork consisted of visiting representative reaches throughout the watershed to assess habitat conditions. Intensive habitat data collection was conducted on approximately 2.4 miles of Class I stream. Each intensive survey segment was at least 20 bankfull widths long to capture variability in the channel. Another 5.4 miles was surveyed to determine the upstream extent of fish distribution and had a reduced level of habitat data collection. Field data were entered into an Access database and analyzed by sub-basin and Channel Geomorphic Unit (CGU). A CGU is a reach or number of reaches of stream that have similar geologies and gradients. It is assumed that channels with similar physical characteristics respond similarly to inputs of wood, water, and sediment.

The methods employed for this assessment were those described in PALCO (2000a). The Fisheries Module analyst conducted many of the in-stream habitat surveys with assistance from other qualified fisheries biologist and technicians. Instream surveys typically involved data collection efforts for several assessment modules; thus, data for the habitat parameters described in PALCO (2000a), LWD inventories, barrier locations, and amphibian observations were often collected concurrently. Field data from this module in some cases led to the modification of some stream classifications. The Channel Module analysts also provided LWD inventory, channel substrate characteristics, and geologic information that proved useful during development of the biological vulnerability calls.

2.1.1 Maps

Several maps were produced as part of this analysis including;

- Fish distribution map (Map F-1)
- Stream classification map with modifications (Map F-2)
- Spawning location map (Map F-3)
- Spawning areas of concern (Map F-4)
- Summer and winter rearing areas of concern (Map F-5)
- Sampling location sites (Map F-6)

2.2 SUBSTRATE AND WATER QUALITY PARAMETERS

2.2.1 Substrate Composition

Sediment samples were collected between 1989 and 1999 using three separate methods. These included freeze cores from Barnard (1992), gravel bar samples collected by Pacific Watershed Associates (PWA) for this analysis, and shovel samples amassed as a part of the PALCO monitoring program. The differing sampling methods and locations limits comparisons between the datasets. For example, the freeze cores were sampled only in locations containing known coho redds, while the PWA samples concentrated on gravel bars, and the shovel samples were taken at random pool tails regardless of spawning activity. In addition, there may be biases associated with these sampling techniques. The gravel bar bulk samples may not contain the same substrate composition as those collected at pool tail or redd locations due to different channel hydraulics and depositional patterns. Young et al. (1991) reported that freeze cores over-sampled particles in the 25-50 mm range in their laboratory tests using known substrate compositions. Young et al. (1991) also found that freeze cores, McNeil, and shovel samples tended to under-sample particles 6.3-9.5 mm and less than 0.212 mm in diameter. The authors (Young et al. 1991) found few differences between the McNeil and shovel samples with the McNeil's producing samples that most frequently approximated the true composition. The freeze cores and gravel bar samples are also limited because they were conducted for only a single year each; therefore, trends cannot be ascertained. However, the PALCO shovel samples were conducted for one to five years depending on location, which does enable limited comparisons over a relatively short period of time. See Map F-6 for locations of sampling sites.

2.2.2 Temperature

PALCO recorded water temperatures between 1996 and 1999 at four to six stations in the watershed with automated temperature probes as part of its company-wide monitoring program. Water temperature stations were located in: (1) Upper Freshwater, approximately 8,250 ft upstream of South Fork Freshwater (Station 36); (2) Cloney Gulch, approximately 1,000 ft upstream of the confluence with Freshwater (Station 92); (3) Mainstem Freshwater, approximately 750 ft downstream of South Fork Freshwater (Station 33, no longer in use); (4) Little Freshwater, approximately 500 ft upstream of the confluence with Freshwater (Station 18); (5) Southfork Freshwater, approximately 1,000 ft upstream of the confluence with Freshwater (Station 37, no longer in use); (6) McCready Gulch, approximately 3,750 ft upstream of the confluence with Freshwater (Station 135); and (7) Southfork Freshwater, a Class II watercourse, very high up in drainage in a Class II basin. See Map F-6 for locations of sampling sites.

2.2.3 Turbidity and Total Suspended Sediment Evaluations and Relationships to the Hydrograph

Evaluations of turbidity and TSS for the Fisheries Assessment Module focused on data collected at an RSL continuous monitoring station located on Freshwater Creek at the residence of Dr. Terry Roelofs. This continuous monitoring station is located upstream of the principal tributaries draining into the system and therefore is limited in spatial coverage. Estimates of turbidity and sediment recruited into individual sub-basins are provided in the Stream Channel and Cumulative Effects reports and are not a focus of this report.

Stage/discharge relationships, hydrographs, sedigraphs, and turbidigraphs were produced from the data collected by RSL at the continuous monitoring station. These evaluations considered the period of record for which data were collected by the RSL, including roughly half of hydrologic year (HY) 1999 (January through July 1999), and data from HY 2000 (October through April 2000). Flow, stage, and turbidity measurements were calibrated by RSL for the entire period of record. Suspended sediment data that had undergone full quality control review were available for the HY 1999 data only. Some of these analyses are similar to what has been prepared by the Redwood Sciences Lab (RSL), as available for review on the Freshwater Creek web site (www.rsl.psw.fs.fed.us/projects/water/freshwater).

In addition to the development of hydrographs, sedigraphs, and turbidigraphs, we explored the relationship between rainfall and suspended sediment to ascertain to what extent a given rainfall event (i.e., storm) correlated with a given TSS concentration. For these analyses, we used the median TSS concentration, as done with the subsequent TSS risk assessment procedures (Section 2.2.4). In distributions skewed to the left (positive), such as turbidity and TSS concentrations vs. time (in individual storm events), the median provides a more conservative estimate of the typical concentration to which a fish might be exposed during the course of an entire storm.

Cumulative rainfall was calculated for each "storm" identified from the hydrograph by summing all rainfall over the period under which discharge peaked and returned to a "steady state." The effect of rainfall on streamflow was assumed to be integrated over the basin upstream of the monitoring station, although the monitoring station recorded temporally and spatially discrete rainfall events. To address the effects of rainfall on suspended sediment, it was necessary to combine some adjacent small storms identified in the hydrograph because of the lag in peak discharge following peak rainfall events. Given the highly exploratory nature of this analysis, and the necessity to capture as many data "points" for this analysis, we deviated from the requirement that data used specifically for the TSS risk assessment undergo a quality control check (Section 2.2.4). Thus, for this analysis, we also used the limited suspended sediment data from the 2000 hydrologic year as well as the earlier QA/QC'd 1999 TSS data, although a quality control check on the former data set had not been completed.

2.2.4 TSS Risk Assessment Model Application

To address the potential impacts of TSS to salmonids in the Freshwater Creek basin for this Watershed Analysis, quality controlled and checked suspended sediment data were used for the analysis of risk only (see Section 2.2.4 for full details). This requirement restricted the analysis of TSS risk to storm events that occurred between January and July 1999; suspended sediment data from 2000 HY data were not considered in the calculation of TSS risks.

The Newcomb and Jensen (1996) model, a refinement of the Newcomb and McDonald model (1991), was used to quantify the frequency of TSS exposure events that could impart a "behavioral," "sublethal," or "lethal" risk on the basis of conservative assumptions factored into the model. The model projects risk on a 15-point scale, where each numeric qualifier may be associated with potential effects (Table 2-1). The authors developed six regression equations for use in predicting risk that varied by species and/or life stage. The general equation for each equation was as follows:

$$\text{Effect Severity} = a + b(\log_e x) + c(\log_e y), \qquad [1]$$

Where a, b, and c are constants that vary dependent on the exposure group, x is the exposure duration (ED) in hours, and y is the measured suspended sediment concentration (TSS) in mg/L.

Table 2-1: Salmonid severity of effects rankings from suspended sediment.

Severity Rank	Category	Description of effect
0	Nil effect	No behavioral effects
1	Behavioral effects	Alarm reaction
2	Behavioral effects	Abandonment of cover
3	Behavioral effects	Avoidance response
4	Sublethal effects	Short-term reduction in feeding rates; short-term reduction in feeding success
5	Sublethal effects	Minor physiological stress; increase in rate of coughing; increased respiration rate
6	Sublethal effects	Minor physiological stress
7	Sublethal effects	Minor habitat degradation; impaired homing
8	Sublethal effects	Indications of major physiological stress, long-term reduction in feeding rate and success; poor condition
9	Lethal & paralethal effects	Reduced growth rate; delayed hatching; reduced fish density
10	Lethal & paralethal effects	0-20% mortality; increased predation; moderate to severe habitat degradation
11	Lethal & paralethal effects	>20-40% mortality
12	Lethal & paralethal effects	>40-60% mortality
13	Lethal & paralethal effects	>60-80% mortality
14	Lethal & paralethal effects	>80-100% mortality

We used the equation developed by Newcomb and Jensen for juvenile and adult salmonids only, as these age classes were the relevant endpoints of interest in the Watershed Analysis, and the effects of sediment on spawning habitat, represented by different risk equations, were addressed elsewhere in the Fisheries Module through an evaluation of substrate embeddedness. Other equations developed by Newcomb and Jensen were not relevant to salmonids. The general equation to calculate severity of effect for the juvenile and adult salmonid group ('group 1' in the Newcomb and Jensen model) is as follows:

$$SEV = a + b(\log_e ED) + c(\log_e TSS) \qquad [2]$$

a = 1.0642
b = 0.6068
c = 0.7384

The equation for juvenile and adult salmonid risks assumes that sediment grain sizes are between 0.5 and 250 um. The risk summary data presented are based upon estimated TSS concentrations predicted from a "LOESS" regression (LOESS = local regression) regression of actual measured data over the time period. The advantage of using the extrapolated data is that they provide for a measure over the entire data set evaluated. Without the extrapolation, such an analysis would be restricted to the select time periods when TSS measurements were made (i.e., TSS was not measured on every time point that turbidity was analyzed). See Section 5.4 for a discussion of the limitations of this approach.

3.0 SUMMARY DATA

3.1 SALMONID LIFE HISTORY REQUIREMENTS

This Fisheries Assessment focuses on instream habitat conditions influencing the growth and survival of coho (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*), steelhead/rainbow trout (*O. mykiss*), and coastal cutthroat trout. Other stream-dwelling fish such as speckled dace (*Rhinichthys osculus*), prickly sculpin (*Cottus asper*), riffle sculpin (*Cottus gulosus*), Pacific lamprey (*Lampetra tridentata*), brook lamprey (*Lampetra pacifica*), and three-spine stickleback (*Gasterosteus aculeatus*) are not addressed in this report. No non-native species were observed during the Watershed Analysis or described in any historical report. However, non-native stocks of salmon and steelhead were occasionally planted in Freshwater Creek, with eggs being supplied from hatcheries in northern California, Oregon, and Washington (Higgins 2000). Higgins (2000) also reported evidence of chum salmon (*O. keta*) and summer steelhead (*O. mykiss*) presence in Freshwater Creek as recently as the 1940s. Chum salmon are still occasionally caught and released at the Humboldt Fish Action Council's (HFAC) upstream migrant trap.

Partial barriers for upstream migrating adult salmonids and complete barriers for upstream migrating juvenile salmonids exist along the county road system in the WAU (Map F-1). There are also a number of natural barriers to anadromous migration within the WAU. However, resident rainbow and cutthroat trout have been observed above many of these barriers. Anadromous salmonids have been observed spawning below these barriers. No information regarding fish species presence in the School Forest sub-basin was found in the reference materials. In addition no fish were observed in School Forest during habitat typing, underwater snorkel, or electrofishing surveys conducted during the analysis field work.

3.1.1 Coho Salmon (*Oncorhynchus kisutch*)

Upstream adult spawning migration generally occurs from mid-October to mid-February (HFAC 1999) when water temperatures are 4-14°C (40-58ºF). Coho migrate up and spawn in streams that flow directly into the ocean or tributaries of larger rivers (Moyle et al. 1995). Coho generally spawn in smaller streams than those used by chinook. Coho preferred gravel sizes ranging from 1.3-10.2 cm. Average redd size and recommended gravel area per spawning pair are 2.8 m^2 and 11.7 m^2, respectively (Bjornn and Reiser 1991). Adults die within 10-14 days following spawning. Embryos hatch after 8 to 12 weeks of incubation and emerge from the gravel several weeks later. Studies summarized by Spence et al. (1996) stated that intergravel mortality of coho and steelhead occurs when fine sediments (<0.85 mm.) exceed 13% of the substrate composition. Bjornn and Reiser (1991) reported that emergence rates for swim-up fry declined when the percentage of fines (2-6.4 mm.) exceeded 20%. The PFC Matrix states proper function for embryo survival is attained when fine sediment (<0.85mm) is less than 11-16% of the substrate composition.

After emergence, young fry rear in edgewater habitats and move gradually to deep, well-shaded pools by summer. Highest densities are usually associated with pools ≥1 meter in depth, with plenty of overhead cover, undercut banks, logs, and other woody debris, and water temperatures not exceeding 22-25°C (72-77ºF) for extended periods of time (Moyle et al. 1995). Preferred water temperatures are in the 7.2-16.7°C (45-62ºF) range (Hassler 1987). The PFC Matrix states properly functioning condition should not exceed a maximum weekly average temperature (MWAT) of 16.8ºC (62.2ºF).

The fry/juvenile stages spend 10 to 15 months in stream habitats. Downstream migration to the ocean starts around March when the coho are about one year old. The migration peaks around mid-May and continues until mid-June. Coho then spend two to three years at sea before migrating back to their natal streams to spawn. Readers interested in additional details on coho salmon life history are referred to Weitkamp et al. (1995).

Coho 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. Streams with particularly high use include Cloney Gulch, Upper Freshwater, McCready Gulch, and possibly the mid- to lower mainstem. See Fisheries Map F-1: Fish Distribution.

3.1.2 Steelhead/Rainbow Trout (*Oncorhynchus mykiss*)

Winter run steelhead generally enter the watershed in early December through spring and begin spawning soon after. Preferred water temperatures for spawning migration are 3.9-9.4°C (39-49ºF). Steelhead are capable of repeat spawning. Up to 30% can survive to spawn a second or third time, but in large drainages where fish migrate long distances, the proportion is much lower (Meehan and Bjorn 1991). Steelhead tend to construct redds averaging 4.4 - 5.4 m^2 for egg deposition in gravels ranging in size from 0.6-10.2 cm (Bjornn and Reiser 1991). Egg development is temperature-dependent and usually takes 31 days at 10°C (50ºF) (Flosi et al. 1998). Intergravel mortality of steelhead can occur when fine sediments (<0.85 mm) exceed 13% of the substrate composition (Spence et al. 1996). 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 (Busby et al. 1996).

Preferred water temperatures for rearing are reported to be 10-13°C (50-56ºF), with an upper lethal limit of 23.9°C (74ºF) (Bjornn and Reiser 1991). However, juvenile steelhead are known to utilize the lower Mad, Eel, and Van Duzen Rivers in Humboldt County, where summertime maximum daily water temperatures can exceed 24°C (75ºF) for several weeks at a time (Halligan 1998, 1999). Most downstream smolting migration takes place in spring and early summer. The majority of steelhead spend 2 years in the ocean before returning to spawn. Readers interested in additional details on steelhead life history are referred to Busby et al. (1996).

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. Upper Freshwater appears to be the reach with the highest use. See Fisheries Map F-1: Fish Distribution.

3.1.3 Chinook Salmon (*Oncorhynchus tshawytscha*)

Chinook salmon generally leave ocean waters and enter Freshwater Creek in early November through mid-January (HFAC 1999). Spawning usually occurs from November through January when water temperatures are between 5.6-13.9°C (41-57°F) (Bjornn and Reiser 1991). Chinook are riffle spawners and tend to utilize gravel substrate at the head of riffles or pool tails ranging in size from 1.3-15 cm. Average redd size and recommended gravel area per spawning pair are 5.1 m^2 and 20.1 m^2, respectively (Bjornn and Reiser 1991). Chinook die after spawning. The eggs develop in the gravel for 50-60 days before hatching, depending on water temperatures. Embryo survival rates begin to decrease when the amount of substrate smaller than 6.35 mm exceeds 20% (Bjornn and Reiser 1991). 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. Chinook will remain in the ocean for 3 to 5 years before returning to freshwater to spawn.

In the Freshwater basin, chinook tend to be found primarily in reaches that contain significant deposits of coarse gravel from the Franciscan formation. These reaches include Upper Freshwater (C1 and C2) and Middle Freshwater (MS1). Their distribution in Upper Freshwater is limited by the presence of natural barriers. See Fisheries Map F-1: Fish Distribution.

3.1.4 Coastal Cutthroat Trout (*Oncorhynchus clarki*)

Resident and anadromous coastal cutthroat trout are known to inhabit the Freshwater Watershed. Some coastal cutthroats may spend their entire lives in freshwater, but most are anadromous, spending the summers in saltwater habitats (Moyle et al. 1995). However, even populations where the vast majority of fish are anadromous may have members that do not migrate to sea every year (Johnson et al. 1999). Their upstream migration usually occurs in the late fall or early winter and, typically, spawning takes place in small streams (Flosi and Reynolds 1994) when water temperatures are between 6.1-17.2°C. They are frequently found above barriers to steelhead migration. They are capable of repeat spawning. Spawning substrate size can range from 0.6-10.2 cm, with smaller fish utilizing smaller substrate (Bjornn and Reiser 1991). The eggs hatch after 6 to 7 weeks with the alevin remaining in the gravel for an additional 1 to 2 weeks while the yolk sac is absorbed. Embryo survival rates decrease fairly rapidly when the amount of substrate <6.35 mm increases. Juveniles rear for two or more years in freshwater before migrating to the estuaries or the sea. Bjornn and Reiser (1991) reported there is a positive correlation between the amount of cover in a stream and standing crops of cutthroat.

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 portion of the stream network, they are the dominant species upstream of barriers to steelhead and salmon. It is possible that some of the cutthroat have residualized, that is, reverted from anadromy to resident status. See Fisheries Map F-1: Fish Distribution.

3.2 AVAILABLE FISHERIES INFORMATION

Fish population information has been collected for a number of years by the HFAC, California Department of Fish and Game (CDFG), PALCO, and Humboldt State University (HSU) students. HFAC concentrated primarily on collecting upstream migrant trap counts, carcass/redd surveys, and downstream migrant trapping. PALCO and the CDFG conducted electrofishing on several index reaches throughout the basin. HSU students conducted a number of surveys using varied methodologies including downstream migrant trapping and electrofishing. An inventory of available fisheries information is summarized in Table 3-1.

Table 3-1: Inventory of available fisheries information in Freshwater Creek.

Surveyor	Year	Survey Type/Location	Notes
CDFG	1952-1989	Various ocular stream inventory reports regarding barrier locations, habitat quality, fish species	Spot checks
CDFG	1993-1994	Stream inventory reports for Graham Gulch, Cloney Gulch, Little Freshwater, South Fork Freshwater	Flosi et al. (1991) protocol
CDFG	1993-1999	Index reach electrofishing	Depletion protocol
HFAC	1998	Stream habitat inventory using Flosi et al. (1994) by subbasin	Reports not developed. QA/QC problems suspected
HFAC	1996-2000	Downstream migrant trapping results for Little Freshwater, McCready, Cloney, Graham, Upper Freshwater, South Fork	Trapping effort and locations varied
HFAC	1978-1999	Upstream migrant trapping summaries	Trapping effort varied
HFAC	1988-1990	Spawner/redd surveys	Survey effort varied
HFAC	1994-1999	Spawner/redd surveys	Survey effort varied
HFAC	1987-1996	Various progress reports on trapping, spawner surveys, escapement estimates, stream rehab. Projects	
PALCO	1998-1999	Index reach electrofishing	Depletion protocol
PALCO	1994-1999	Database summaries of macroinvertebrate, sediment, water temperatures, LWD, and thalweg surveys	Survey effort and parameters increased overtime
HSU	1985-1996	Student papers on downstream migration, habitat quality, sediment size distribution, and salmonid abundance and distribution	
NRM (Natural Resources Mngmt. Corp.	1995-1996	Stream survey notes for McCready, Falls, and Cloney Gulches	

3.3 FISH DISTRIBUTION

Map F-1 illustrates the distribution of all salmonid species occurring in the WAU. The distribution map is based on the fish survey work conducted by CDFG, HFAC, PALCO, and watershed analysts.

Coastal cutthroat trout inhabit the entire fish bearing network within the Freshwater Creek basin. However, they are the dominant species in the reaches upstream of anadromous migration barriers. Cutthroat are known to be capable of surmounting barriers that would block upstream steelhead migration. Therefore, it is possible that there are anadromous cutthroat upstream of these barriers. However, this species is also known to residualize above migration barriers and probably have resident populations in the upstream most reaches.

Steelhead trout tend to be found in each subbasin up to the point where upstream migration is no longer possible due to natural barriers. According to downstream migrant trapping data, Upper Freshwater Creek and Cloney Gulch contain the highest populations.

Coho salmon are also found in each subbasin up to natural migration barriers. Based on downstream migrant trapping data, the highest coho production occurs in Upper Freshwater, South Fork Freshwater, and McCready and Cloney Gulches.

Chinook salmon are primarily found within Upper Freshwater and the mainstem downstream of the South Fork confluence. Low numbers have periodically been recorded in Little Freshwater and Graham and Cloney Gulches.

No reference information was found regarding fish presence in School Forest. No fish were observed during streambank, underwater, and electrofishing surveys conducted during the analysis.

A number of watercourses were subject to underwater and streambank observation and limited electrofishing to determine the upstream extent of fish-bearing waters. These surveys filled gaps in fish distribution information and helped groundtruth GIS-generated stream classifications on maps. In some cases, streams that were identified on base maps as non-fish bearing were determined to be fish-bearing and vice-versa. As a result of the surveys, the stream classification layer on the GIS basemap was modified. A number of low gradient watercourses with intermittent flow but no barriers were upgraded from Class II to Class I due to the presence of fish or potential for seasonal utilization during winter runoff periods. By contrast, a number of streams were downgraded from Class I to Class II due to the presence of permanent natural barriers downstream, no fish observed, and steep gradients. In one instance, the reach was considered a Class I watercourse due to the presence of a domestic water supply as required under the California Forest Practice Rules. Table 3-2 summarizes the miles of fish-bearing streams and miles of upgrades and downgrades. Map F-2 illustrates the locations of the classification changes and reaches in need of further investigation.

Table 3-2: Summary of fish-bearing streams and classification modifications

Stream Classification	Miles of Stream
Class I (Total on PALCO) *	22.75
Upgraded from Class II to Class I	1.75
Downgraded from Class I to Class II	2.5
Class I (Outside PALCO) **	9.8
Class I due to domestic water supply ***	0.7

* Includes approximately 1 mile within PALCO ownership above the Road 15 crossing in upper Upper Freshwater and 0.8 mile in School Forest that may be downgraded to Class II pending further investigation.
** Includes approximately 2.4 miles off PALCO land in upper Upper Freshwater that may be downgraded to Class II pending further investigation.
*** Located in McCready Gulch tributary. No fish present.

3.4 FISH POPULATION INFORMATION

There has been a great deal of fisheries population work done in the Freshwater Creek WAU; PALCO, CDFG, HFAC, and HSU have been collecting data for many years. Data collection has been associated with electrofishing index reaches, upstream and downstream migrant trapping, as well as redd, spawner, and carcass surveys. Although many surveys have been conducted over the years, variation in protocols and effort as well as relatively short monitoring duration make trend analysis difficult. In addition, the influences of the 1986-1994 drought, reduced ocean productivity during the late 1980s and 90s, and the recent El Niño may also affect salmonid populations. See Attachment F-1 for summaries of downstream migrant trapping, upstream migrant trapping, index reach electrofishing, and spawner surveys.

Although no hard population data exist, historic newspaper reports and the perceived need to establish the HFAC indicate that salmonid populations in the WAU were once more abundant than they are today. In addition, Higgins (2000) cited newspaper accounts from the late 1940s that reported the presence of chum salmon and summer steelhead in Freshwater Creek. The HFAC upstream migrant trap also collects an occasional chum salmon, although not nearly in the numbers the newspaper accounts suggest. Higgins (2000) stated that the reduction or absence of species that once existed in Freshwater Creek indicates some Pacific salmon diversity has been lost.

3.5 FISH HABITAT FIELD SURVEYS

Fish habitat information has been collected by PALCO, CDFG, HFAC, and HSU students since about 1980. For most of this time, no standardized protocol was used by the investigators. In 1993, the first stream inventories were conducted using a standard protocol (Flosi and Reynolds 1991). In 1998, HFAC repeated the surveys using Flosi et al. (1998), an updated version of the earlier CDFG protocol. The HFAC survey reports have yet to be developed and therefore were not utilized for this Watershed Analysis. Although useful, the CDFG protocols do not provide some data necessary to compare instream conditions to the PFC Matrix targets or Habitat Condition Indices. Therefore, the 1999 survey conducted for this watershed analysis further modified the Flosi et al. (1998) protocol to answer specific questions relating to the module.

Habitat typing is recognized as a relatively poor tool for monitoring activities. Poole et al. (1997) stated

> “Habitat unit classification can be a useful descriptive tool in hierarchical stream classification. However, a critical evaluation reveals that it is applied inappropriately when used to quantify aquatic habitat or channel morphology in an attempt to monitor the response of individual streams to human activities… Stream habitat managers and scientists should only use habitat unit classification to descriptively stratify in-stream conditions. They should not use habitat unit classification as a means of quantifying and monitoring aquatic habitat and channel morphology.”

Some of the reasons for the relative weakness of utilizing habitat typing as a trend monitoring tool stem from the variability of habitat calls by different observers, lack of precision and repeatability of the ocular estimates, and transferability of the method. Therefore, if one were to monitor instream habitat conditions it is far better to use quantitative measurement techniques such as V*, surveyed cross sections and long profiles, bulk sediment samples, LWD surveys, and residual pool depths rather than subjective ocular estimates.

Due to the nature of the historical information and variability in habitat condition from year to year, the lead Fisheries Assessment analyst decided to base much of the assessment on data collected specifically for the Watershed Analysis. It was also necessary to use current information to ensure temporal consistency with data collection being conducted by the other modules. The results from substrate bulk samples, V* measurements, and LWD surveys were also used to enhance and cross-check the more subjective habitat evaluation calls. Previously collected quantitative data from the 1994 CDFG habitat surveys (e.g., residual pool depths) were used to “fill out” or further inform the overall assessment. See Attachment F-2 for summaries of habitat parameters by subbasin and CGU.

3.5.1 Habitat Condition Evaluation

The Watershed Analysis requires that comparisons be made between the existing conditions and a table of indices of resource conditions. During the analysis, it was realized that it would be extremely difficult to make comparisons between the existing conditions and all the potential habitat indices contained in the manual. To make the comparisons easier, an abbreviated habitat condition matrix was developed during the Synthesis process with input by the Signatory Review Team. The modified Habitat Conditions Indices are presented in Table 3-3.

Habitat conditions that were quantitatively and qualitatively sampled during the field visit are summarized in Tables 3-4 through 3-9.

Additional information regarding water temperature, substrate composition, and residual pool volume (V*) was reported in Higgins (2000). A synopsis of that information is presented in Section 3.6.4. Aquatic macroinvertebrate information (Lee 1999) and habitat summaries sorted by CGU and subbasin are presented in the attachments.

Table 3-3: Comparisons of percent of pool area, percent pools by stream length, and number of pools >2 feet deep between 1994 and 1999.

Stream Name	% Pool Area 1994 / 1999	% Pool by length 1994 / 1999	Pools >2’ deep 1994 / 1999
Little Freshwater	65 / 73	56 / 60	47 / 13
Graham Gulch	34 / 50	23 / 35	40 / 11
South Fork	51 / 72*	38 / 47	33 / 7
Cloney Gulch	51 / 75*	31 / 45	38 / 26

* Intermittent flow may have resulted in elevated 1999 values since % pool area is based upon wetted area and these subbasins contain intermittent reaches.

Pool Condition Evaluation

Based on comparisons with the PFC Matrix, the information presented in Table 3-4 show generally fair to good pool conditions in the sampled channel segments. However, four segments (302, 601, 791, and 1267) had poor ratings in some instances. Segment 601 rated poorly in the pool cover diagnostic since most pools were due to bedrock scour and cover LWD complexity was relatively simple. Segments 302, 791, and 1267 suffered from intermittent flow conditions during the summer, which reduced their pool frequency and surface area. The Habitat Indices (Table 3-3) contain one subjective index relating to the quality and complexity of instream cover since the PFC Matrix did not address it. The analyst felt it necessary to include a cover component due to its importance to summer and winter salmonid habitat.

Comparisons were made between the 1994 stream inventories conducted by the California Conservation Corps in Little Freshwater Creek, Graham Gulch, South Fork Freshwater, and Cloney Gulch and instream habitat data collected for this watershed analysis in 1999 (Table 3-3). The reason for the comparisons was to see if there were changes in quantitative measurements of pool characteristics between the two time periods. There appear to have been increases in pool area and percentage of the stream made up of pools. However, there has been a significant decrease in the number of pools greater than two feet deep from 1994 to 1999. This shallowing of pools was also observed during the V* data collection and analysis as explained in Section 3.6.4 and the Stream Channel Assessment.

Although contained in the PFC Matrix, pool depth (>3 feet deep) was not considered by the SRT as an appropriate habitat diagnostic tool for Freshwater Creek. In many stream systems, a 3-foot deep pool may be the exception rather than the rule even in pristine conditions. As drainage area gets smaller, stream power and channel width naturally decrease and so does pool depth. By contrast, as stream order increases, a three-foot deep pool may be considered too shallow for a reach with that amount of drainage area. In addition, the Stream Channel Assessment reported “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 thus play a role in determining whether NMFS PFC targets for pool depth are attainable in some streams.”

Substrate Condition

An analysis of the data shows that generally poor to fair substrate conditions exist in the sampled channel segments (Table 3-5). The two segments with good ratings (601, 501) also correspond to the reaches with the heaviest spawning utilization. The poorest ratings tended to correspond with the unconsolidated geology and are generally utilized to a lesser degree by spawning salmonids.

Along with criteria approved by the SRT and contained in the PFC Matrix, the Habitat Condition Indices contain two subjective indices that the analyst believed necessary to obtain a better understanding of substrate and habitat conditions. These are "Substrate Quality" and "Gravel Availability," which were taken from WDNR (1997). The substrate quality parameter relates to the abundance of sand and small gravel filling interstitial spaces in boulder or cobble dominated units, which could affect winter concealment cover. Gravel availability relates to the abundance of spawnable size particles. This gives the analyst and readers an idea of potential spawning gravel abundance. See Section 3.6.3 for a discussion of the percentage of fine sediment within the substrate and a comparison to the PFC Matrix targets.

LWD Loads

Large woody debris data were collected, analyzed, and reported within the Stream Channel Assessment Module. A review of the LWD data and comparison with the Habitat Condition Indices and PFC matrix shows generally fair to good wood loading in the most of the CGUs (Tables 3-6 and 3-7). However, CGUs U1, MS1, MS2, and MS3 did not meet the PFC target criteria for either the number of pieces greater than 10 cm wide and greater than 2 m long and/or key piece abundance.

Summary Table

Table 3-7 represents a consolidation of the sampled channel segment diagnostics to gain a generalized understanding of conditions within each CGU. The information shows that pool and LWD conditions are generally at fair to good levels. The substrate appears to be of generally poor to fair quality throughout the system. It must be emphasized these are generalities, and conditions likely vary within each CGU.

Table 3-4: Indices of habitat conditions.

Habitat Parameters (Source)	Channel Type	**Habitat Quality Ranking**		
LWD		Poor	Fair	Good
Minimum functional size (Synthesis/PFC Matrix)	15-45 ft channels	Length <1 bfw Width <1 ft diameter	Length > 1 bfw Width > 1 ft. diameter	Fox (1994) targets
Debris Pieces per 100' Channel Length, >10 cm diameter and 2 m in length (Bilby and Ward 1989, PFC Matrix)	15-20' wide 20-25' wide 25-30' wide 30-45' wide			12-16 9-12 7-9 5-7
Canopy Closure % within RMZ (Synthesis)	All types	<70%	70-85%	>85%
SUBSTRATES				
Substrate Quality (WDNR 1997)	All types	Sand or small gravel is subdominant in boulder- or cobble-dominant units (i.e., interstices filled absent or infrequent).	Sand is subdominant in some units with cobble or boulder dominant (interstices reduced).	Sand or small gravel is only rarely subdominant in any unit (interstices clear).
% fines <0.85mm (PFC Matrix)	Pool/riffle <3% grade			<11-16%
Gravel Availability (WDNR 1997) (measured at pool tail-outs)	All types	Absent or infrequent.		Frequent spawnable areas
V*	3rd Order, <3% grade			<20%
% Embeddedness / DFG Equivalent Rating (Synthesis)	All types	>40% / >2.5	25-40% / 2-2.5	<25% / 1-2
POOLS				
Pools (PFC Matrix and Synthesis)	<3% 3-6.5%			>25% pool area, >1 pool / 6 cw >20% pool area, > 1 pool / 3 cw
% Pools assoc. with LWD (PFC Matrix)	<3% >3%			50% of pools 90% of pools
Shelter Rating (Flosi et al. 1998)	all			>80

bfw = bankfull width, cw = channel width

Table 3-5: Freshwater pool condition evaluation/diagnostic calls.

Channel Segment	CGU Number	% Pool Wetted Area/ Summer (Winter) Pool Freq. (channel widths/pool)	Summer (Winter) Overall Pool Rating	Pool Cover %pools LWD formed/ %pools assoc/LWD/ pool shelter rating	Overall Cover Rating	Comments
1	U1	76 / 1.9 (1.9)	Good	45 / 91 / 85	Good	
527	U1	60 / 3.7 (3.7)	Good	43 / 100 / 88	Good	Bank erosion
1101	U1	73 / 3 (3)	Good	50 / 100 / 48	Fair	
1110	U1	78 / 3.4 (3.4)	Good	75 / 100 / 91	Good	
18	U2	65 / 3.4 (3.4)	Fair	100 / 100 / 134	Good	McR. Gl. Trib.
1201	U2	94 / 2.8 (2.5)	Good	90 / 100 / 153	Good	Class II
203	U3	75 / 2 (2)	Good	25 / 67 / 81	Fair	High gradient
601	C1	47 / 3.3 (3.3)	Good	0 / 71 / 48	Poor	Bedrock controls
609	C1	70 / 2.3 (2.3)	Good	71 / 93 / 101	Good	
901	C1	75 / 2.5 (2.5)	Good	30 / 70 / 67	Fair	
908	C2	70 / 1.6 (1.6)	Good	87 / 100 / 143	Good	
605	C2	71 / 1.4 (1.4)	Good	20 / 73 / 80	Fair	
980	C2	60 / 5.3 (5.3)	Fair	100 / 100 / 188	Good	Class II
608	C3	63 / 1.7 (1.7)	Good	25 / 75 / 92	Fair	High gradient
791	C3	53 / 8 (4)	Poor (Fair)	67 / 83 / 112	Good	Intermittent
1267	C3	100 / 10.3 (3.4)	Poor (Fair)	33 / 83 / 67	Fair	Dry but for 2 pools
301	GG	50 / 2.8 (2.8)	Good	44 / 100 / 91	Good	LWD structures
302	GG	35 / 10.7 (4.3)	Poor (Fair)	80 / 100 / 54	Good	Intermittent
101	CG	72 / 3 (3)	Good	11 / 78 / 58	Fair	
103	CG	78 / 2.2 (2.2)	Good	33 / 92 / 75	Fair	Intermittent
501	MS1	69 / 3.1 (3.1)	Good	17 / 67 / 61	Fair	
503	MS1	57 / 2.9 (2.9)	Good	50 / 88 / 56	Good	
510	MS3	88 / 3 (3)	Good	29 / 86 / 51	Fair	Resident Reach
511	MS3	90 / 3.3 (3.3)	Good	17 / 83 / 112	Fair	Resident Reach

Table 3-6: Freshwater substrate condition evaluation/diagnostic calls. These ratings are determined by comparing ocular estimates of habitat parameters with the Habitat Condition Indices. The overall rating was determined by averaging the individual ratings.

Channel Segment	CGU Number	Subst. Quality (Dom/Subdom)	Spawning Grav. Available	Embeddedness Number/Rating	Overall Rating	Comments
1	U1	Poor	Poor	2.9 / Poor	Poor	
527	U1	Poor	Poor	3.9 / Poor	Poor	
1101	U1	Poor	Good	3.8 / Poor	Poor	
1110	U1	Poor	Good	3.2 / Poor	Poor	
18	U2	Poor	Poor	3.8 / Poor	Poor	
1201	U2	Poor	Poor	3.6 / Poor	Poor	Class II
203	U3	Fair	Poor	1.9 / Fair	Fair	Class II
601	C1	Fair	Good	1.4 / Good	Good	
609	C1	Good	Fair	2.5 / Poor	Fair	
901	C1	Poor	Good	2.7 / Poor	Fair	Embeddedness good in spots
908	C2	Fair	Fair	2.3 / Fair	Fair	
605	C2	Fair	Fair	2.7 / Poor	Fair	
980	C2	Good	Poor	2.5 / Poor	Poor	Class II
608	C3	Poor	Fair	3.2 / Poor	Poor	
791	C3	Poor	Fair	2.4 / Fair	Fair	Upper F.C. trib.
1267	C3	Good	Poor	2.1 / Fair	Fair	
301	GG	Fair	Good	3.3 / Poor	Fair	
302	GG	Poor	Good	2.5 / Fair	Fair	
101	CG	Fair	Good	2.2 / Fair	Fair	
103	CG	Fair	Good	2.7 / Poor	Fair	
501	MS1	Good	Good	2.1 / Fair	Good	
503	MS1	Poor	Good	3.1 / Poor	Poor	
510	MS3	Poor	Good	2.2 / Fair	Fair	Good in spots
511	MS3	Poor	Good	3.2 / Poor	Poor	

Table 3-7: LWD abundance in sample plots distributed by CGU. Underlined values (pieces per 100 ft of channel length) indicate CGUs where the observed abundance is less than the target abundance. Note that the LWD survey plot widths presented here may not be identical to average channel widths in presented in other width data summaries. Table modified from Stream Channel Assessment Report (Rating added).

CGU	Plot Average Channel Width (ft)	Pieces per 100 ft	PFC Target (Bilby & Ward)	Total # Pieces	Total Length of Plots (ft)	Rating
CG	24	11.8	9-12	132	1115	Good
GG	31	23.3	6-7	170	731	Good
U1	19	7.1	12-16	178	2503	Poor
C1	38	12.3	5-6	554	4517	Good
C2	20	14.6	12	102	700	Good
C3	24	18.0	9-12	36	200	Good
MS1	28	3.8	7-9	107	2800	Poor
MS2	45	0.3	5	3	1000	Poor
MS3	38	4.4	5-6	156	3550	Fair

Table 3-8: Key LWD piece abundance in sample plots distributed by CGU. Underlined values (pieces per 100 ft of channel length) indicate CGUs where the observed abundance is less than the target abundance. Table modified from Stream Channel Assessment Report (Rating and U2 added).

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	PFC Key Piece Average Volume	Observed Key Piece Volume	Rating # Pieces / Volume per piece
CG	24	22	2-2.5	3.3	88	170	Good/Good
GG	31	25	1.4-1.7	5.5	212	166	Good/Fair
U1	19	16	2.5-3.3	4.1	35	102	Good/Good
U2 *	11	<16	<3.3	10	<35	148	Good/Good
C1	38	25	1.2-1.4	2.3	212	202	Good/Good
C2	20	22	2.5	3.6	88	62	Good/Fair
C3	24	22	2-2.5	8.5	88	212	Good/Good
MS1	28	22	1.7-2.0	0.5	88	314	Poor/Good
MS2	45	25	1.1	0.0	212	n.a.	Poor/Poor
MS3	38	25	1.2-1.4	0.3	212	437	Poor/Good

* Key piece LWD data recorded during fisheries field data collection

Table 3-9: Summary channel geomorphic unit fisheries habitat ratings. The intent of this table is to give the analyst and reader a brief review of the various habitat quality ratings based upon the previous comparisons of field data with the Indices of Habitat Condition. The table is also designed to give the reader an understanding of limiting factors to salmonid production at a glance. See Tables 3-4 through 3-7 for numerical/narrative ratings of individual CGU segments.

CGU Number	Pool Rating	Pool Cover Rating	Substrate Rating	Bilby LWD Rating	Fox # LWD Key Piece	Fox LWD Volume/Piece
U1	Good	Good	Poor	Poor	Good	Good
U2	Good	Good	Poor	NA	Good	Good
U3	Good	Fair	Fair	NA	ND	ND
C1	Good	Fair	Fair	Good	Good	Good
C2	Good	Good	Fair	Good	Good	Fair
C-3	Good	Good	Poor	Good	Good	Good
GG	Good	Good	Poor	Good	Good	Fair
CG	Good	Fair	Fair	Good	Good	Good
MS1	Good	Fair	Fair	Poor	Poor	Good
MS2	ND	ND	ND	Poor	Poor	Poor
MS3	Good	Fair	Poor	Fair	Poor	Good

ND=No data collected

3.6 SUBSTRATE AND WATER QUALITY PARAMETERS

3.6.1 Turbidity and Total Suspended Sediment

Hydrograph, Turbidigraph, and Stage/Discharge Relationships

In total, 18 storms were identified during the winter and spring of 1999 where discharge exceeded 100 cubic ft per second (cfs) (Figure 3-1). Noticeably, turbidity and suspended sediment measured earlier in the season at a given flow event were generally reduced later in the season for flows of similar peak discharge. For example, the peak flows measured around 1/16/99, 1/23/99, and 2/10/99 were each approximately 400 cfs (+/-20) (Figure 3-1), yet the measured turbidity of these events peaked at 585, 305 and 330 NTUs, respectively. The flows measured at the latter two dates were decreased by approximately 5 and 10%, respectively, relative to the 1/16/99 event, yet the turbidity reductions per unit flow declined by over 40% (Figure 3-2). Such reductions are generally to be expected as the system flushes proportionately more sediment out early in the hydrographic year relative to later in the cycle. However, significant new inputs of sediment, such as from landslides or road erosion, could lead to spikes in turbidity at a given flow regardless of seasonal timing. The best fit line for discharge relative to stage height conformed uniformly to a first order power equation (Figure 3-3).

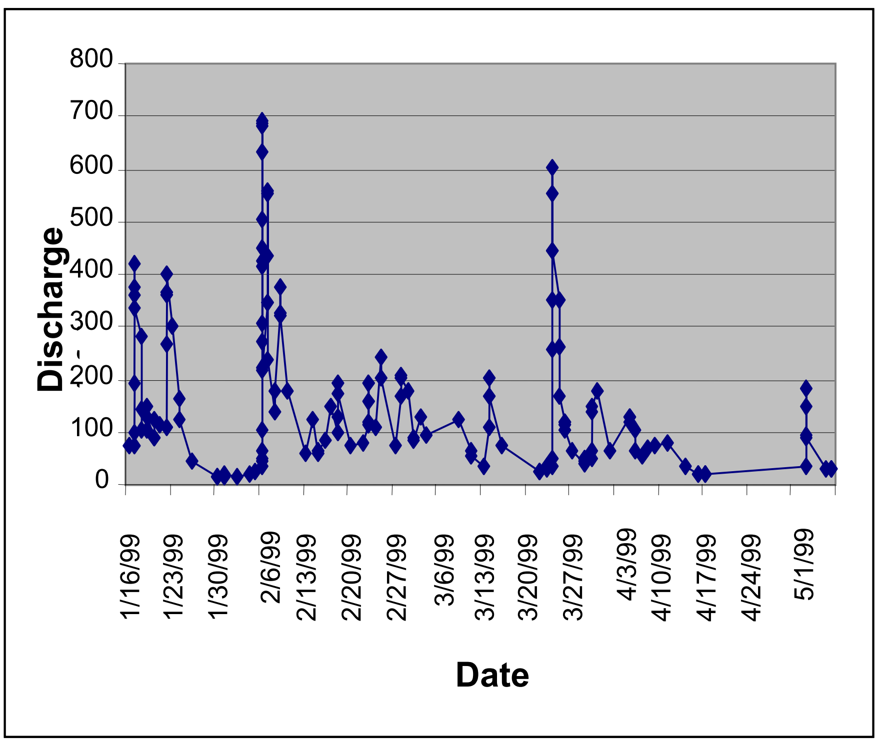

Figure 3-1: Freshwater Creek Discharge, winter and spring 1999.

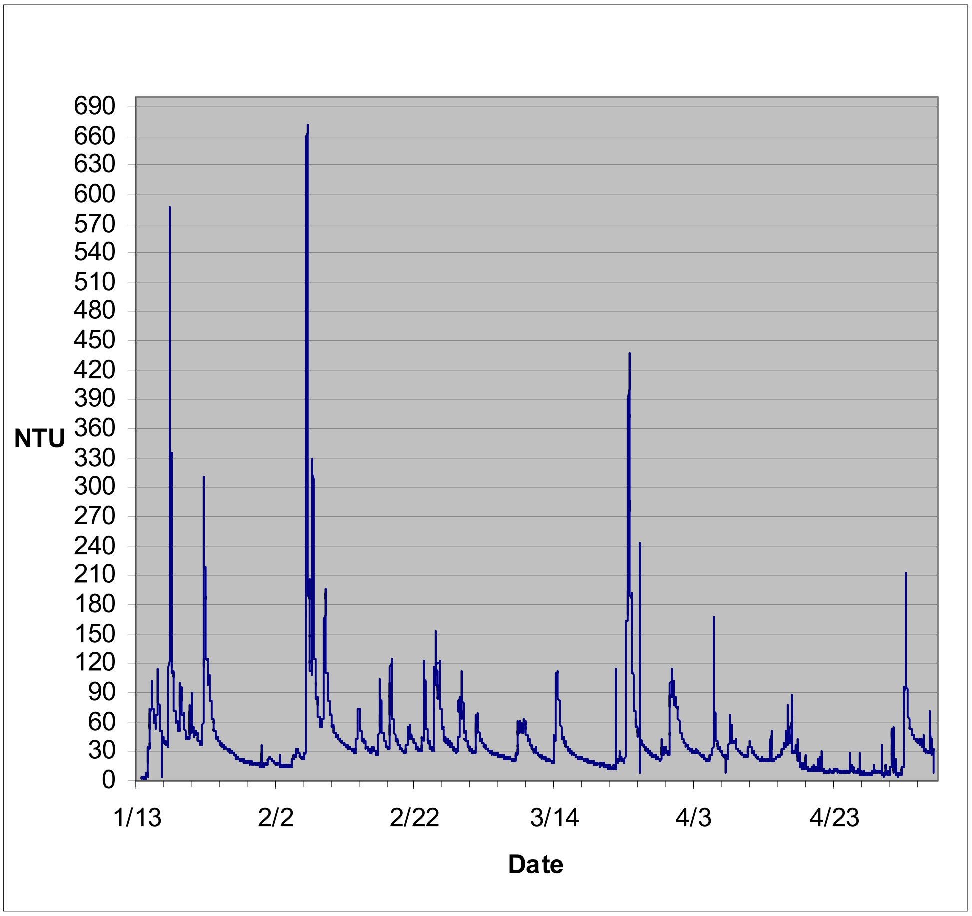

Figure 3-2: Turbidity in Freshwater Creek, winter and spring 1999.

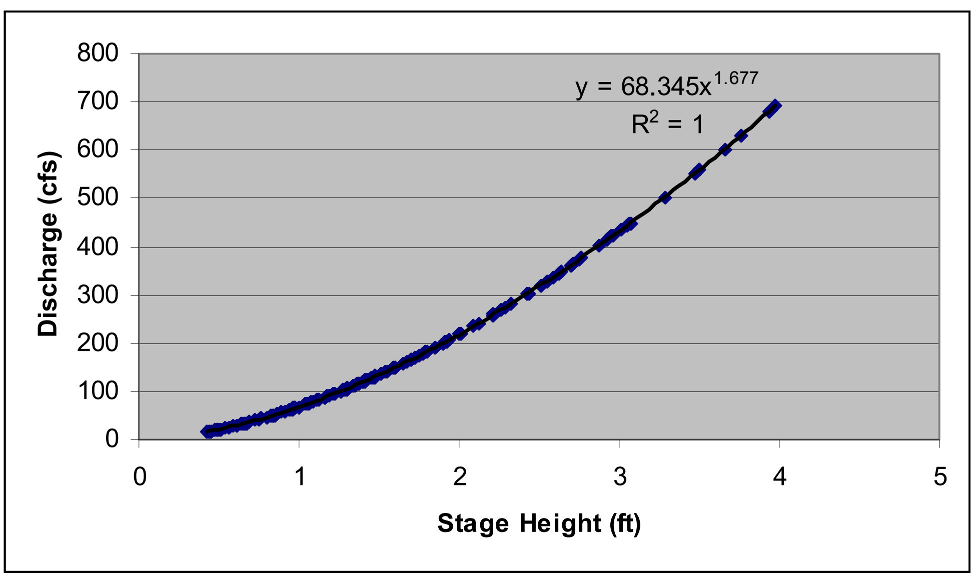

Figure 3-3: Freshwater Creek Stage vs. Discharge, winter and spring 1999.

Relationships Between Discharge, Turbidity, and Suspended Sediment

Flow (i.e., discharge) appears to be a good predictor of turbidity in Freshwater Creek (Figure 3-4), although the predictive power of flow for this measurement endpoint is affected by histeresis. Histerisis is created by disproportionately high turbidity and suspended sediment during the ascending phase of the hydrograph and low turbidity during the descending phase, as measured in discrete storm events. Thus, for a discrete rainfall (storm) event that might peak at a discharge of 220 cfs, the turbidity and suspended sediment concentration measured at 100 cfs during the ascension to this peak will exceed that measured during descension at 100 cfs. These histerisis "loops" appear more pronounced in the fall (Figure 3-5) as opposed to the spring (Figure 3-6). When all data points are considered over the entire period of record (i.e., multiple storm events combined), the effect of histeresis is dampened but is still evident (Figures 3-5 and 3-6). The more pronounced histeresis observed during the fall 2000 monitoring period relative to the spring provides additional evidence of higher sediment transport during the early portion of the annual hydrograph relative to the latter period.

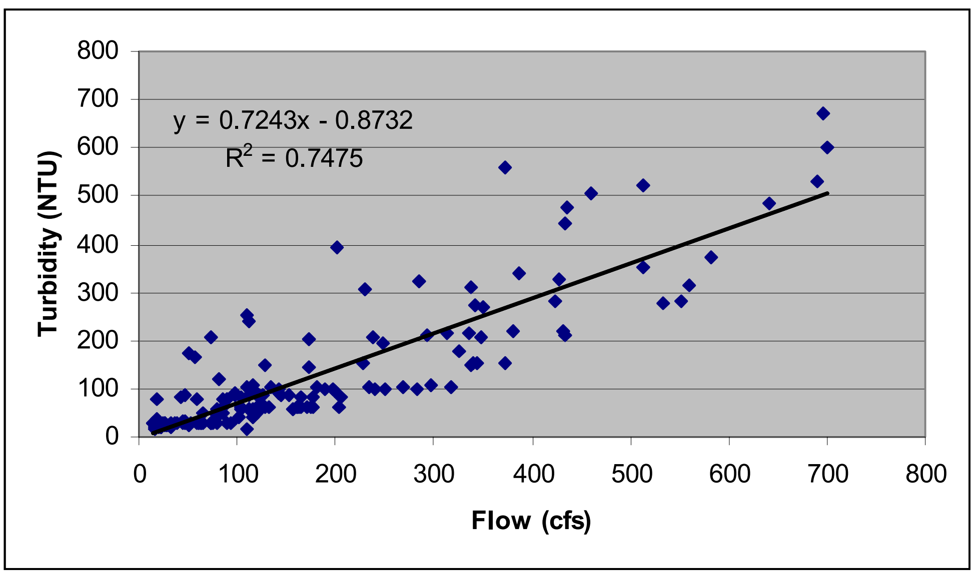

Figure 3-4: Flow (discharge) versus turbidity in Freshwater Creek, 1999.

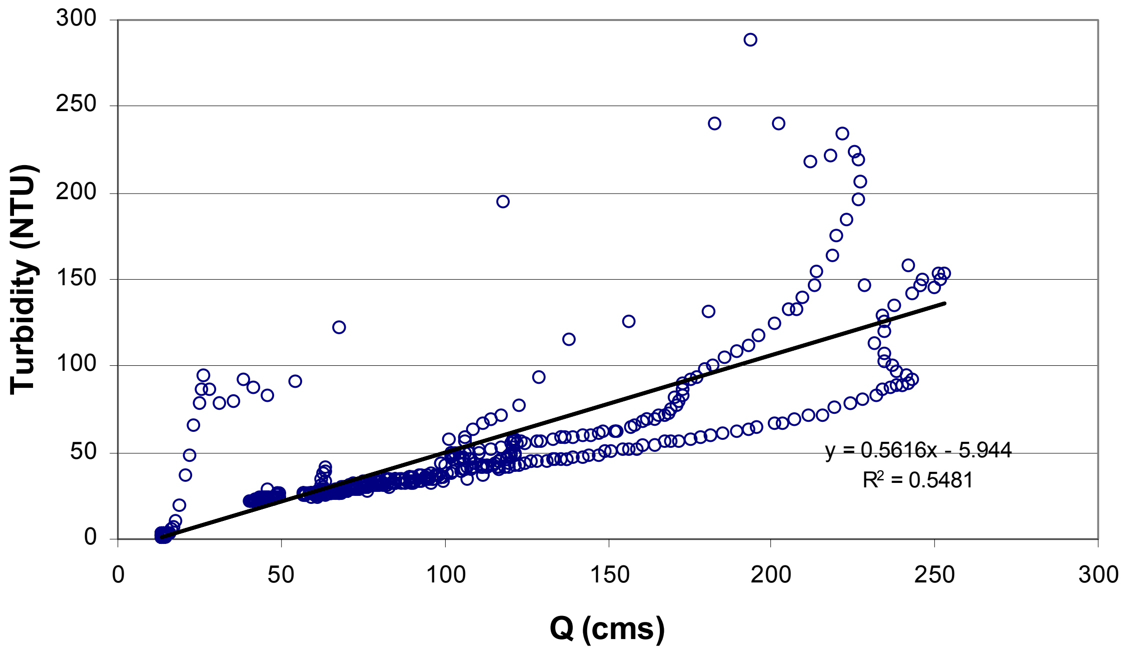

Figure 3-5: Flow (cubic meters/second) versus turbidity, fall 2000.

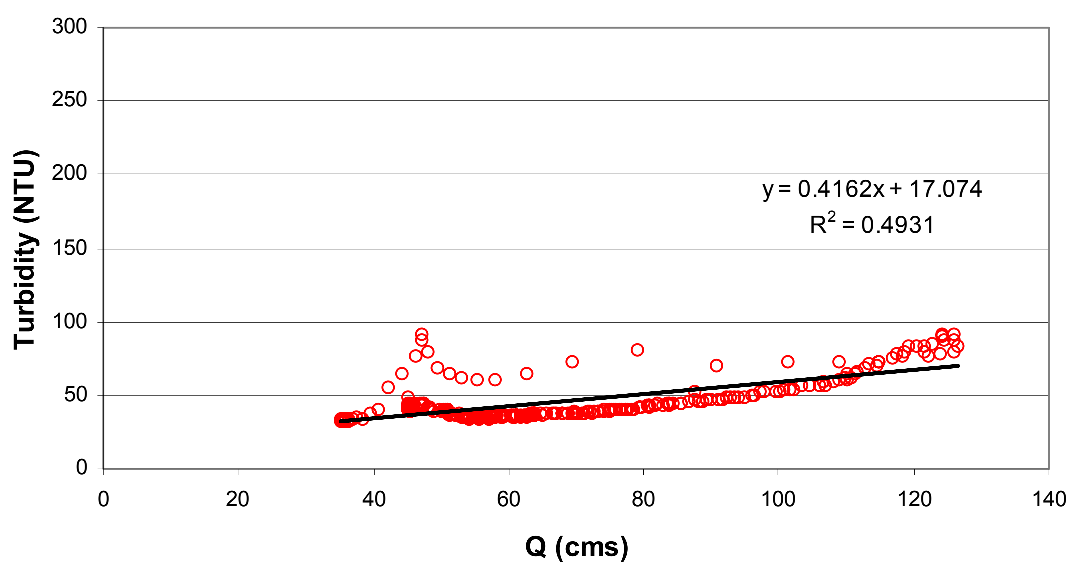

Figure 3-6: Discharge versus turbidity, spring 2000.

The relationship of suspended sediment to flow (Figure 3-7) reflected that of turbidity, with no effective difference in the strength of the relationship ($R^2_{turbidity} = 0.75 = R^2_{TSS}$). In contrast, turbidity was an excellent predictor of suspended sediment concentration (Figure 3-8) in Freshwater Creek, consistent with previous studies by the RSL. Because turbidity is composed of both dissolved and particulate fractions, the relationship is weaker at the lower values of turbidity, as organic acids constitute a disproportionately higher amount of the turbidity reading.

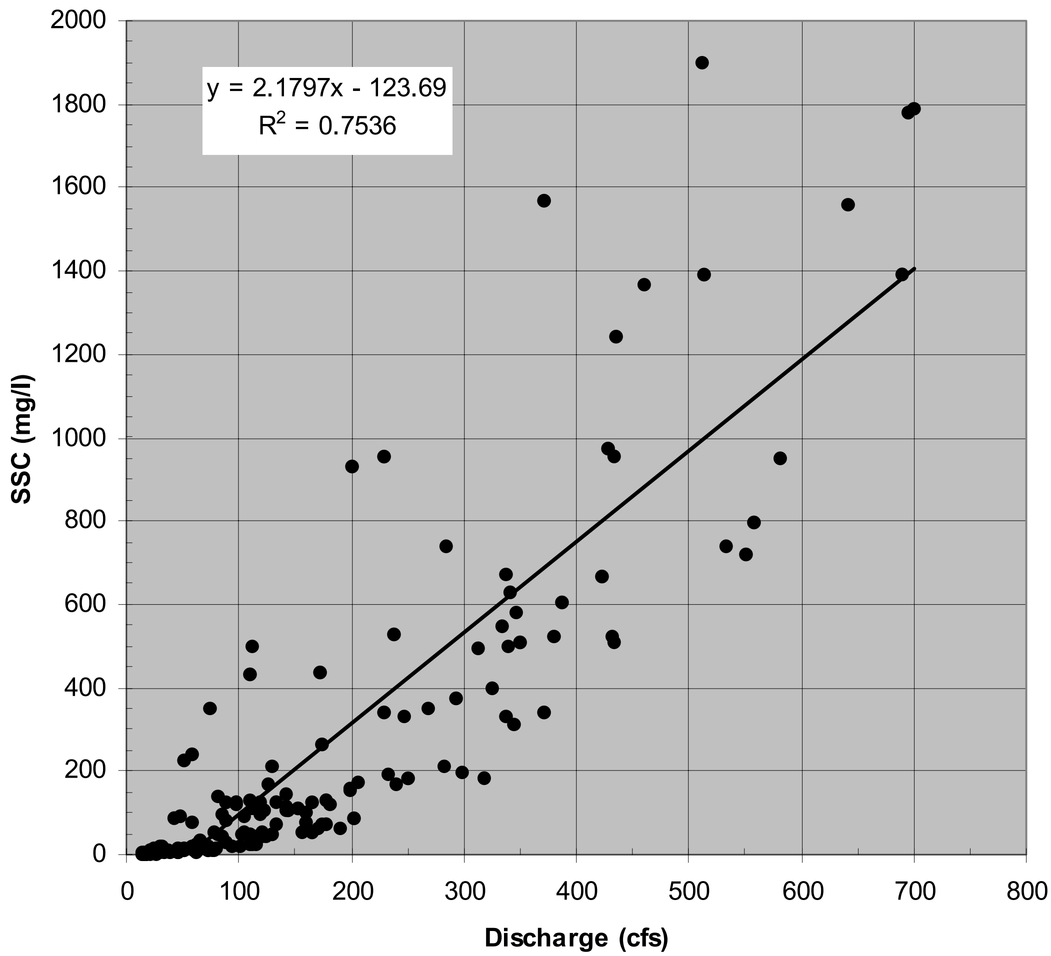

Figure 3-7: Suspended sediment vs discharge, Freshwater Creek, January to August 1999.

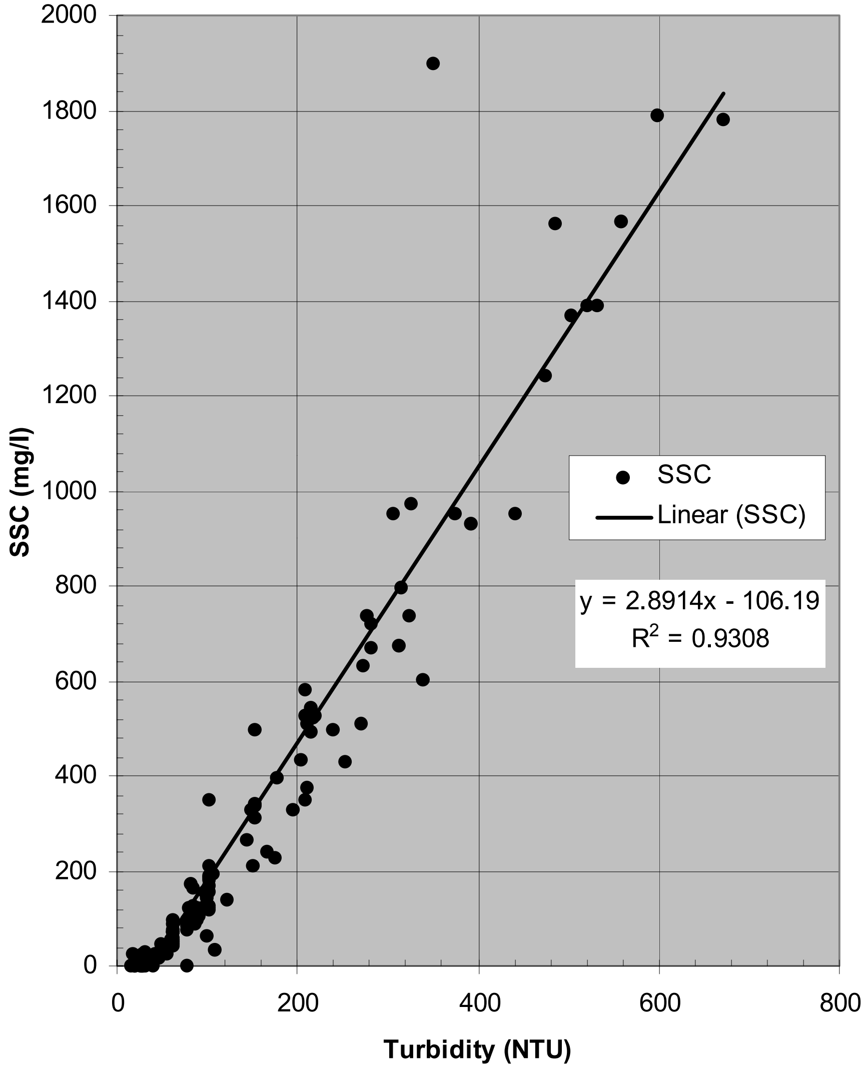

Figure 3-8: Turbidity versus suspended sediment, 1999.

Summary statistics for turbidity and suspended sediment for the entire period of record are provided in Table 3-10. Turbidity and TSS at the 90th percentile were within levels that have caused behavioral changes in fishes as reported in the literature (Attachment F-1). However, the mean, median, or lower quartile values for turbidity and TSS, were generally below risk screening values provided in the published literature (Newcomb and Jensen 1996; Attachment F-1).

Table 3-10: Stage, discharge (flow), and turbidity summary, January 13, 1999 to April 2, 2000. Total suspended sediment concentration calculated from 1/13/99 to 8/2/99 only.

	Stage	Flow (cfs)	Turbidity (NTU)	TSS (mg/l)
Average	0.58	39.6	21.5	24.6
sd	0.54	67.8	49.5	87.8
Median	0.40	4.8	10	2
Mode	0.11	1.0	0	2
25%	0.18	4.0	0	2
75%	0.83	49.9	28	17.6
90%	1.26	100.6	48	49.4

Load Estimation

The total load of suspended sediment delivered past the monitoring station into Freshwater Creek was calculated using the estimated TSS as recorded by the RSL, and integrated over time, between January 13, 1999 and July 31, 1999 (Table 3-11). The additive assessment provided below simply represents the summation of TSS by discharge, over the period of record. The linear and LOESS model estimates were calculated by the RSL. Suspended sediment data from hydroyear 2000 have not undergone complete quality control and are therefore not presented in this report. However, preliminary load estimates for this latter period of record have been addressed in the Surface Erosion Report (Appendix B).

Table 3-11: Estimates of total load of suspended sediments.

Linear Model	LOESS Model	Additive Model
2,845,365 kg	2,800,470 kg	2,804,875 kg
826 kg/ha	813 kg/ha	814 kg/ha
236 ton/sq mi	232 tons/sq mi	282.7 tons/sq mi

Relationship between Rainfall and Suspended Sediment

The response of TSS to rainfall was evaluated to explore the potential for using rainfall to predict sediment loads and risk events. When considered over discrete time points such as the late winter and spring storms of 1999, rainfall was found to represent a reasonably good predictor of suspended sediment (R^2 = 0.883) (Figure 3-9). However, over longer time periods, such as when considering all storm events on record (as identified by peak stream discharge) the relationship was not strong (R^2 = 0.33) (Figure 3-10).

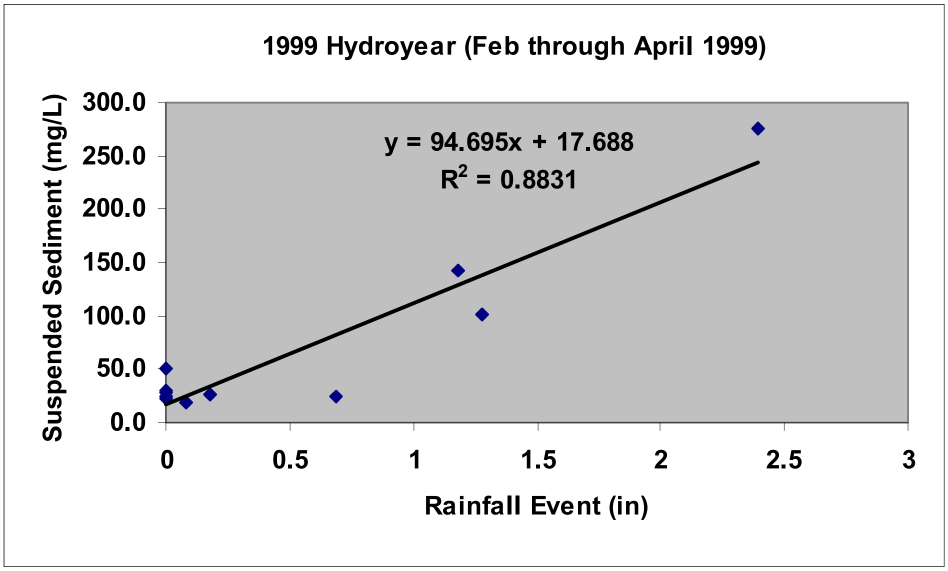

Figure 3-9: Suspended sediment in Freshwater Creek following discrete rainfall events in 1999.

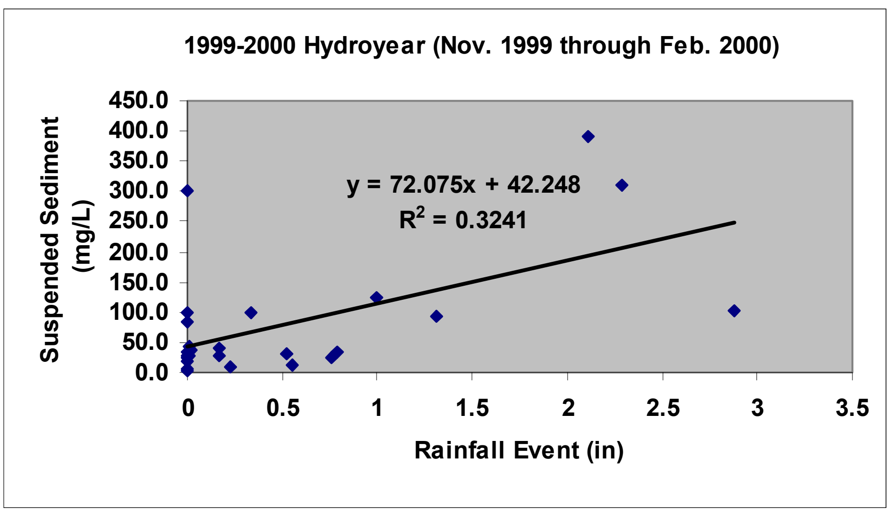

Figure 3-10: Suspended sediment in Freshwater Creek following storm events in hydrologic year 2000.

The strength of the association for all time points was reduced because of the lag time between rainfall in the upper watershed and its measurement at the rain gauge, and because rainfall is not uniform within a watershed. Thus, a single measuring station is equally likely to over- or under-represent total rainfall for specific storm events. The use of rainfall to gauge suspended sediment could therefore be enhanced by rainfall gauging at multiple stations to provide a spatially integrated reading for the watershed; however, this is not currently being done for the Freshwater Creek Watershed. Nevertheless, rainfall measured at only the single station provides a fair-to-good index of potential suspended sediment concentrations realized after a storm, and the potential sediment loading of fines into the watershed. For example, using either of the regressions provided in Figures 3-9 or 3-10, one would estimate a total suspended sediment concentration of (approximately) 113 mg/l following a 1-inch rainfall event. Similarly, a half-inch event would result in a TSS concentration of approximately 65 to 75 mg/l. With further refinement, this type of analysis could be useful for predicting sediment loading into streams from a given rainfall event under existing management practices (e.g., miles of roads in watershed, etc.). Thus, it may be possible to predict sediment loading under different management practices in the future under similar rainfall conditions. Clearly, further refinement of this analysis will be considered.

Risk Characterization of Suspended Sediment Concentrations to Salmonids

Over the entire period of record, no conditions within the basin imparted risk numbers that would be associated with direct mortality, or paralethal effects such as reduced growth, as the highest risk number recorded did not exceed 8 (Figure 3-11).

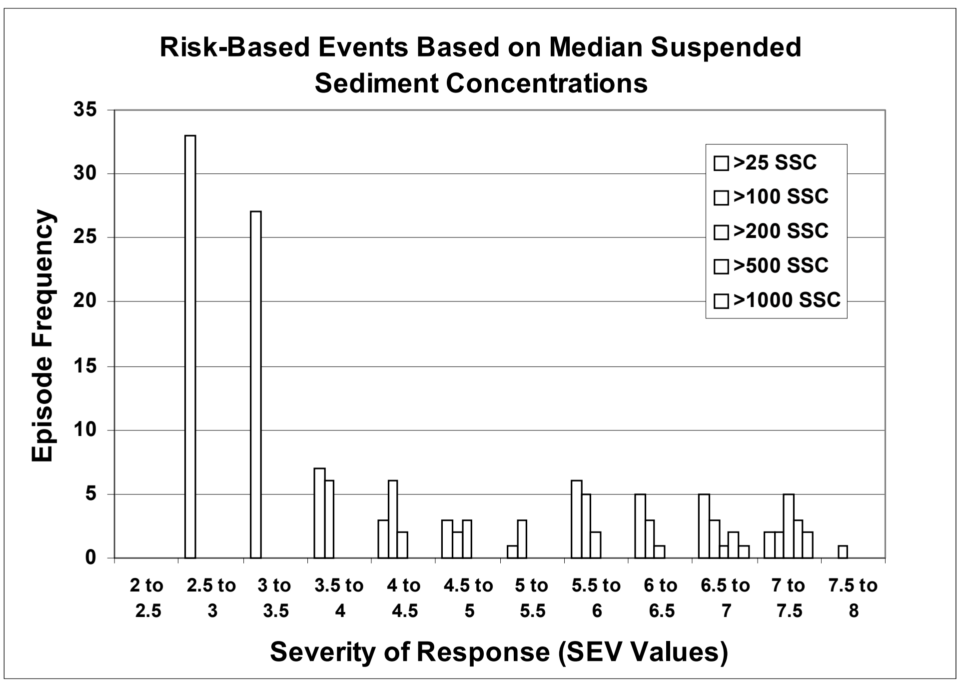

Figure 3-11: Episodic frequency of severity scores for suspended sediment concentration (TSS) induced risks to juvenile and adult salmonids.

The majority of risk numbers were associated with behavioral effects such as alarm and avoidance (SEV scores of 1 to 3), or sublethal effects such as reduced feeding (SEV score of 4), or minor physiological stress (SEV scores of 5 and 6). For comparative purposes, suspended sediment concentrations greater than 25 mg/l were assumed to be influenced by management related sediment inputs; a level of 25 mg/l is also roughly equivalent to the lowest effect level reported in the literature (Sigler 1988). As demonstrated in Figure 3-11, turbidity events >25mg/l but less than 100 mg/l (the next grouping) resulted in the majority of the risk events recorded. Severity of effect scores of 7 and above, associated with habitat degradation, were recorded a total of 15 times (Figure 3-11) and were associated with either very long duration events at low TSS, or brief exposures at very high concentrations.

While the depiction of SEV score frequencies is helpful in understanding conditions of potential effect, it is also worthwhile to examine the frequency that exposure durations at elevated concentrations are actually realized in the basin. Figure 3-12 represents this information, and reflects that most of the exposure conditions that are factored into the SEV frequency analysis (Figure 3-11) are occurring under transient conditions lasting less that 6 hours. Exposure conditions of more than 96 hours occurred only twice, and only at the >25 mg/l exposure category.

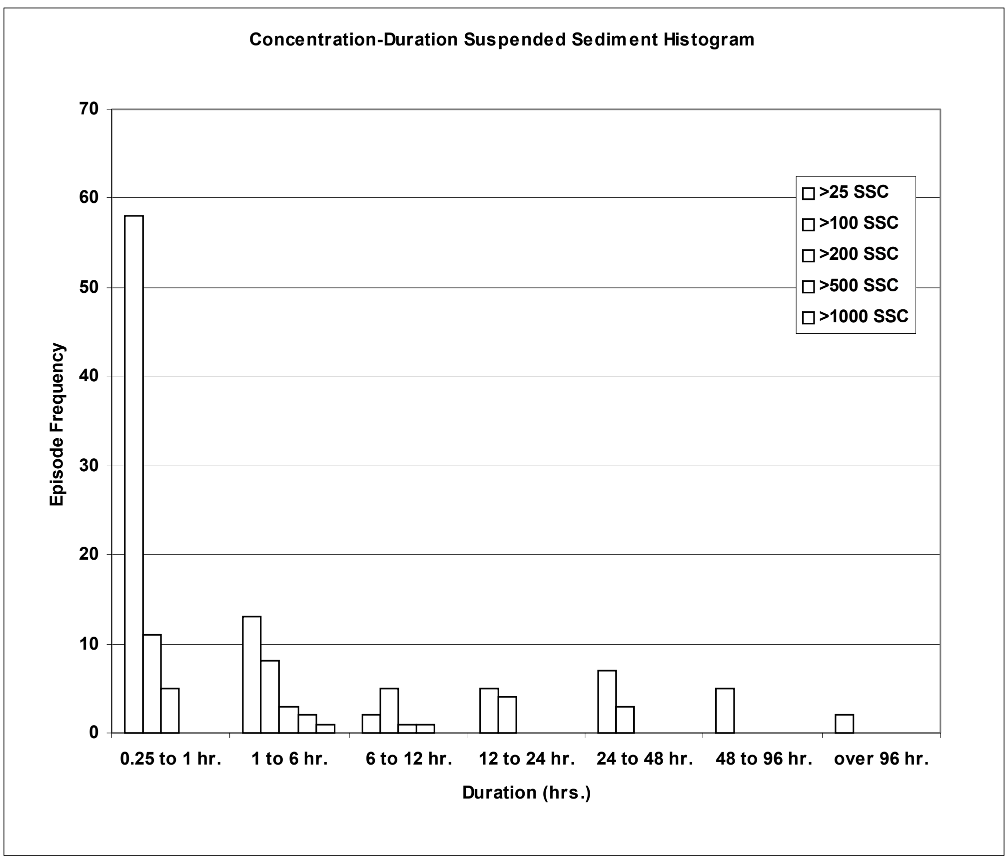

Figure 3-12: Episodic frequency of exposure duration by suspended sediment concentration.

This is potentially important because such short exposures, coupled with lower winter water temperatures that reduce metabolic activity levels in fish, suggests that actual impacts may be significantly lower than those indicated by the Newcombe and Jensen model results. Exposures of 24 to 96 hours, typical for acute bioassay protocols, occurred 15 times, 13 of which were associated with total suspended sediment concentrations in the >25 mg/l category (Figure 3-12).

The frequency of specific storms that achieved an SEV of at least 2 was compared between the mean and median TSS concentration data for those TSS concentrations that exceeded the nominal "background" of 25 mg/L used throughout the analysis. The average of all SEV scores where the median TSS concentration of each storm event was used to calculate the SEV (keeping in mind that each individual storm event will generate an SEV score), exceeded the average SEV score calculated from the mean TSS concentrations over the same storm events. However, the use of the mean TSS to calculate the SEV resulted in substantially more risk events than if the median TSS for each storm event was used to calculate the SEV (e.g., 102 vs. 57 at >25 mg/l, Table 3-12). The median analysis represents a better approximation of the geometric mean, a more conservative measure of the TSS concentration to which fish would be exposed during the course of a storm event.

Table 3-12: Comparison of SEV scores calculated with the mean or median TSS.

SEV Score -->	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**	**8**
Median TSS ≤ 25 mg/l	1	34	15	15	2	6	15	2	1				
Median TSS > 25 mg/l			16	16	4	4	0	5	7	2	4	0	1
Mean TSS > 25 mg/l		28	21	21	4	4	1	9	7	4	1	3	1
		Median < 25			**Median > 25**				**Mean > 25**				
Average SEV Score		3.50			4.4				3.8				
St. Deviation		1.04			1.4				1.4				
Median		3.02			3.6				3.2				

3.6.2 Water Temperature

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 (Table 3-13). The maximum weekly average temperatures (MWATs) 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.

Table 3-13: Summary of temperature data collected on in the Freshwater Watershed 1996 to 1999.

DATES			Station	Days	Average	Maximum Temperature		MWAT			Data
Yr	From	To	Id		Temp. ºC	Value ºC	Date	Value ºC	From	To	Source
96	06/15	09/30	Sta 92-96 Cloney Gulch	108	14.23	17.81	07/26	16.10	07/25	07/31	PALCO
96	06/15	09/30	Sta 36-96 Upper Freshwater	108	12.00	16.55	07/30	14.27	07/25	07/31	PALCO
96	06/15	09/30	Sta 33-96 Main Freshwater	108	14.43	18.34	07/30	16.19	07/25	07/31	PALCO
97	06/15	09/30	Sta 18-97 Little Freshwater	108	15.74	18.76	08/25	16.67	07/15	07/21	PALCO
97	06/15	09/30	Sta 37-97 SF Freshwater	108	15.44	17.53	07/18	16.19	07/15	07/21	PALCO
97	06/15	09/30	Sta 33-97 Main Freshwater	108	16.02	19.72	08/07	17.00	07/14	07/20	PALCO
97	06/15	09/30	Sta 135-97 McCready Gulch	108	14.45	16.93	09/04	15.45	08/31	09/06	PALCO
97	06/15	09/30	Sta 36-97 Main Freshwater	108	12.58	14.59	08/08	13.41	08/08	08/14	PALCO
97	07/01	09/30	Sta 159-97 SF Freshwater – class II	92	12.12	13.14	08/08	12.57	09/24	09/30	PALCO
98	06/15	09/28	Sta 36-98 Upper Freshwater	106	12.21	15.38	08/14	13.83	09/01	09/07	PALCO
98	06/15	09/28	St 135-98 McCready Gulch	106	13.39	15.57	08/12	14.59	08/11	08/17	PALCO
99	07/01	10/15	Sta 36-99 Upper Freshwater	107	11.56	14.59	07/13	13.32	08/23	08/29	PALCO
99	07/01	10/15	Sta 135-99 McCready Gulch	107	12.58	16.27	08/22	14.62	08/21	08/27	PALCO
99	07/20	10/15	Sta 18-99 Little Freshwater	88	13.06	17.72	08/22	15.49	08/21	08/27	PALCO
99	06/22	10/07	Sta 34-99*	108	14.00	18.79	07/26	14.00	08/21	08/27	Willey
99	1/31	8/2	Roelof's Gauge		10.6						RSL

* Temperature monitored at Pool Tail rather than Riffle

Station 92	Cloney Gulch, approximately 1,000 ft upstream of the confluence with Freshwater.
Station 36	Mainstem Freshwater, approximately 8,250 ft upstream of South Fork Freshwater.
Station 33	Mainstem Freshwater, approximately 750 ft downstream of South Fork Freshwater (no longer in use).
Station 18	Little Freshwater, approximately 500 ft upstream of the confluence with Freshwater
Station 37	South Fork Freshwater, approximately 1,000 ft upstream of the confluence with Freshwater (no longer in use)
Station 135	McCready Gulch, approximately 3,750 ft upstream of the confluence with Freshwater.
Station 159	South Fork Freshwater, Class II watercourse, very high up in drainage. Side tributary, Located approximately 1,500 ft upstream of confluence with Sf Freshwater; put in under or near Road 15 crossing of first Class II tributary closest to Road 15 Bridge over SF Freshwater

3.6.3 Substrate Composition

The bulk sediment sampling data show a general variability in substrate composition over the sampling periods (Tables 3-14 and 3-15, and Figure 3-13). The most recent shovel sampling data found that 11 to 47% of the substrate sampled was composed of fines <0.85 mm, and 25 to 59% of the substrate sampled was composed of fines <4.7 mm. In general, the highest values were associated with streams flowing through Wildcat Formation geology. The majority of recorded values for <0.85 mm exceed 11-16% targets in the PFC matrix. There is no diagnostic criteria in the PFC Matrix or Habitat Condition Indices for the <4.7 mm size fraction. However, Bjornn and Reiser (1991) in a summary of scientific literature reported a 50% decline in salmonid emergence when the percentage of sediment in the 2-6.4 mm range exceeded 24-35%. See Section 5.4 for a discussion of the PFC Matrix targets for fine sediment.

Table 3-14: Percentage of substrate composition less than 0.85 mm from PALCO shovel samples collected during late summer or early fall 1994 - 1999. The PFC target is 11-16%*.

PL Station # / CGU	Location	1994	1996	1997	1998	1999
15 / C1	Lower South Fork	23	24	21	24	27
18 / U1	Little Freshwater	-	36	29	47	47
19 / GG	Lower Graham G.	21	27	32	29	20
20 / GG	Upper Graham G.	24	22	23	-	-
32 / MS1	Mainstem	23	12	15	12	13
33 / MS1	Mainstem	12	13	15	-	
34 / C1	Lower Upper Fresh	17	19	17	15	17
35 / C1	Lower Upper Fresh	20	23	23	-	-
36 / C3	Rd. 15 Upper Fresh	23	22	22	19	11
37 / C1	Lower South Fork	20	23	20	-	-
92 / CG	Cloney Gulch	-	-	-	16	25
135 / U1	McCready Gulch	-	47	44	39	26
165 / C2	Mid Upper Fresh	-	-	-	14	11

*All reported values are averages based on multiple samples

Table 3-15: Percentage of substrate composition less than 4.7 mm from PALCO shovel samples collected during late summer or early fall 1994 - 1999. The <4.7mm size fraction is not represented in the PFC Matrix or Habitat Condition Indices*.

PL Station # / CGU	Location	1994	1996	1997	1998	1999
15 /C1	Lower South Fork	49	43	40	39	46
18 / U1	Little Freshwater	-	51	41	55	59
19 / GG	Lower Graham G.	36	47	66	56	43
20 / GG	Upper Graham G.	39	47	50	-	-
32 / MS1	Mainstem	35	28	30	25	36
33 / MS1	Mainstem	19	27	33	-	-
34 / C1	Lower Upper Fresh	27	32	38	36	29
35 / C1	Lower Upper Fresh	33	48	40	-	-
36 / C3	Rd. 15 Upper Fresh	49	43	50	38	28
37 / C1	Lower South Fork	34	40	39	-	-
92 / CG	Cloney Gulch	-	-	-	37	46
135 / U1	McCready Gulch	-	66	60	59	53
165 / C2	Mid Upper Fresh	-	-	-	32	25

*All reported values are averages based on multiple samples

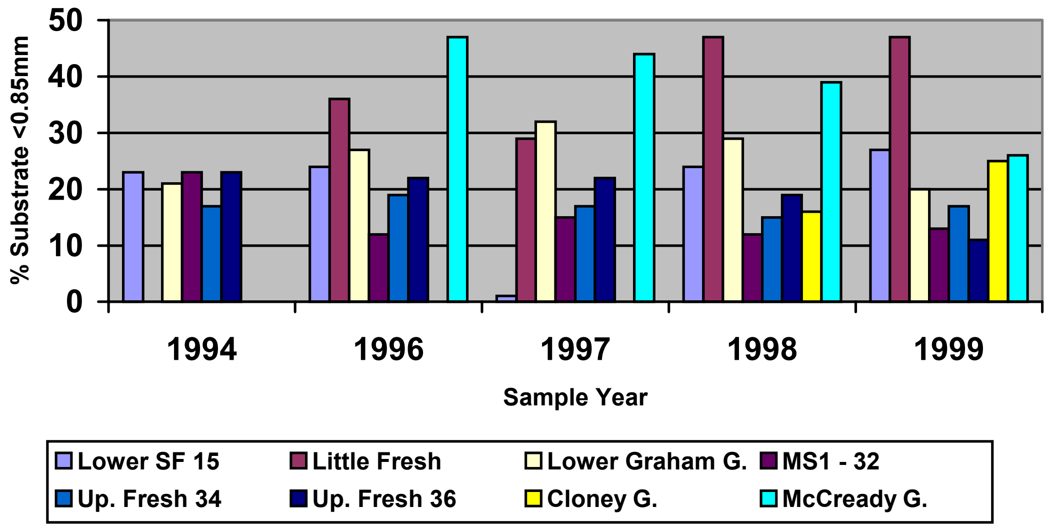

Figure 3-13: Percentage of substrate composition less than 0.85 mm from PALCO shovel samples collected during late summer or early fall 1994 - 1999. The PFC target is 11-16%.

3.6.4 V*

Higgins (2000) reported that Knopp (1993) sampled fine sediment in pools (V*) and streambed particle size distribution in 1992 and 1993 in Graham Gulch, South Fork, and upper Freshwater Creek. V* values represent the proportion of total scoured pool volume that is occupied by fine sediments. The same reaches were re-sampled in 1999. Results from both surveys are shown in Figure 3-14.

V* values for South Fork Freshwater Creek remained fairly constant in all years, with values ranging from 0.52 to 0.59. Graham Gulch showed an increase from 0.35 to 0.51 between 1992 and 1999. The North Fork of Freshwater Creek showed the greatest increase in V*, varying from 0.19 in 1992 to 0.15 in 1993 then rising to 0.46 in 1999. Although this is a limited dataset, the V* information shows a general pool filling trend in the survey reaches. The 1999 V* results exceed the PFC Matrix target of less than 0.2. Please see the Stream Channel Assessment for an expanded discussion of V*.

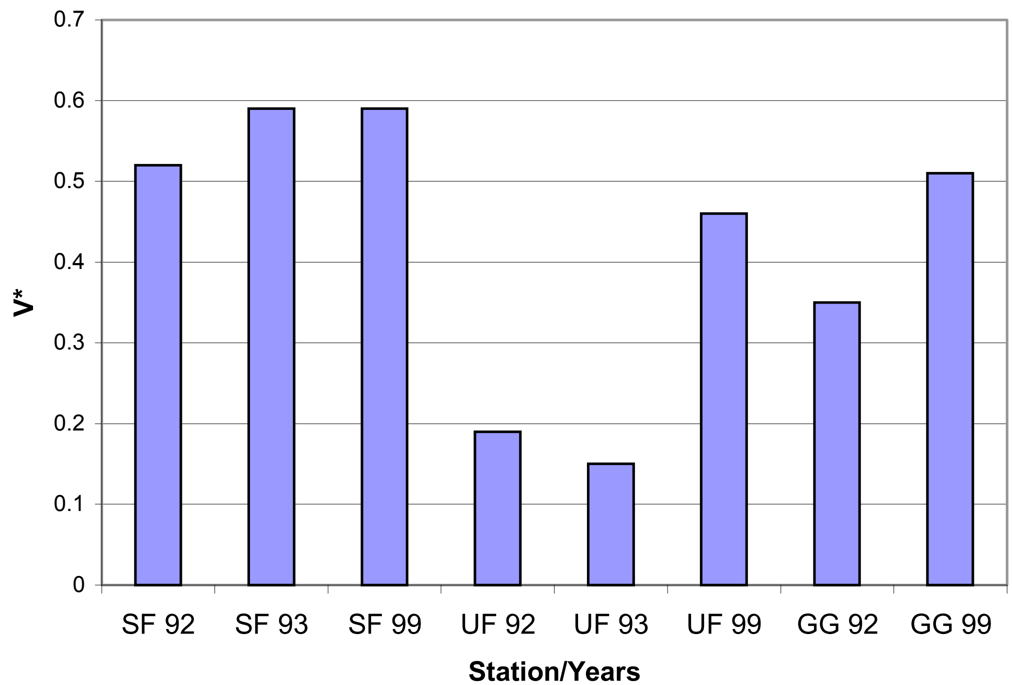

Figure 3-14: V* results from 1992, 1993, and 1999 at three locations in Freshwater Creek: the lower South Fork (SF), Upper Freshwater (UF) above the convergence with the South Fork, and Graham Gulch (GG). Data from Knopp (1993) and PALCO. The PFC target is V* <0.2.

3.7 AREAS OF CONCERN

An "Area of Concern" is an area that has degraded habitat, limited habitat availability, refuge areas, or has high utilization by a particular species or life phase. These areas warrant additional management consideration due to their biological sensitivity and importance. For example, although salmonids spawn throughout the Class I watercourse system, a few reaches have particularly high utilization and importance. These high use reaches (MS1, CG, and C1-Upper Freshwater) are considered spawning areas of concern.

3.7.1 Spawning Areas of Concern

Chinook salmon spawning generally occurs in Upper Freshwater and the mainstem down to the mouth of McCready Gulch (Map F-3). These reaches generally have higher flows and relatively large patches of spawning gravel. Coho salmon and steelhead are known to spawn in every subbasin to the limit of anadromy. They can generally utilize smaller watercourses and smaller patches of gravel than chinook. Coho generally spawn in smaller streams than chinook (Moyle et al. 1995). Coastal cutthroat trout spawn throughout the basin including upstream of salmon and steelhead migration barriers. They can utilize small pockets of gravel in headwater areas.

Generally spawning habitat conditions are poor in the unconsolidated CGUs and the lower reach of MS3. These include McCready Gulch (U1), lower Little Freshwater (U1), School Forest (U2), Graham Gulch (GG), and the resident reach of Freshwater Creek (MS3). The fine-grained nature and general absence of gravels in soils derived from the unconsolidated geologic formations (e.g., Wildcat) may partially explain this observation. The best spawning habitat occurs in MS1 (South Fork to Graham Gulch), C1 (upper Freshwater and lower South Fork), and CG (Cloney Gulch). Good quality spawning habitat also occurs in mid-Little Freshwater, MS2 and upper MS3, although the number of spawning observations are relatively low. Of the 1,054 redds observed by HFAC between 1986 and 1999, 723 (or 68%) were found in MS1, C1, and CG. However, the Substrate Condition Evaluation (Table 3-5) indicates that the presence of sand and fine sediment and relatively high embeddedness levels reduces the quantity and quality of spawning habitat in many reaches throughout the WAU. See Map F-4: Spawning Areas of Concern.

Adult salmonids generally move into the WAU during the fall, winter, and spring and hold in pool habitats prior to spawning. In some cases, adult salmonids may have to hold at the spawning grounds until their gonads mature prior to spawning. These fish typically require deep pools with cover elements during these periods. The CGUs with the greatest percentages of pools deeper than two feet (measured at summer low flow, not the higher winter spawning flows) are C1, CG, MS1, and MS3. With the exception of MS3, these CGUs also correspond to the areas with highest spawning use.

3.7.2 Rearing Areas of Concern

Salmonid rearing habitat is made up of several instream habitat characteristics including cover components (LWD, boulders, undercut banks, rootwads, bubble curtains, etc.), adequate stream-flow, appropriate water temperature, substrate composition, pool depth, 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. Downstream migrant trapping records and electrofishing data were also used determine fish utilization. Water temperatures were not used as a diagnostic metric since they are generally within the preferred range for salmonids in the WAU.

Salmonids rear in every accessible reach in the WAU. Based on the 1999 and 2000 downstream migrant trapping data (HFAC 1999), chinook rearing occurs primarily in the mainstem between the South Fork and Graham Gulch (MS1). Coho and steelhead tend to utilize the mainstem (MS1), Upper Freshwater and lower South Fork (CG1), Cloney Gulch (CG), and McCready Gulch (U1). Coastal cutthroat tend to be found throughout the WAU and inhabit reaches upstream of anadromous migration barriers.

The South Fork Freshwater (C1) and Upper Freshwater Creek had the highest densities of juvenile salmonids according to index reach electrofishing summaries. Lowest utilization by juvenile salmonids appears to be in Graham Gulch (GG), where a significant portion of the upper channel reaches have intermittent flow. According to the Pool Condition Evaluation (Table 3-4), every CGU sampled contains fair to good rearing habitat. However, the Substrate Condition Evaluation (Table 3-5) and V* results indicate that the presence of sand and fine sediment in pool and riffle habitat reduces the quality and may reduce the quantity of rearing habitat in many locations in the Freshwater watershed. See Map F-5: Rearing Areas of Concern.

Good winter rearing areas for salmonids contain a number of characteristics including large substrate with interstitial spaces, plentiful LWD, complex pools, and access to floodplains and side channels. Upper Freshwater (C1, C2, C3) appears to provide the best winter rearing habitat in the basin, followed by middle to upper Little Freshwater (U1, U2) and middle McCready Gulch (U2). This is due to abundant instream LWD cover and access to velocity refugia on floodplains. Relatively poor winter rearing conditions exist in Lower Freshwater (MS3) and the School Forest (U2) due to heavily embedded substrates that restrict juvenile salmonids from using interstitial spaces in the streambed as cover, poor access to floodplains, and low LWD complexity. Graham Gulch (GG) provides fair to good winter rearing habitat, but the presence of the county road culvert, which tends to block upstream juvenile migration, restricts the ability of juvenile salmonids to utilize the subbasin. County culverts on McCready and Cloney Gulches also appear to restrict fish movement into these basins (see Section 3.7.3)

3.7.3 Migration Areas of Concern

There are no man-made barriers to salmonid migration on PALCO land within the WAU. However, upstream adult migration ceases when it reaches high gradient reaches, waterfalls, and/or impassable boulder roughs in each of the subbasins.

Three road crossings downstream of PALCO land in the lower reaches of McCready Gulch, Cloney Gulch, and Graham Gulch are either seasonal or permanent migration barriers for salmonids (Taylor 2000). The McCready Gulch crossing is located on an old county road that is outside PALCO land. It is constructed of a perched concrete box culvert with a natural bottom and may be a velocity barrier to juvenile migration at high flows. 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 due to jump height and outlet flow pattern. 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 due to jump height. See Resource Sensitivity Report – Migration, as well as Map F-1: Salmonid Distribution Map. Intermittent reaches exist in upper Cloney Gulch, Graham Gulch, and South Fork Freshwater Creek. In these areas, low summer flows travel through sediment deposits in the channel bed rather than as overland flow. These reaches create summer season migration barriers for juvenile salmonids. See Map F-5 for migration areas of concern locations.

4.0 RESOURCE VULNERABILITY

Channel segments with similar physical characteristics (stream gradient and geology) and responses are grouped into 12 channel geomorphic units (CGU). The Stream Channel Module (Appendix E) developed the CGU descriptions. Data on habitat conditions and salmonid life history and distribution patterns, obtained from field surveys and historical analysis, were extrapolated to all segments in each CGU and used to determine the potential biological and habitat response to changes in input factors. These inputs are LWD, bank stability, peak flow, coarse sediment, and fine sediment. The potential for biological or habitat response to the input variables is termed the "resource vulnerability." The Fisheries Module analyst has consulted with other module analysts to determine the vulnerability of the fisheries resources to increases or decreases in inputs (Table 4-1). The logic behind how these vulnerability calls were developed for each CGU follows.

Table 4-1: Fish Habitat Vulnerabilities (Low, Medium, High) for each Channel Geomorphic Unit.

CGU		LWD	Bank Stability	Peak Flow	Coarse Sediment *	Fine Sediment *
Consolidated Geology						
C1	0-3%	H+	L	H	H	H
C2	3-6.5%	M+	L	M	M	M
C3	6.5-20%	M+	L	L	L	L [2]
C4**	20+%	L+	L	L	L	H[2]
Unconsolidated Geology						
U1	0-3%	H+	L	H	H+	H
U2	3-6.5%	H+	L	M	H+	M
U3	6.5-20%	L [1]	L	L	M+	L [2]
U4**	20+%	L+	L	L	M	L
Exceptions						
MS[1] (South Fork to Graham Gulch)		H+	L	H	H [3]	H
MS[2] (Graham Gulch to Little Freshwater)		H+	L [4]	H	M	H
Ms[3] (Little Freshwater to 3 Corners)		H+	L [4]	M	M	M
GG (Graham Gulch 0-6.5%)		H+	L	H	H	M
CG (Cloney Gulch 0-3%)		H+	L	H	H+/H	H

* Coarse sediment: >8 mm for fish, >2 mm for channel processes, Fine sediment: 8 mm or less
** Non-fish bearing streams
+ Increase in coarse sediment may have positive effects in this gravel-poor geology
[1] May have been more prior to first harvest
[2] High negative impact to amphibians, low for fish due to scarcity, filling of seeps with fines
[3] Too much coarse sediment can destabilize channel, but moderate increases may be beneficial
[4] Bank erosion could create more complex habitats if residents allowed it to occur

4.1 U1 - UNCONSOLIDATED WILDCAT

Description: Confined, pool-riffle channel with gradients of 0-3%. Substrate is predominantly sand and fines. Wood frequency is high. Pool area (60-76% of wetted channel area) is good.

Pool frequency is good with one pool every 1.9-3.7 channel widths. Most pools in this CGU are formed or associated with LWD. Some pools are formed by scour along bedrock. Bank erosion is present in some of the habitat units. Floods are able to spill over onto narrow floodplains in some locations. This CGU is located in portions of Little Freshwater Creek, McCready Gulch, and Falls Gulch.

Fish Habitat Conditions: The dominance of sand and fines in the substrate, typical of Wildcat geologies, has created poor spawning conditions and adversely affected rearing habitat. Although an average of 8.5% of the channel area contained spawning gravels, the embeddedness level was very high at 3.4. The high percentage of pools and LWD cover provides fair to good conditions for rearing salmonids. The high level of canopy cover provides abundant shade and source areas supplying terrestrial insects to the watercourses. Winter rearing habitat is fair with complex LWD cover in pools and low to moderate access to narrow floodplains. *Anomalous Segments*: NA

Conditions and Response Potential

LWD - Abundant functional LWD that meets the PFC Matrix key piece targets was observed in the surveyed reaches. Unstable banks are significant factors for recruitment of LWD into this channel type. Given the unconsolidated nature of the geology, LWD is an important habitat-forming structure due to its ability to facilitate pool scour and trap sediment. Due to the highly embedded substrates, LWD provides the majority of the rearing cover for juvenile salmonids. LWD also provides an important winter rearing habitat component whether it is in the bankfull channel or on the floodplain. *High Vulnerability +*

Bank Stability - Unstable banks are present in some of the habitat units and in some cases are associated with flow being deflected by LWD. Some of the erosion was the result of high flows scouring the banks. Bank erosion can increase as streambeds aggrade. However, bank erosion is a minor contributor of sediment to the channel when compared to landslides and the road network. *Low Vulnerability*

Peak Flow - Due to the relatively small substrate size, confined nature of the channel, and (when present) narrow floodplains, peak flows have the potential to scour redds. Winter rearing survival of juvenile salmonids is dependent on access to complex LWD and floodplains during high flows. *High Vulnerability*

Coarse Sediment - Coarse sediment accumulations are currently limited in this CGU. The Wildcat Group is composed of mudstones and siltstones that rapidly deteriorate during discharge events that transport bedload and tend to embed those rare coarse sediments that may be present. Therefore, any accumulation of coarse sediment is considered beneficial for fish. *High Vulnerability +*

<u>Fine Sediment</u> - There is an abundance of fine sediment in this CGU that fails to meet the PFC Matrix targets. The fine sediment load is due to natural contributions from the unconsolidated geology and management activities. A reduction in fine sediment input could increase the availability of coarse gravels and provide a significant improvement in spawning habitat quality. Not all fines flush during high flows so pool quality could be moderately affected by increases. *High Vulnerability*

4.2 U2 - UNCONSOLIDATED WILDCAT

<u>Description</u>: Confined, pool-riffle channel with gradients of 3-6.5%. Substrate is predominantly fine sediment. Gravel is subdominant in those reaches downstream of consolidated geologies. Wood frequency is high and meets PFC targets. Pool area and frequency is good and meet the PFC targets. Ninety four percent of the pools in this CGU are formed from LWD. Average wetted and bankfull widths are 2 and 14 ft, respectively. This CGU is located in portions of Little Freshwater Creek, McCready Gulch, and School Forest.

<u>Fish Habitat Conditions</u>: The dominance of fines in the substrate has created poor spawning habitat conditions that fail to meet the PFC Matrix targets. Only 2% of the channel area contained spawning gravels; the embeddedness level in these gravels was very high averaging 3.7. The high percentage of pools and LWD cover provides good to fair conditions for rearing salmonids that would probably be better without the heavy fine sediment load. The high level of canopy cover provides abundant shade and source areas supplying terrestrial insects to the watercourses. Winter rearing habitat is fair with complex LWD cover in pools. *Anomalous Segments*: NA

<u>Conditions and Response Potential</u>

<u>LWD</u> - Abundant functional LWD that meets the PFC Matrix key piece targets was observed in the surveyed reaches. Given the unconsolidated nature of the geology, LWD is an important habitat-forming structure due to its ability to facilitate pool scour and trap sediment. Unstable banks are one of the primary factors for recruitment of LWD into this channel type. Due to the highly embedded substrates, LWD provides the majority of the rearing cover for juvenile salmonids. LWD also provides an important winter rearing habitat component, whether it is in the bankfull channel or on the floodplain. *High Vulnerability +*

Bank Stability - Unstable banks are present in some of the habitat units and in some cases is associated with flow being deflected by LWD. Some of the erosion was the result of high flows scouring the banks. However, bank erosion is a minor contributor of sediment to the channel when compared to landslides and the road network. *Low Vulnerability*

Peak Flow - These segments have low spawning use due to their higher gradient and lack of spawning gravel. Therefore, potential impacts of scour are limited. High volumes of LWD help stabilize channel, reducing the potential for scour *Moderate Vulnerability*

Coarse Sediment - Coarse sediment accumulations are currently limited in this CGU. The Wildcat Group is composed of mudstones and siltstones that rapidly deteriorate during discharge events that transport bedload and tend to embed those rare coarse sediments that may be present. Therefore, any accumulation of coarse sediment is considered beneficial for fish. *High Vulnerability +*

Fine Sediment - There is an abundance of fine sediment in this CGU that fails to meet the PFC targets. The fine sediment load is due to natural contributions from the unconsolidated geology and management activities. The fines have a detrimental impact on spawning habitat quality, although there is limited spawning in these CGUs. Fines tend to flush during high flows so pool development is only moderately affected by increases. *Moderate vulnerability*

4.3 U3 - UNCONSOLIDATED WILDCAT

Description: Confined, step pool/cascade channel with gradients of 6.5-20%. The vast majority of watercourses in this CGU are either Class II or Class III streams with intermittent or ephemeral flow. Substrate is composed of predominantly mudstone and siltstone bedrock with boulders in several reaches from upstream consolidated geologies. Although directed LWD surveys were not conducted in this CGU, instream wood frequency is good. Pool area and frequency are good, meeting PFC targets. Most pools in this CGU are either plunge or bedrock formed. This CGU is located in many of the Little Freshwater, McCready Gulch, School Forest, Upper Freshwater, and South Fork tributaries.

Fish Habitat Conditions: The high gradient and geology type have limited the availability of spawning habitat in this CGU. Only 1.6% of the channel area contains spawning habitat, which has an embeddedness rating of 1.9. In those reaches with perennial flow, the high percentage of pools and boulder cover (provided by upstream Franciscan or Quaternary formations) provides good conditions for rearing salmonids. The high level of canopy cover provides abundant shade and source areas supplying terrestrial insects to the watercourses. Winter rearing habitat is good with boulder and LWD cover in pools. However, the high gradient severely limits utilization by salmonids. As stated above, many of these CGU units are located in Class II or Class III watercourses. Bank erosion is present in some units.

Anomalous Segments: PWA 203 in Falls Gulch has a natural high gradient boulder fish barrier located downstream.

Conditions and Response Potential

LWD - LWD provides for sediment storage and channel stability in this CGU. However, pool formation and salmonid summer and winter rearing cover are provided primarily by bedrock, boulders, and large cobble. *Low Vulnerability*

Bank Stability - Unstable banks are present in some of the habitat units. However, the sediment produced from the erosion would consist of small particles that are easily transported during high flows and do not significantly affect aquatic habitat in this CGU. *Low Vulnerability*

Peak Flow - Due to the confined, high gradient nature of the channel, high flows move with great velocity and create a cascading effect. There are ample locations for juvenile salmonids to take advantage of velocity cover behind or under the LWD, boulders, and cobbles in the Class I reaches during high flows. The high flows have the ability to scour out any redds present in the pool tailouts, although the gradient in many segments may be too high for most spawning salmonids. *Low Vulnerability*

Coarse Sediment - Coarse sediment is limited in this CGU due to the high gradient and poor ability of the Wildcat formation to produce gravel. Any coarse sediment present originates in upstream consolidated geologic formations. The pool habitats are currently composed of plunge and bedrock scour pools. A significant increase in coarse sediment may result in some filling of these habitats and a decrease in rearing potential, but these tend to be poor habitats for fish. An increase in competent gravel could improve amphibian habitat. *Moderate Vulnerability +*

Fine Sediment - Due to the steep gradients and confined channels, fines tend to flush from these reaches during high flows. However, excessive fines could fill in the interstitial spaces in seeps affecting amphibians. *Low Vulnerability for fish, High for amphibians*

4.4 GG - GRAHAM GULCH

Description: Confined, sediment-rich channel with gradients of 0-6.5%. Substrate is predominantly small cobble and gravel. Wood frequency is high, with 57% of the pools being formed by LWD. One hundred percent of the pools are associated with LWD. LWD key piece numbers meet PFC targets, but piece volume is slightly lower than target levels. Much of the LWD, especially in the lower reach, was manually placed during instream habitat enhancement activities. Pool area (50%) and frequency (1 pool every 2.8 channel widths) meet PFC targets in the lower reaches, but fall short in the upstream aggraded area. Surface flow becomes intermittent in the upstream reach. Floods are able to spill over onto narrow floodplains in some locations. A large, deep-seated landslide approximately midway up the drainage contributes large volumes of coarse sediment to the channel, resulting in aggradation. A review of this landslide conducted by the California Division of Mines and Geology (CDMG) staff led them to conclude that this feature occurred in the 1940s or 1950s and is probably of natural origin. There is a culvert under the county road that forms a partial barrier for upstream migrating adult salmonids and a complete barrier for juveniles.

Fish Habitat Conditions: The dominance of coarse substrate has created aggraded conditions and subsequently poor to fair spawning habitat conditions in upstream reaches. Although an average of 14.9% of the channel area contained spawning gravels, the embeddedness level was high (3.0 rating), and the bed may be susceptible to shifting during high flows. Rearing habitat quality is good in the lower reach. Summer rearing habitat quality in the upper reach is poor due to intermittent flow conditions, but becomes good once surface flows commence. The high level of canopy cover provides abundant shade and source areas supplying terrestrial insects to the watercourses. Winter rearing habitat is fair with complex LWD cover in pools and low to moderate access to narrow floodplains. Bank erosion is present in some of the habitat units. The combination of poor quality habitat elements, unstable substrate conditions, and blockage of fish passage by a county road culvert greatly reduces utilization of this CGU by salmonids.

Anomalous Segments: PWA Segment 302 (downstream of deep seated landslide) has intermittent flow, which eliminates summer rearing habitat potential and creates seasonal juvenile migration barriers. This condition may improve once the slide stabilizes and high flows transport excessive bedload from the system.

Conditions and Response Potential

LWD - Functional LWD was observed in many pools in the surveyed reaches. LWD is an important habitat-forming structure due to its ability to facilitate pool scour and trap sediment. This functionality is especially important in this CGU due to the high sediment inputs that aggrade the streambed in many places. LWD also provides an important winter rearing habitat component whether it is in the bankfull channel or on the floodplain. *High Vulnerability +*

Bank Stability - Unstable banks are present in some habitat units and upstream in the vicinity of the earthflow. However, sediment produced from the earthflow significantly exceeds the contribution from bank erosion. *Low Vulnerability*

Peak Flow - Sustained high flows have the potential to transport bedload and aid in pool development. High flows have the potential to mobilize bed and scour redds in this CGU. *High Vulnerability*

Coarse Sediment - Coarse sediment is extremely abundant in this CGU. The landslide contributes large amounts of coarse sediment, which aggrades the channel and degrades spawning and fills in rearing habitats in many places. Therefore, any additional accumulation of coarse sediment is considered detrimental to fish. *High Vulnerability*

Fine Sediment - There is an abundance of sand and fine sediment in the spawning substrate. Embeddedness is very high due to excessive sediment inputs, which results in poor spawning habitat quality. However, should the landslide stabilize and road erosion control work continue, the relatively high gradient (average 3% in fish-bearing reach) and corresponding high water velocities may help flush fines from the subbasin. *Moderate Vulnerability*

4.5 CG - CLONEY - GULCH

Description: Gravel-rich, 1.5–3% gradient pool-riffle channel. Substrate is predominantly small cobble and gravel. The number of pieces and volume of LWD meet or exceed PFC targets, although its contribution to pool formation is lower than ideal with a range of 11–33% of the pools being formed by LWD. Approximately 78–92% of pools are associated with LWD. Much of the LWD is old with limited recruitment of new pieces. Pool area (75% of wetted channel area) is good. Pool frequency is good with one pool for every three channel widths. Some pools are formed by scour along bedrock. Several pools in the lower reach contain man-made LWD structures. Floods are able to spill over onto narrow floodplains in some locations.

Fish Habitat Conditions:

Lower Reach: There is fair quality spawning habitat conditions in the lower reach. An average of 7% of the channel area contained spawning gravels, and the embeddedness level was moderate. The high percentage of pools (51% by length) with 44% greater than 2 ft deep provides good conditions for rearing salmonids. The high level of canopy cover provides abundant shade and source areas supplying terrestrial insects to the watercourses. Winter rearing habitat is poor to fair with limited functional LWD cover in pools and small substrate. Access to floodplains is low. Bank erosion is present in some of the habitat units.

Upper Reach: The dominance of coarse substrate has created aggraded conditions in many locations and subsequently poor to fair spawning and rearing habitat conditions. The aggraded streambed also exhibits intermittent flow conditions during the summer. Coarse sediment may have been delivered by shallow slides originating on the steep inner gorge slopes. Although an average of 10.5% of the channel area contained spawning gravels, the embeddedness level was high. The high canopy cover provides abundant shade and source areas supplying terrestrial insects to the watercourses. Although there is a moderate amount of functional LWD cover in pools winter rearing habitat is of poor to fair quality due to high embeddedness levels and little access to floodplains.

Anomalous Segments: There is a half-arch culvert with a concrete floor downstream at the county road. This creates a partial barrier for upstream migrating adults and a complete barrier for juveniles. Upper Cloney exhibits intermittent flow characteristics in aggraded areas during the summer. This creates a seasonal migration barrier for juvenile salmonids and desiccation of individual fish as portions of the reach dry up.

Conditions and Response Potential

LWD - A low to moderate level of pool-forming LWD was observed in the surveyed reaches. The majority of these LWD pieces were either relatively old or man-made structures. LWD is an important habitat-forming structure due to its ability to facilitate pool scour and trap sediment. Due to the highly embedded substrates, LWD provides the majority of the rearing cover for juvenile salmonids. LWD also provides an important winter rearing habitat component whether it is in the bankfull channel or on the floodplain. *High Vulnerability +*

Bank Stability - Unstable banks are present in some of the habitat units. However, bank erosion is a minor contributor of sediment to the channel when compared to landslides and the road network. Unstable banks are one of the primary factors for recruitment of LWD into this channel type. Approximately 46% of the newly recruited LWD, for which an input mechanism could be determined, came from bank erosion. *Low Vulnerability*

Peak Flow - Due to the relatively confined nature of the channel and narrow floodplains, peak flows have the potential to scour redds. LWD pool formation is relatively low, which could reduce bed stability. *High Vulnerability*

Coarse Sediment - The lower reach is contained in unconsolidated geology, which is composed of mudstones and siltstones that rapidly deteriorate into very fine-grained particles during discharge events large enough to transport bedload. The particles subsequently tend to embed any coarse sediments present. Therefore, accumulation of competent coarse sediment from the upstream consolidated geology could be considered beneficial for fish. *High Vulnerability +*

The upper reach flows through consolidated geology and contains excessive amounts of coarse sediment in many locations. Additional coarse sediment inputs in this area could simplify aquatic habitats, bury redds, and exacerbate intermittent flow conditions. *High Vulnerability*

Fine Sediment - There is an abundance of fine sediment in this CGU. A reduction in fine sediment input would likely increase the availability of coarse gravels and improve in spawning habitat quality. Not all fine sediment flushes during high flows so pool development is moderately affected by increases. However, reductions in LWD could reduce turbulent flow within the channel and result in pools filling with fine sediment. *High Vulnerability*

4.6 C1 - CONSOLIDATED

Description: Confined, 0–3% gradient pool-riffle channel. Substrate is primarily small cobble and gravel. Pool-forming wood frequency is moderate, with 42% of the pools formed by LWD. Pools make up approximately 58% of the channel area, which exceeds the PFC target. A few pools are formed by scour along bedrock. This CGU is located in the lower reaches of Upper Freshwater and South Fork, middle portions of Little Freshwater, and McCready Gulch.

Fish Habitat Conditions: Pools make up approximately 48% and 58% of stream length and area, respectively. However, only 19% have a residual depth greater than 2 ft. Rearing habitat is fair, with an average of 42% pools formed by LWD, 81% associated with LWD, and a shelter rating of 78 (per Flosi et al. 1998). Instream LWD meets or exceeds PFC targets. An average of 7% of the channel area contained spawning gravels with fair (2.3 rating) levels of embeddedness. Heavy spawning utilization in these areas has been observed. The high level of canopy cover (81%) provides abundant shade and source areas supplying terrestrial insects to the watercourses. Winter rearing habitat is composed of a good amount of functional LWD cover, fair substrate embeddedness, and little access to floodplains.

Anomalous Segments: The Lower South Fork contains windthrow that recruited to the stream and a seasonal barrier for salmonids.

Conditions and Response Potential

LWD – Pool-forming LWD was observed in 42% of the pools in the surveyed reaches, with 81% of the pools being associated with LWD. LWD is an important habitat-forming structure due to its ability to facilitate pool scour and trap sediment. There is an average of 2.3 key pieces of

LWD per 100 feet of channel length with an average of volume of 260 ft^3 per piece, which meets PFC targets. These are good levels, but further increases in LWD would likely improve pool formation and summer and winter rearing habitat quality. LWD also provides an important winter rearing habitat component whether it is in the bankfull channel or on the floodplain. A decrease in LWD levels would have an adverse effect on fish habitat. *High Vulnerability +*

Bank Stability - Unstable banks are present in some of the habitat units. However, bank erosion is a relatively minor contributor of sediment to the channel when compared to harvest unit landslides and the road network. Unstable banks are one of the primary factors for recruitment of LWD into this channel type. Approximately 57% of the newly recruited LWD, for which an input mechanism could be determined, came from bank erosion. *Low Vulnerability*

Peak Flow - This CGU is generally heavily utilized by spawning salmonids. An increase in peak flows may put redds at risk of being washed away. The lower reach of Upper Freshwater (PWA Segment 601) may be more susceptible to peak flows due to bedrock outcrops combined with lower levels of LWD that is capable of stabilizing the streambed and storing sediment. *High Vulnerability*

Coarse Sediment - Coarse sediment is plentiful in this CGU due to the higher durability of the consolidated geology. Point bars and meanders develop in areas of deposition. The heavily utilized spawning habitat depends on supply of this material. However, too much coarse sediment could aggrade the channel and fill in pools, reducing rearing habitat. *High Vulnerability*

Fine Sediment - There is a moderate amount of sand and fine sediment in the spawning substrate. Embeddedness averages 30%, which is a fair rating according to the Habitat Condition Indices. The amount of fines in the substrate has a direct effect on spawning habitat quality. V* results, although limited, indicate that some pool filling has occurred, which likely has reduced rearing habitat quality in some locations. *High Vulnerability*

4.7 C2 - CONSOLIDATED

Description: Confined, 3-6.5% gradient step pool channel. Boulder and cobbles dominate the substrate. Pool forming wood frequency is moderate, with 60% of the pools formed by LWD. Pools make up approximately 70% of the channel area, which exceeds the PFC target. A few pools are formed by scour along bedrock and plunges. This CGU is mostly found in the upper reaches of Upper Freshwater and South Fork, with additional portions in each of the other tributary sub-basins.

<u>Fish Habitat Conditions</u>: Pools make up 46% of the stream length, of which 20% have a residual depth greater than 2 ft. Rearing habitat is fair to good with one pool every 1.9 channel widths, shelter rating averaging 123, and LWD levels that approach or exceed PFC targets. An average of 5% of the channel area contains spawning gravels with fair (2.5 rating) levels of embeddedness. The high level of canopy cover provides abundant shade and source areas supplying terrestrial insects to the watercourses. Winter rearing habitat is fair to good being composed of boulder and cobble substrate, high instream cover complexity, and moderate substrate embeddedness.

Anomalous Segments: A series of natural migration barriers are located downstream of the Road 15 bridge in Upper Freshwater Creek (Segment 608). No fish were observed during Watershed Analysis surveys and two years of electrofishing surveys above this point. There are some riffles in the Upper South Fork that become intermittent during summer low flows and create seasonal juvenile migration barriers.

Conditions and Response Potential

LWD - Pool forming LWD was observed in 60% of the pools in the surveyed reaches, and 89% of the pools were associated with LWD. LWD is an important habitat-forming structure due to its ability to facilitate pool scour and trap sediment. There is an average volume of 69 ft^3 per key piece of LWD with 3.6 key pieces of LWD per 100 feet of channel length, which approach or meets PFC targets. However, the higher gradient and confined channel result in pool formation that is not dependent on LWD in many cases. LWD also provides an important winter rearing habitat component, whether it is in the bankfull channel or on the floodplain. However, winter rearing habitat is also provided by the large-sized substrate. *Moderate Vulnerability +*

Bank Stability - Unstable banks are present in some of the habitat units. However, bank erosion is a minor contributor of sediment to the channel when compared to landslides and the road network. Unstable banks are one of the primary factors for recruitment of LWD into this channel type. *Low Vulnerability*

Peak Flow - Sustained high flows have the potential to transport bedload and aid in pool development. However, the large substrate in this CGU is resistant to transport, except at very high flows. *Moderate Vulnerability*

Coarse Sediment - Coarse sediment is currently plentiful in this CGU. Scouring of coarse sediment develops pools by high flows. In these higher gradient reaches, fish are dependent on the larger sized fraction coarse sediment for cover habitat. The smaller size fractions of coarse sediment tend to be flushed out of the system. However, an oversupply of coarse sediment could aggrade the channel and degrade habitat. *Moderate Vulnerability*

Fine Sediment - There is a moderate amount of sand and fine sediment in the spawning substrate. Embeddedness averages >30% (2.5 rating), which is a fair rating according to the Habitat Condition Indices. The amount of fines in the substrate has a direct effect on spawning habitat quality. However, field observations indicate that fines do not tend to accumulate in these higher gradient reaches and fill spawning gravels and pools unless there is an oversupply. *Moderate Vulnerability*

4.8 C3 - CONSOLIDATED

Description: Confined, 6.5-20% gradient step pool-cascade channel. Bedrock and boulders dominate the substrate. Pool-forming wood frequency is moderate, with 38% of the pools being formed by LWD. However, the channel in many locations is choked by LWD exceeding the PFC targets. Pool habitat parameters exceed the PFC targets and make up 62% of the stream area with a frequency of 3.6 channel widths per pool in the summer and 2.5 channel widths per pool in the winter. Due to the high gradient, many pools are naturally formed by scour along bedrock and plunges. Many of these CGUs are located in Class II or Class III watercourses with intermittent or ephemeral flow. This CGU is located in the middle reaches of Upper Freshwater and South Fork.

Fish Habitat Conditions: Pools make up 27% of the stream length, although significant portions or these CGUs exhibit intermittent flow. Only 6% of the pools in this CGU are greater than 2 feet deep, which is to be expected given the narrow channel width and small drainage area. Few habitat units were measured as the channel was filled with LWD. Rearing habitat is poor due to very low or intermittent flows. An average of 4% of the channel area contained spawning gravels, although the steep gradient may restrict spawning activity. The moderate level of canopy cover provides ample shade and source areas supplying terrestrial insects to the watercourses. Winter rearing habitat is of good quality, with a large amount of functional LWD cover in pools and boulder and cobble substrate. *Anomalous Segments*: NA

Conditions and Response Potential

LWD – Pool-forming LWD was observed in 38% of the pools in the surveyed reaches, with 79% of the pools being associated with LWD. LWD is an important habitat-forming structure due to its ability to facilitate pool scour and trap sediment. However, the high gradient and confined channel also result in pool formation that is not dependent on LWD. LWD provides an important winter rearing habitat component, whether it is in the bankfull channel or on the floodplain. *Moderate Vulnerability +*

Bank Stability - Unstable banks are present in some of the habitat units. However, bank erosion is a minor contributor of sediment to the channel when compared to landslides and the road network. Unstable banks are one of the primary factors for recruitment of LWD into this channel type. The relatively high gradient is capable of flushing downstream most of the sediment introduced from unstable banks. *Low Vulnerability*

Peak Flow - Sustained high flows or increases in peak flows have the potential to transport bedload and aid in pool development. However, the large substrate in this CGU is resistant to transport except at very high flows. In addition, the relatively small drainage areas associated with this CGU may not be able to generate the significant peak flow increases necessary to mobilize bedload. Fish respond to these high flows by seeking cover under or behind the substrate and LWD. However, these areas probably have relatively little utilization by fish due to the high gradient. *Low Vulnerability*

Coarse Sediment - Coarse sediment (boulder size, >10 inches) is currently the dominant or subdominant particle size in many of the habitat units in this CGU. Scouring of smaller coarse sediment by high flows develops pools. In these higher gradient reaches, fish are dependent on the larger sized fraction of coarse sediment for cover habitat. The smaller size fractions of coarse sediment tend to be flushed out of the system. A large oversupply of coarse sediment could aggrade the channel and degrade habitat. *Low Vulnerability*

Fine Sediment - There is a relatively small amount of sand and fine sediment in the spawning substrate. Embeddedness averages >40% (2.7 rating), which is a poor rating according to the Habitat Condition Indices. However two of the three stream segment sampled for this analysis had fair embeddedness condition ratings of 2.1 and 2.4. Fines may not accumulate in large quantities in these high gradient reaches and fill pools or aggrade the channel unless stream power was low and there was a significant oversupply. *Low Vulnerability for fish, High vulnerability for amphibians*

4.9 MS1 - SOUTH FORK FRESHWATER TO GRAHAM GULCH

Description: Alluvial transport reach, <1.5% gradient. Substrate is primarily small cobble and gravel with areas of exposed bedrock and large cobble substrate. There are a poor number of LWD pieces (approximately 0.5 key pieces of LWD per 100' of channel length) that fail to meet the PFC targets. However, the average volume of each key piece (313 ft^3) meets the PFC target. Pool-forming wood frequency is low compared to other CGUs, with 36% of the pools being formed by LWD. Bedrock scour and corner pools account of 43% of the pools. This CGU carries high flows, which tend to flush small diameter LWD downstream. Pools make up approximately 63% of the channel area, which exceeds the PFC target. Pool frequency meets PFC targets with one pool every three channel widths.

Fish Habitat Conditions: Pools make up 52% of the stream length, of which 36% have a residual depth greater than 2 ft. Rearing habitat is fair with one pool every three channel widths, shelter rating averaging 58, canopy closure of 76% over the stream, and key LWD that exceeds the per piece volume PFC target but not the number per 100 feet criteria. An average of 10% of the channel area contained spawning gravels with generally fair to poor (2.1 to 3.1 ratings) levels of embeddedness, although several habitat units in the upper segment have low embeddedness levels. This CGU has some of the highest spawning habitat use in the basin. The moderate level of canopy cover provides ample shade and source areas supplying terrestrial insects to the watercourses. Canopy was rated as moderate due to the relatively wide channel. Winter rearing habitat is of poorer quality in the downstream reach of this CGU due to a relatively low amount of complex LWD cover in pools, limited access to floodplains, sand being the dominant or subdominant particle size in some habitat units, and high embeddedness levels. Winter rearing habitat is of better quality in the upper reach of this CGU due to boulder and cobble being dominant or subdominant in many habitat units and lower embeddedness levels.

Anomalous Segments: Man-made LWD structures in the upstream reach trap sediment, creating better spawning habitat than the downstream reach.

Conditions and Response Potential

LWD – Pool-forming LWD was observed in 36% of the pools in the surveyed reaches, with 79% of the pools being associated with LWD. LWD is a secondary habitat-forming parameter because high flows and confined channel conditions in many locations tend to displace all but the largest pieces of LWD. The LWD that is stable traps sediment and small woody debris and provides important spawning and winter rearing habitat components. *High Vulnerability +*

Bank Stability - Unstable banks are present in some of the habitat units. This CGU contains some of the most valuable spawning habitat in the basin and is sensitive to fine sediment inputs. However, bank erosion is a minor contributor of sediment to the channel when compared to landslides and the road network. Unstable banks are one of the primary factors for recruitment of LWD into this channel type. Approximately 85% of the newly recruited LWD, for which an input mechanism could be determined, came from bank erosion. *Low Vulnerability*

Peak Flow - Sustained high flows are the primary habitat-forming parameter in this CGU. The confined nature of the channel and high flows have a direct influence on salmonid winter survivability. Redds are potentially vulnerable to scour in this CGU. The Hydrology Module calculated the increased potential for scour to egg pocket depth (12cm) as being 0.98% at baseline to 1.3% for a storm event with a 5-year return interval. However, due to the importance of this CGU for spawning, any increased scour is undesirable. *High Vulnerability*

Coarse Sediment - Coarse sediment is currently more plentiful in the lower reach of the CGU than the upper reach where bedrock is present in many locations. Scouring of coarse sediment by high flows develops pools. Coarse sediment stability is dependent on the presence of functional LWD. Spawning habitat depends on supply of this material. The upper reach of this CGU is one of the three primary spawning locations in the Freshwater Creek basin and as such is vulnerable to sediment increases, which can destabilize the bed. However, decreases in course sediment supply could reduce spawning habitat availability in this area, especially since many areas have already been scoured to bedrock. *High Vulnerability*

Fine Sediment - There is a moderate amount of sand and fine sediment in the spawning substrate. Embeddedness varies from poor (3.1 rating) in the lower reach to fair (2.1 rating) in the upper reach. There are several habitat units in the upper reach of this CGU that have good (1-2) embeddedness values. This upper reach is a high spawning use area. The amount of fines in the substrate has a direct effect on spawning habitat quality. *High Vulnerability*

4.10 MS2 - GRAHAM GULCH TO LITTLE FRESHWATER

No instream habitat data were collected in this CGU for this watershed analysis. The information presented below in the Description and Fish Habitat Condition section is drawn from 1987 habitat typing information by HSU graduate students.

Description: Alluvial aggradational reach with gradients <1%. Substrate is predominantly gravel with inputs dominated by Graham Gulch contributions. Most pools formed by corner or bedrock scour. Pool area is poor with approximately 20% of channel length in pools. LWD frequency is low due to an absence of large conifer riparian vegetation and LWD removal by residents that live adjacent to the creek in this reach. Few pools formed by LWD. Floods are able to spill over onto floodplains.

Fish Habitat Conditions: The presence of gravel from Graham Gulch has created good spawning habitat conditions in some locations in this CGU, although historic surveys suggest utilization has been low to moderate. Embeddedness levels are fair. Most instream habitat cover is provided by overhanging terrestrial vegetation and small woody debris. The fair level of canopy cover provides moderate shade and source areas supplying terrestrial insects to the watercourses. Winter rearing habitat is poor with low amounts of complex LWD cover in pools and limited access to floodplains until flows overtop the banks. Bank erosion is present in a few locations. *Anomalous Segments*: NA

Conditions and Response Potential

LWD - A low level of functional LWD was observed in the surveyed reaches. Adjacent non-PALCO landowners have significantly modified adjoining riparian forests and reduced LWD levels through active LWD removal. Winter rearing habitat is of low quality in part due to the low level of LWD. LWD is an important habitat-forming structure due to its ability to facilitate pool scour, provide cover, and trap sediment. *High Vulnerability* +

Bank Stability - Unstable banks are present in some of the habitat units. Bank erosion is a minor contributor of sediment to the channel when compared to landslides and the road network. However, the spawning habitat in the CGU may be sensitive to additional sediment inputs. In addition, the narrow strip of riparian vegetation in this CGU may not have the ability to stabilize the bank adequately during high flow events. The human-induced confinement of the channel limits its ability to meander and create higher quality habitats. *Low Vulnerability*

Peak Flow - Due to the relatively entrenched nature of the channel, peak flows have the potential to scour redds, although only limited to moderate spawning occurs here. Winter rearing survival of juvenile salmonids may be affected during high flows due to the lack of complex LWD, large substrate, and velocity refugia. Lack of LWD may also result in less stable substrate, which may scour redds. *High Vulnerability*

Coarse Sediment - Coarse sediment is currently abundant in this CGU, much of which is provided by inputs from Graham Gulch. Coarse sediment contributes to simplification of habitats when there are limited roughness elements that can scour habitat features, such as seen in this CGU. The coarse sediment from Graham Gulch provides some very good spawning habitat although utilization is limited. *Moderate Vulnerability*

Fine Sediment - There is a significant amount of fine sediment in this CGU. An increase in fines could have a detrimental impact on spawning and rearing habitat quality and aquatic insect production. *High Vulnerability*

4.11 MS3 - LITTLE FRESHWATER TO 3 CORNERS

Description: Alluvial aggradational reach with gradients <0.5% and an entrenched channel. Levees confine the channel in the lower reach. The majority of this CGU is influenced by tidal action to some degree depending on streamflow. Substrate is predominantly gravel and sand with small cobble subdominant in the upper reaches. LWD frequency is low and does not meet PFC targets with only 0.3 key pieces per 100 feet of channel length. Pools make up approximately 89% of the channel area, which exceeds the PFC targets. Most pools in this CGU are corner pools. The two longest pools (dammed pools) are formed by sediment plugs at the tailout. Floods are able to spill over onto floodplains. The channel appears to be constricted by encroaching streamside vegetation that, in combination with flooding caused by high tides coincident with high flows, encourages sediment deposition on the banks and further narrowing. The riparian zone is narrow due to agricultural and residential uses which, in turn, significantly limit LWD recruitment. In many places, the extent of riparian vegetation is one tree wide. LWD removal by residents also reduces inchannel LWD levels.

Fish Habitat Conditions: The dominance of small gravel and sand has created poor spawning habitat conditions in the lower reach of this CGU. Embeddedness levels have an average rating of 2.7. The upper segment contains some habitat units with very good quality spawning gravel, although it has relatively low utilization. An average of 5% of the channel area contains spawning gravels that are highly embedded in downstream areas and have low embeddedness in most upstream habitat types. The high percentage of pools and overhanging vegetation provides fair rearing conditions for juvenile salmonids. The instream shelter rating averages 79, which is a fair rating according to the Habitat Condition Indices. However, pools are shallow and the habitat fairly simplified in a large part because of the absence of LWD. The fair level of canopy closure over the stream (66%) provides moderate shade and source areas supplying terrestrial insects to the watercourses. Although the streambank vegetation can provide some velocity refugia, winter rearing habitat is poor with low amounts of complex LWD cover in pools and limited access to floodplains until flows overtop the banks. Bank erosion is present.

Anomalous Segments: The upstream reach contains areas of good spawning habitat although it is has low utilization.

Conditions and Response Potential

LWD - A very low level of pool-forming LWD was observed in the surveyed reaches. In addition, existing riparian conditions are impaired and are unlikely to provide future LWD. LWD is an important habitat-forming structure due to its ability to facilitate pool scour and trap sediment. Nearly all the winter rearing habitat is associated with the encroaching deciduous riparian vegetation and the few pieces of LWD that are present. Removal of LWD by residents diminishes the quality and quantity of fish habitat in this CGU. *High Vulnerability +*

Bank Stability - Unstable banks are present in some of the habitat units. Bank erosion is a minor contributor of sediment to the channel when compared to landslides and the road network of the upstream watershed area. The relatively high quality spawning habitat in the upper reach of the CGU may be sensitive to additional sediment inputs. The human-induced confinement of the channel limits its ability to meander and create more complex habitats. Bank erosion in this CGU could have beneficial effects by developing off-channel habitats, causing channel avulsion, and increasing meander wavelength and amplitude. *Low Vulnerability*

Peak Flow - Due to the relatively entrenched nature of the channel, peak flows have the potential to scour redds, although only limited spawning occurs here. Winter rearing survival of juvenile salmonids may be affected during high flows due to the lack of complex LWD, large substrate, and velocity refugia. However, some velocity refugia is provided by willows and bank vegetation. *Moderate Vulnerability*

Coarse Sediment - Coarse sediment is currently limited in the downstream reaches of this CGU. In part, this is due to increasing contributions to the bed sediment from areas draining Wildcat Group geology. The Wildcat Group is composed of mudstones and siltstones that rapidly deteriorate into fine grain sediments during discharge events that transport bedload. The coarse sediment component of the bedload is reduced as substrate particles undergo attrition as they move into the CGU. There is some Franciscan coarse sediment from Graham Gulch in the upper reach that provides very good spawning habitat. *Moderate Vulnerability*

Fine Sediment - There is an abundance of fine sediment in this CGU due to the unconsolidated geology that contributes bedload, as noted above. In addition, the very low stream gradient and reduced stream power encourages deposition of fine sediment. A reduction in fines would improve spawning habitat quality to some degree. However, spawning habitat quality may have been historically relatively poor in the low gradient downstream depositional reaches that are influenced by tidal action. Being at the downstream end of the watershed, the natural attrition of cobble and gravel particles as they tumble and roll from further up in the watershed during runoff events contributes fines and small substrates. *Moderate Vulnerability*

5.0 CONCLUSIONS

5.1 HABITAT CONDITIONS

Analysis of the data indicates that fair to good conditions exist for summer rearing and holding salmonids in the WAU. Pool area and frequency meet target levels. Pool habitat cover complexity and LWD abundance are at fair to good levels. There is a need for more pool-forming LWD in C1, U1, MS1, MS2, and MS3. Increased complex LWD would improve the summer and winter rearing habitats in these CGUs. Summer water temperatures generally do not exceed MWAT target levels in the PFC Matrix. Substrate conditions are generally poor to fair throughout the watershed. There is evidence of fine sediment accumulating in and shallowing pool habitats. This indicates that salmonid abundance may be limited by sediment inputs that reduce successful spawning through emergence of fry and rearing habitat quality. Substrate quality is not good in CGUs C1, C2, MS1, and CG and it is generally poorer in U1, U2, GG, and MS3. This could be expected since these latter CGUs are either poor gravel production areas and/or have excessive fine sediment bedload. The Mass Wasting, Surface Erosion, and Stream Channel Assessment Modules provide information on sediment sources and the relative contribution from natural and anthropogenic causes.

5.2 TURBIDITY/TOTAL SUSPENDED SEDIMENT

The Watershed Analysis methods developed by PALCO recognize that turbidity and suspended sediment may directly or indirectly affect fish and fish habitat. For the current Freshwater Creek Watershed Analysis, a temporally extensive but spatially limited data set was available to evaluate turbidity and TSS and assess their potential impacts to salmonids. The risk modeling provided in this report demonstrated that behavioral and mild sublethal stressful conditions likely occur in Freshwater Creek during some peak flow conditions; however, no conditions measured in the basin were of adequate duration or concentration to lead to direct mortality or deficits in growth. Exposure durations over the period examined were generally less than 24 hours, and would not result in biological impairment at the concentrations realized. It must be noted, however, that the analyses provided here considered storm events from January through July of 1999 only. Data from the early storms of HY 1999 could not be analyzed because no TSS data were collected during this period. Early storms of HY 2000 were not analyzed because the TSS samples collected had not been completely analyzed and reviewed for quality control.

Analyses of turbidigraphs and hydrographs demonstrated that the conditions of greatest concern may 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. Given this evidence it is certainly possible that the severity of effects from storms would be greater earlier in the season than later. Notwithstanding, most exposures to high TSS concentrations occur during periods of low water temperatures, when the metabolic rates of fish are depressed thereby reducing the likelihood of behavioral or physiological impairment (Sullivan 19xx). Furthermore, any interpretation of impact must be made cautiously because the effects reported (e.g., are often difficult to compare due to the inconsistencies in study designs and methods (see Attachment F-1 for general review). No site-specific studies have been completed to validate the effects of turbidity or TSS on salmonids in Freshwater Creek. The possibility that salmonids in Freshwater Creek are more or less sensitive to turbidity or TSS than the modeling results would suggest cannot be discounted at present. The Newcomb and Jensen model is inherently conservative because the source data used to develop the risk equations were largely derived from laboratory studies on fish stocks adapted to waters of naturally low turbidities in more ecologically stable regions.

The analysis of rainfall as the mechanism for sediment recruitment suggests that events of approximately ½ inch of rain could yield suspended sediment concentrations of at least 65 mg/l, which in turn would yield turbidity of approximately 60 NTU. The lowest observable effect concentration for suspended sediment reported in the literature is 20 mg/l, which interfered with home stream preference in Chinook (Sigler 1988); however, numerous other researchers have reported no effects at concentrations over 10 times higher. The variability in the sensitivity of fish to turbidity and suspended sediment highlights the local adaptation of some stocks to naturally turbid waters. Whether salmonids from the Freshwater Creek basin are more tolerant of suspended sediments and/or turbidity because of the relatively erosive geology and naturally high turbidity levels within the basin is not known.

5.3 TEMPERATURE

The Aquatic Properly Functioning Conditions Matrix states that the indicator range for temperatures is 11.6 to 14.5°C. This is consistent with the preferred temperature range of 11.8 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. The average water temperatures were within the preferred range of temperatures. This indicates there are no chronic temperature problems in the Freshwater watershed.

5.4 INSTREAM FINE SUBSTRATE COMPOSITION

Bjornn and Reiser (1991) consolidated the results of several studies and showed that the success of emergence of swim-up fry (i.e., salmonid fry emerging from the gravel) began to decline when the percentage of fine sediment (smaller than 2-6.4 mm) increased beyond 8 to 23%. McHenry et al. (1994) reported that a threshold conditions exists at >13% of fines <0.85 mm, above which egg to alevin survival drops rapidly. The PFC Matrix recommends a target range of <11-16% for fine sediment <0.85 mm, above which there could be a decrease in embryo survival due to a reduction in gravel permeability. PALCO substrate samples found that 11 to 47% of the substrate sampled was composed of fines <0.85mm, and 25 to 59% of the substrate sampled was composed of fines <4.7 mm. Thus, it appears survival of salmonids from the egg to emergence stages is adversely affected by fine sediment levels in the watershed. This corresponds with the generally poor to fair substrate embeddedness conditions found during the Watershed Analysis field surveys. However, the field surveys also found localized areas of good gravel quality within reaches containing generally poor conditions. This was likely due to localized hydraulic patterns that enabled the flushing of fine sediments from the gravel. Thus, survival of salmonid eggs and fry is likely higher in many sites than the averaged substrate data would suggest.

The PFC Matrix referenced three papers that were used to develop the HCP and subsequently Freshwater Creek Watershed Analysis target of 11-16% fine sediment <0.85 mm. These papers were Chapman (1988), Peterson et al. (1992), and Burns (1970). Chapman (1988) described results from a variety of authors who sampled substrates and analyzed incubation and emergence within active redds and laboratory conditions. Chapman (1988) noted that redds contain a significantly lower proportion of fines than the surrounding substrate due to construction by female salmonids. Peterson et al. (1992) reviewed papers by researchers that looked at substrate composition within streams in Oregon, Washington, British Columbia, and Alaska to come up with their target of 11-16% fine sediment <0.85 mm. Burns (1970) collected multiple samples of spawning substrate (not redds) at riffle crests for three consecutive years. Burns' (1970) unlogged control reaches in Humboldt and Mendocino Counties contained an average of 16.4 to 23.2% fine sediment <0.83 mm for the same soil types found in Freshwater Creek.

It is important to note that of the three papers only Burns (1970) contained information specific to coastal Humboldt County soil types. In addition, the protocol Burns (1970) utilized was very similar to the method recommended by the PFC Matrix, Valentine Protocols (1995), and the substrate sampling protocol used by PALCO. The PALCO protocol did not sample within redds and Valentine (1995) does not recommend it. Redd sampling could also be viewed as a take of listed salmonids. Many of the studies reviewed by Chapman (1988) specifically sampled within redds, which makes those results incompatible with the Valentine protocols and PALCO monitoring program. Peterson et al. (1992) stated "Basin geology can have a significant effect on percent fines and this suggests that a universal target condition applied indiscriminately across geologic boundaries may be inappropriate." Peterson et al. (1992) targets may be representative of unlogged conditions in the Pacific Northwest and Alaska soil types and geologies, but not those in Humboldt County, California. The PFC Matrix states "Given the natural variation in sediment loading between and within watersheds, a watershed inventory and analysis should determine existing sediment levels and identify reasonable interim targets…" It appears that the Chapman (1988) sampling techniques and the Peterson et al. (1992) fine sediment target (11-16% <0.85 mm) are inappropriate for the Freshwater Creek watershed. Of the three papers, Burns (1970) appears to contain the most representative target criteria (16-23% <0.85 mm) for this and other watersheds containing similar soil types.

6.0 RESOURCE SENSITIVITY REPORT

A Resource Sensitivity Report (RSR) is written for those situations that occur off PALCO property but have an effect on fisheries resources in the watershed. The RSRs are similar to Causal Mechanism Reports but are not used in the Prescription writing process due to the lack of regulatory authority for properties outside PALCO ownership. However, RSRs can be used to identify potential restoration sites or suggest modifications for current downstream land use that could benefit salmonid species.

6.1 FISHERIES ASSESSMENT 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 (Taylor 2000). The McCready Gulch crossing is located on an abandoned county road within 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 F-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. Barriers limit access by juveniles seeking refuge from high mainstem flows, thereby potentially affecting winter survival.

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

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.

7.0 CONFIDENCE IN RESULTS

Confidence in the fish species list is good. None of the reviewed reports and surveys recorded observations of exotic species. Confidence in fish distribution is good 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. Confidence in spawning locations is moderate due to the difficulties inherent in conducting spawner surveys. Confidence in the habitat calls is moderate since there were areas where data were not collected. Confidence in the area of concern and vulnerability calls is moderate to good due to analysis of field data and correlation with the stream channel and amphibian modules. Confidence in determination of substrate quality as the primary limiting factor to salmonid production in the WAU is high. Confidence in the LWD calls is low to moderate since data were not collected in 13 out of 24 channel segments.

8.0 DEVIATIONS FROM THE STANDARD METHODS

There were no deviations from the standard data collection methodology. However, the Habitat Condition Indices Matrix in the Methods (PALCO 2000a) proved to be too unwieldy, complex, and sometimes contradictory for rating habitat conditions. In addition the PFC Matrix, which is a draft "Work in Progress," contains a target (pools >3 feet deep) that is not applicable for Freshwater due to shallow alluvium over bedrock. The SRT was consulted, and a modified set of Habitat Condition Indices were developed that rated critical habitat parameters. The analyst added three subjective indices (Substrate Quality, Gravel Availability, and Shelter Rating) due to the additional understanding these parameters contributed toward determination of spawning and rearing habitat quality. These modified indices are presented in Table 3-3. The methods worked well and are recommended for future watershed analyses.

9.0 MONITORING SUGGESTIONS

The field validation of the original base map Class I stream classification was conducted during summer low flows. Although the analysts were conservative on their classification calls, field visits should be conducted during timber harvest planning activities to further determine the upstream extent of fish residence. This is particularly true for low gradient intermittent watercourses that may have seasonal utilization by salmonids, particularly coastal cutthroat trout. It is recommended these reaches be visited prior to July 1 (while there is still surface flow) to determine their suitability for cutthroat trout. Surveyors should look for pool tail gravel 2-5 cm in size in patches greater than 0.3 m^2 and no downstream migration barriers, which would suggest spawner utilization. The surveyors should also look for habitats that contain complex LWD, which could indicate use as high winter flow refugia.

Additional surveys (electrofishing) should be conducted in School Forest and upper Upper Freshwater Creek to determine if these reaches warrant classification changes from Class I to Class II (See Map F-2). It is recommended that at least three years of surveys be conducted to determine fish absence (Larry Preston, pers. comm.). Monitoring locations in these reaches were previously electrofished (Upper Freshwater [PL Station 36] in 1998 and 1999, School Forest in 1999) with no fish being captured.

Continuation of PALCO's ongoing stream monitoring program is recommended. Turbidity monitoring is recommended in selected subbasins.

Bulk sediment samples should continue and include analysis of particles <6.5 mm in size to compare with the PFC Matrix. However, PALCO and the agencies need to rectify the PFC Matrix which sets a fine sediment target based on redd substrate composition within redds and the PALCO bulk sampling that samples outside of redds. Redds typically contain less fine sediment due to the construction process than the surrounding substrate.

There is a gap in monitoring data in CGUs MS2 and MS3. Public monitoring efforts should emphasize physical and biological sampling in areas outside PALCO property, such as the residential reaches in the basin.

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ATTACHMENTS

ATTACHMENT F-1: SUMMARIES OF DOWNSTREAM MIGRANT TRAPPING, UPSTREAM MIGRANT TRAPPING, INDEX REACH ELECTROFISHING, AND SPAWNER SURVEYS

ATTACHMENT F-2: EFFECTS OF SUSPENDED SEDIMENT & TURBIDITY ON SALMONIDS: AN OVERVIEW OF THE LITERATURE

ATTACHMENT F-3: A MULTIMETRIC ANALYSIS OF BENTHIC MACROINVERTEBRATE DATA COLLECTED FROM THE FRESHWATER CREEK WATERSHED (HUMBOLDT COUNTY, CALIFORNIA) 1994-1998

ATTACHMENT F-1

Summaries of Downstream Migrant Trapping, Upstream Migrant Trapping, Index Reach Electrofishing, and Spawner Surveys

The HFAC has been conducting downstream migrant trapping for the past four years. The level of basin coverage tended to vary with funding and volunteer availability. Trapping effort varied due to stream flow and trap installation timing. Table F-1 summarizes the past four years of downstream migrant trapping data.

Table F-1: HFAC Downstream Migrant Trapping Summaries.

Year	Coho YOY	Coho 1+/smolt	Trout YOY	Steelhead 1+	Steelhead Smolts	Chinook	Coastal Cutthroat	Trapping Days
Mainstem Freshwater								
1996	922	18	288	38		5	12	43
1997	1116	5	507	114	28	0	27	43
1999 *	3894	105	2418	107	689	7150	19	94
2000	954	174	1324	107	37	0	20	60
South Fork Freshwater								
1996	100	37	8	19		0	17	51
1997	215	37	0	10	0	0	40	42
1999	No data							
2000	1778	64	486	41	10	0	58	63
Graham Gulch								
1996	7	35	173	151		3	7	67
1997	44	0	4	54	7	3	13	61
1999	No data							
2000	0	1	733	109	24	0	2	64
Cloney Gulch								
1996	7142	260	185	160		215	40	94
1997	2641	184	346	87	43	0	39	67
1999	869	140	11	39	141	0	45	76
2000	652	317	5	48	9	0	24	67
McCready Gulch								
1996	3124	116	8	12		0	127	81
1997	3135	52	1	10	1	0	54	75
1999	165	1	25		1	0	73	76
2000	493	68	61	4	0	0	71	60
Little Freshwater Creek								
1999	311	112	0	64	206	1	40	63
2000	131	227	4	127	15	0	64	71

* Trap moved downstream from previous location. Comparisons with other years not appropriate.

The HFAC has been conducting adult salmonid trapping operations in Freshwater Creek for the past two decades. The primary objectives of the project are to provide eggs for the McCready Creek rearing station and help sustain or enhance salmonid population in Freshwater Creek. Once the fish are of suitable size they are planted in various tributaries within the basin. A secondary objective is to provide educational opportunities for local school children. Table F-2 summarizes the upstream migration trapping data.

Table F-2: HFAC Upstream Migrant Trapping Records*.

Season	All Coho	Wild Coho	All Chinook	Wild Chinook	Steelhead	Effort (days)
78/79	56		0			
79/80	35		2			
80/81	202		5		88	45
81/82	32		1			
82/83						
83/84						
84/85	153		3			82
85/86	73		5		21	102
86/87	68	58	13	12	29	53
87/88	65	37	8	8		
88/89	24	20	3	3		50
89/90	28	19	1	1	2	38
90/91	27	5	1	1		
91/92	130		5			75
92/93	286		10		38	69
93/94	235	234	10	10		
94/95	199	199	39	37	37	37
95/96	532	527	18	17	33	45
96/97	126	126	20	18	38	38
97/98	28	28	16	5	8	38
98/99	116	116	39	16		79

Note: This table was developed from a combination of HFAC and CDFG file information.

The level of trapping effort varied from year to year, which confounds any extrapolation to run size.

The CDFG and PALCO have been conducting juvenile salmonid index reach sampling within the Freshwater Creek watershed since 1993. Sampling locations have been periodically added over the years. Tables F- 3 through F - 10 contain summaries of the survey efforts.

Table F-3: Summary of CDFG Juvenile Salmonid Index Sampling in Little Freshwater Creek.

Year	Est. # Coho	Surface Area (m^2)	Total Biomass (g)	Density (fish/m^2)	Unit Biomass (g/m^2)
1993	18	73.2	61	0.25	0.83
1994	8	64.1	26	0.12	0.41
1996	41	63.8	95	0.64	1.49
1997	120	270	356	0.45	1.32
1998	6	157	29	0.04	0.18
1999	52	148.6	197.1	0.35	1.32
1993	5	73.2	14	0.07	0.19
1994	20	64.1	71	0.31	1.11
1996	9	63.8	59	0.14	0.92
1997	4	270.0	22	0.02	0.08
1998	21	157.5	169.1	0.13	1.07
1999	17	148.6	197.7	0.11	1.33

Table F-4: Summary of Juvenile Salmonid Index Sampling in S.F. Freshwater Creek.

Year	Est. # Coho	Surface Area (m^2)	Total Biomass (g)	Density (fish/m^2)	Unit Biomass (g/m^2)
1993	31	55.8	66	0.56	1.22
1994	50	67.7	108	0.74	1.60
1996	51	99.8	162	0.59	1.59
1997	25	116.8	90	0.21	0.77
1998	39	120.5	239	0.32	1.98
1999	77	94.9	177	0.81	1.87
1993	3	55.8	6	0.05	0.11
1994	32	67.7	62	0.47	0.92
1996	20	99.8	20	0.20	0.2
1997	7	116.8	106	0.06	0.91
1998	20	120.5	171	0.17	1.42
1999	93	94.9	204	0.98	2.16

Table F-5: Summary of Juvenile Salmonid Index Sampling in Cloney Gulch.

Year	Est. # Coho	Surface Area (m^2)	Total Biomass (g)	Density (fish/m^2)	Unit Biomass (g/m^2)
1993	49	202.8	130.7	0.24	0.65
1994	30	224.8	204	0.13	0.91
1996	59	110.1	119	0.53	1.08
1997	14	90.8	24	0.15	0.26
1998	0				
1999	52	209.6	136.5	0.25	0.65
1993	9	202.8	137	0.05	0.67
1994	24	224.8	225	0.11	1.00
1996	12	110.1	67	0.10	0.61
1997	8	90.8	18	0.09	0.20
1998	21	218.8	134.4	0.10	0.61
1999	25	209.6	285.6	0.11	1.36

Table F- 6: Summary of Juvenile Salmonid Index Sampling in McCready Gulch.

Year	Est. # Coho	Surface Area (m^2)	Total Biomass (g)	Density (fish/m^2)	Unit Biomass (g/m^2)
1996	59	110.1	119	0.53	1.08
1998	0				
1999	16	57.1	53.2	0.11	0.93
1996	12	110.1	67	0.10	0.61
1998	5	123.0	156	0.41	1.27
1999	7	57.1	85.1	0.12	1.49

Table F-7: Summary of Juvenile Salmonid Index Sampling in Graham Gulch.

Year	Est. # Coho	Surface Area (m^2)	Total Biomass (g)	Density (fish/m^2)	Unit Biomass (g/m^2)
1993	23	47.2	65	0.48	1.38
1994	14	26.9	51	0.52	1.9
1998	0				
1993	7	47.2	16	0.15	0.34
1994	7	26.9	17	0.26	0.65
1998	56	83.4	241	0.67	2.89

Table F-8: Summary of Juvenile Salmonid Index Sampling in Upper Freshwater Creek.

Year	Est. # Coho	Surface Area (m^2)	Total Biomass (g)	Density (fish/m^2)	Unit Biomass (g/m^2)
1998a	16	183.5	73.4	0.87	0.4
1998b	1	138.2	5.9	0.01	0.04
1998c	8	310.8	45	0.03	0.15
1999a	146	176.2	370	0.82	2.1
1999b	111	155.3	213.7	0.72	1.38
1999c	83	307.3	198	0.27	0.64
1998a	156	183.5	818.7	0.85	4.5
1998b	84	138.2	315.5	0.61	2.28
1998c	98	310.8	357.4	0.32	1.15
1999a	133	176.2	301.4	0.76	1.71
1999b	54	155.3	177.2	0.35	1.14
1999c	225	307.3	716.2	0.73	2.33

a=500' upstream of the South Fork
b=699' upstream of the South Fork
c=739' upstream of the South Fork

Table F-9: Summary of PALCO Juvenile Coho Index Sampling.

Mainstem Freshwater Creek Station #32			
Year	**Estimated # Coho**	**Survey Area**	**Density (fish/m²)**
1998	8	311	0.03
1999	83	344	0.241
Upper Mainstem Freshwater Creek Station #34			
1998	16	183	0.09
1999	146	183	2.15
Mid-Upper Mainstem Freshwater Creek Station #165			
1998	1	138	0.01
1999	111	169	0.656
McCready Gulch Station #135			
1998	0	95	0
1999	41	100	0.41

Table F-10: Summary of PALCO Juvenile Steelhead Index Sampling.

Mainstem Freshwater Creek Station #32			
Year	**Estimated # Steelhead**	**Survey Area**	**Density (fish/m²)**
1998	98	311	0.32
1999	225	344	2.01
Upper Mainstem Freshwater Creek Station #34			
1998	156	183	0.85
1999	133	183	0.726
Mid-Upper Mainstem Freshwater Creek Station #165			
1998	81	138	0.59
1999	54	169	0.319
McCready Gulch Station #135			
1998	0	95	0
1999	64	100	0.641

ATTACHMENT F-2: EFFECTS OF SUSPENDED SEDIMENT & TURBIDITY ON SALMONIDS: AN OVERVIEW OF THE LITERATURE

Numerous laboratory and field studies have been conducted on pre-emergent, juvenile, and adult life stages of salmonids to address the effects of turbidity and/or total suspended solids (TSS). Responses observed are not only dependent on the concentration of suspended sediment but are a function of life history stage, duration of exposure, and particle size. Effects from suspended sediment can be categorized into four responses: no effect, behavioral effects, sublethal effects, and paralethal/lethal effects. No effect is observed when suspended sediment is introduced into the system (stream or tank) and there is no behavioral or physiological change in the fish. Behavioral effects include alarm reactions (sporadic swimming), avoidance (moving out of turbid conditions), territorial breakdown (fish no longer defended territory), decreased perceived risk of predation (using turbidity as cover), changes in prey preference, and reduced preferences for homewaters. Sublethal effects include reductions in feeding rates, decreased reaction distances (distance fish travel from spotting prey to capture), decrease in navigational aides (ability to see surface or bottom for positioning), increased gill flaring, increased coughing, elevated plasma glucose, depressed leucocrit, and gill tissue damage. Paralethal/lethal effects include mortality, reduced resistance to disease, and delayed hatching.

Pre-Emergent Salmonids

During the pre-emergent life stage of salmonids, high percentages of suspended fines smaller than 0.85 mm can limit survival by inhibiting the ability for oxygenated water to travel through the gravel and provide oxygen to the fish (Ziebell 1960) and by physically blocking the ability to emerge from the gravel, entombing them (Cederholm et al. 1978). Flow of silt-laden water over the streambed deposits silt within the gravel, even though velocities exceed those allowing deposition on the surface (Cooper 1965). The extent of damage to aquatic resources due to sedimentation is greatly influenced by the magnitude and timing of the sedimentation and ability of the stream to flush these sediments during storm periods (Cederholm et al. 1978). Streams with low high-flow: low-flow ratios require less sediment load to make lasting changes in gravel composition (Shapley and Bishop 1965).

The most critical oxygen needs occur at the time of hatching (Alderdice et al. 1958). Oxygen levels limiting survival in Atlantic salmon were greater for eggs (7.5 mg/l at 10°C) than for posthatch alevins (4.5 mg/l) (Hays et al. 1951). Koski (1972) found that an increase of 1% in sediment less than 0.833 mm resulted in a 4.5% decrease in survival from redd to emergence of coho salmon. Fry fitness is also directly related to oxygen levels and the amount of sand in the spawning gravel, and a reduction in fry fitness may have pronounced effects on survival following emergence (Koski 1975). Koski (1975) also suggested that there was a selective mortality against larger fry in gravel containing high amounts of sand.

Juveniles

Behavioral Effects

Behavioral modifications, including avoidance and breakdown of dominance hierarchy, resulted from turbidity of 30 NTU and/or TSS from as little as 20 mg/l up to 650 mg/l (Berg and Northcote 1985, Sigler 1988). Servizi (1988) found that coho acclimated to clear water avoided areas of 70 NTU or greater, while coho acclimated to 2 to 15 NTU avoided areas of 106 NTU or greater. Berg and Northcote (1985) found that the ability of juvenile coho to feed not only decreased as a direct result of increasing turbidity on visibility, but also decreased as an indirect result of the hierarchy breakdown. Feeding effectiveness may be impaired within the 70 to 100 NTU range, well below sublethal stress levels (Bisson and Bilby 1982). Sudden pulses of turbidity appeared to be important in triggering sporadic swimming (Berg and Northcote 1985). This reaction may cause displacement of fish into downstream habitats. This displacement places the fish into new habitats, requiring them to re-establish hierarchical relationships and territories. Additional fish may be displaced farther downstream into unfavorable habitats. The accumulated effects of repeated disruption of dominant-subordinate relationships and territories reduce feeding ability, and physiological stress may incur energetic costs at the expense of growth (Berg and Northcote 1985). Behavioral responses to suspended sediments have been reported by several investigators and are initiated in the range of 22 to 100 NTU.

Sublethal effects, including changes in feeding rates, growth rates, gill flaring and coughing, and navigation, were reduced by turbidities ranging from 22 to 265 NTU and/or TSS concentrations of 2,000 to 3,000 mg/l (Sigler 1988). Berg and Northcote (1985) found that ingestion rates of juvenile coho decreased over 50% at turbidities above 30 NTU. Yearling coho salmon and steelhead trout exhibited decreased feeding rates when exposed to suspended sediment concentrations of 2,000 to 3,000 mg/l (Redding and Schreck 1987). Turbidities as low as 25 NTU have been associated with reduced fish growth (Sigler et al. 1984).

Since behavioral responses and avoidance occur in similar ranges, avoidance may be prompted by irritation of gill tissues by suspended sediments (Servizi 1988). Juvenile coho exposed to turbidities of 20 NTU or greater experienced increased gill flaring and coughing (Berg and Northcote 1985). Juvenile coho tested at Cultus Lake Laboratory, BC, increased their coughing response after being exposed to 190 mg/l of Frasier River sediment (equivalent to 20 NTU) (Servizi 1988).

Fish exposed to turbidities above 30 NTU lowered their holding position to within 10 cm from the bottom, presumably to see the bottom to help them maintain position while in the turbid water (Berg and Northcote 1985).

The May 18, 1980 eruption of Mount St. Helens caused turbidities in the Columbia River to reach as high as 1,500 JTU. This natural disaster became a good opportunity to conduct field studies on the effects of high turbidities and suspended sediment levels on salmon. Several studies documented the diet changes of juvenile salmon. Prior to the eruption, the epibenthic amphipod *Corophium salmonis* was the primary prey for subyearling and yearling chinook, coho, steelhead, and American shad, all of which tended to remain in the upper estuary. After the eruption, however, the primary prey item for salmon was the pelagic cladoceran *Daphina* sp., and a majority of the fish migrated to the central and lower estuary, presumably to avoid the high turbidity (Emmett et al. 1988, Kirn et al. 1986). Newcombe and Flagg (1983) found that juvenile salmon can tolerate aquatic ash loads up to 6,100 mg/l, confirming that high turbidities rarely have been associated with direct mortality.

Several reports have shown that juvenile fishes can be more abundant in turbid water and that some species may actively choose areas with a turbidity of 10 to 80 NTU over clear waters (Blaber and Blaber 1980, Cyrus and Blaber 1987a,b). In nature, resident fishes may offset the effects of reduced visibility with behavioral changes or beneficial utilization of some optical feature of turbid water, such as the shadowing effect of prey items. Modified behavior of spatial distribution in turbid water possibly reflects a reduced perception of risk (e.g., a recognition of the cover provided by turbid water) (Gregory 1988). Boehlert and Morgan (1985) showed enhanced feeding of Pacific herring larvae in suspended sediment concentrations as high as 1,000 mg/l.

Gregory and Northcote (1992) calculated foraging rates of juvenile chinook salmon on surface, planktonic, and benthic prey species. Turbidity significantly affected surface foraging of juvenile chinook salmon. In contrast to the findings of Berg and Northcote (1985), Gregory and Northcote (1992) found that chinook experienced depressed foraging rates at low (< 1 NTU) and high (180 NTU) turbidities and that the highest foraging rates were obtained in intermediate turbidity treatments (35 to 150 NTU).

Gregory (1994) found that the relationship between feeding rate and turbidity varied with juvenile chinook size. Smaller fish (49 to 55 mm fork length [FL]) had highest feeding rates on surface and planktonic prey at the lowest turbidities (≤18 NTU) and feeding rates declined with increasing turbidity, approaching zero at the highest turbidity level (810 NTU). However, feeding rates on benthic prey were highest at intermediate turbidities (18 to 150 NTU) and approached zero in clear water and highly turbid conditions (370 to 810 NTU). Larger fish (57 to 69 mm FL) had highest feeding rates on surface and benthic prey at the intermediate turbidities (18 to 150 NTU) and approached zero in clear water and highly turbid conditions (370 to 810 NTU). However, feeding rates on planktonic prey mirrored those of smaller fish; that is, the highest feeding rates were at the lowest turbidities (≤18 NTU), and feeding rates declined with increasing turbidity, approaching zero at the highest turbidity level (810 NTU). Above 150 NTU, juvenile chinook have reduced feeding rates, regardless of their size or prey type.

Physiological Effects

Gill tissue is the primary site of injury for acute exposure to suspended sediment (Noggle 1978). Injury to gill tissue may interfere with the salmonid's ability to adapt to salt water (Servizi 1988) and can provide entry for infectious organisms. Redding and Schreck (1987) found that infection occurred among yearling steelhead exposed to 2.5 g/l of topsoil for 2 days, even though there was no microscopic evidence of gill injury. Although suspended sediments can result in gill damage, Martens and Servizi (1992) could not determine a relationship between the number of particles in gill tissue (intracellular particle frequency) and exposure to various suspended sediment concentrations. There was no significant difference in intracellular particle frequencies when juvenile coho were exposed to varying amounts of suspended sediments. Small wounds and abrasions which all fish, including controls, must have received from time to time possibly healed less rapidly when continually bathed with a suspension of hard particles, and were more likely to become infected, possibly leading to deaths (Herbert and Merkens 1961).

Lethal effects have been observed in turbidities ranging from 100 to 300 NTU (Sigler et al. 1984). Several species of North American fish were exposed to montmorillonite clay in concentration of 100,000 parts per million (ppm) and survived a week; however, when they were exposed to concentrations of 175,000 to 225,000 ppm, death occurred within 2 hours (Wallen 1951). Rainbow trout exposed to concentrations above 270 mg/l and higher for 3 to 9 months had over 50% mortality; however, surviving fish had similar growth rates to control fish, even at higher concentrations (Herbert and Merkens 1961).

Adults

After the 1980 eruption of Mount St. Helens, there was concern about the effect of the increased turbidity on returning adult salmon. The homing migration is guided by several factors, with the upstream portion guided primarily by olfaction (Hasler et al. 1978). Experiments were conducted to determine if volcanic ash had adverse effects on the homing behavior of adult chinook salmon. Adult male chinook salmon exposed to 650 mg/l of volcanic ash for 7 days were still able to find their natal water (Whitman et al. 1982). However the addition of ash to natal water reduced the salmons' preference to migrate up these waters, not from an inability to identify natal water but because the salmon were avoiding the turbid conditions (Whitman et al. 1982). Reduced preferences for home waters by returning male chinook salmon were affected by turbidity ≥30 NTU and/or suspended sediments from as little as 20 mg/l (Sigler 1988). Studies conducted in the Susitna River, Alaska, indicated that Arctic grayling (*Thymallus arcticus*) and adult rainbow trout also avoided water with turbidities above 30 NTU (Suchanek et al. 1984a,b).