Staff Report
for the Action Plan for the
Scott River Watershed
Sediment and Temperature
Total Maximum Daily Loads

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State of California
North Coast Regional Water Quality Control Board
5550 Skylane Boulevard, Suite A
Santa Rosa, California 95403
707-576-2220
www.waterboards.ca.gov/northcoast

TMDL Development Team

Donald A. Coates
Elmer Dudik
Richard Fadness
Rebecca Fitzgerald
Ranjit Gill
Bruce Gwynne
David Leland
Bryan McFadin
Carey Wilder
Ben Zabinsky

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CHAPTER 2. PROBLEM STATEMENT

Key Points

- Salmonid populations in the Scott River watershed have declined significantly from historic levels. Coho salmon in the watershed are listed as a threatened species under the federal and state Endangered Species Acts.

- Excessive sediment loads and elevated water temperatures have impaired many designated beneficial uses of the Scott River and its tributaries. Several of the primary beneficial uses impaired are those uses associated with the cold water salmonid fishery, which are the primary focus of this TMDL Action Plan.

- Excessive sediment loads and elevated water temperatures have caused the non-attainment of water quality objectives related to sediment and water temperature.

- Excessive sediment:
  - fills in pools, reducing available in-stream salmonid habitat;
  - fills and buries the gravels that salmonids require to spawn;
  - reduces the number of macroinvertebrates available as food for salmonids during rearing;
  - produces wider, shallower channels which are subject to increased solar heating and contribute to the non-attainment of the temperature objective.

- Available data on instream sediment conditions in the mainstem Scott River through Scott Valley show a consistent pattern of sediment impairment, though with indications of improving trends for some parameters.

- Available data on instream sediment conditions in Shackleford-Mill, Etna, French, and Sugar creeks show mixed conditions, with some parameters exceeding desired conditions, some meeting desired conditions, and some with stable or improving trends in fine sediment values.

- Available data on instream sediment conditions in Tompkins, Boulder, and Canyon creeks generally indicate sediment impairment.

- The recommended salmonid temperature criteria during the summer ranges from 16ºC (60.8ºF) to 20ºC (68ºF) 7-DADM, depending on salmonid life stage.

- Summer temperature conditions do not support suitable salmonid rearing habitat in the mainstem of the Scott River and the East Fork of the Scott River.

- Summer temperature conditions do not support suitable salmonid rearing habitat in the lower reaches of Kelsey, Shackleford, Kidder, Patterson (west side), French, Wildcat, Etna, and Big Carmen creeks and the upper reaches of Moffet Creek and Sissel Gulch.

- A suite of instream salmonid habitat and upslope watershed desired conditions is available to help determine water quality and the effectiveness of the TMDL and implementation actions.

- This chapter also includes information on salmonid populations and periodicity in the Scott River watershed.

2.1 INTRODUCTION

This chapter summarizes ways in which increased sediment loads and elevated water temperatures have contributed to the decline of the cold-water salmonid fishery. Increased sediment delivery is produced by management activities including road-related activities, silvicultural and agricultural practices, mining, and ranching. Temperature changes are produced by sediment delivery – through processes including channel aggradation and pool infilling – as well as by other processes, such as changes in riparian cover, increased solar heating, changes in surface flow, changes in channel geometry, and changes in streamside microclimates. This chapter includes a description of the water quality standards and salmonid habitat requirements related to sediment and temperature and a qualitative assessment of existing instream and watershed conditions in the Scott River watershed.

The primary adverse impacts produced by excessive sediment supply in the Scott River and its tributaries are adverse effects on the cold-water salmonid fishery. Excessive sediment fills pools, reducing available habitat. Fine sediment, which constitutes most of the additional sediment load, fills and buries the gravels that salmonids require to spawn. In addition, the influx of fine sediments reduces the number of macroinvertebrates available for food during salmonid rearing. Excess sediment produces wider, shallower channels which are subject to solar heating and contribute to the non-attainment of temperature objectives. Increased water temperatures decrease the area and volume of suitable habitat, and decrease salmonid survival during gestation, rearing, and migration.

The degradation of sediment and temperature conditions below water quality objectives adversely affects beneficial uses related to coho salmon (*Oncorhynchus kisutch*), chinook salmon (*O. tshawytscha*), and steelhead trout (*O. mykiss*). The coho salmon population in this watershed is listed as threatened under the federal Endangered Species Act and the California Endangered Species Act. Additional adverse impacts affect recreational uses, agricultural and municipal water supplies, and ground water recharge.

This analysis is based on data that have been gathered by the Regional Water Board staff and data contributed by landowners and organizations in the Scott River watershed. Because information about habitat parameters in some areas of the watershed is not available, conservative assumptions based on professional judgment were made regarding factors that potentially limit salmonid populations in the basin. As additional data become available from sources such as local groups and government agencies, the TMDL and information contained in this chapter can be modified by the Regional Water Board.

2.2 WATER QUALITY STANDARDS

In accordance with the Clean Water Act, a TMDL is set at a level necessary to achieve applicable water quality standards. Under the Clean Water Act, water quality standards define designated uses, water quality criteria to protect those uses, and an anti-degradation policy. This section describes the State water quality standards applicable to the Scott River TMDL, using the State's terminology of beneficial uses and water quality objectives. The Scott River TMDLs for sediment and temperature are set at levels necessary to protect applicable water quality standards, including the beneficial uses listed in Section 2.2.1 and the water quality objectives listed in Section 2.2.2.

2.2.1 Beneficial Uses

The beneficial uses and water quality objectives for the Scott River are contained in the *Water Quality Control Plan for the North Coast Region* (Basin Plan) adopted, 1993, as amended in 2003 (Regional Water Board, 2003, Table 2-1). Beneficial uses are defined on the basis of two hydrologic subareas: the Scott Bar Hydrologic Subarea and the Scott Valley Hydrologic Subarea.

Existing beneficial uses for the Scott River are:
1. Municipal Water Supply (MUN)
2. Agricultural Supply (AGR)
3. Industrial Service Supply (IND)
4. Groundwater Recharge (GWR)
5. Freshwater Replenishment (FRSH)
6. Navigation (NAV)
7. Hydropower Generation (POW)
8. Water Contact Recreation (REC-1)
9. Non-Contact Water Recreation (REC-2)
10. Commercial or Sport Fishing (COMM)
11. Cold Freshwater Habitat (COLD)
12. Wildlife Habitat (WILD)
13. Rare Threatened or Endangered Species (RARE)
14. Migration of Aquatic Organisms (MIGR)
15. Spawning, Reproduction, and/or Early Development (SPWN)
16. Aquaculture (AQUA) (Scott Valley Hydrologic Subarea)

Potential beneficial uses are:
1. Industrial Process Supply (PRO)
2. Aquaculture (AQUA) (Scott Bar Hydrologic Subarea)

Table 2.1 Water Quality Objectives Applicable to the Scott River TMDL	
Suspended Material	Waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses.
Settleable Material	Waters shall not contain substances in concentrations that result in deposition of material that causes nuisance or adversely affect beneficial uses.
Turbidity	Turbidity shall not be increased more than 20 percent above naturally occurring background levels. Allowable zones of dilution within which higher percentages can be tolerated may be defined for specific discharges upon the issuance of discharge permits or waiver thereof.
Sediment	The suspended sediment load and suspended sediment discharge rate of surface water shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.
Temperature	The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration in temperature does not adversely affect beneficial uses. At no time or place shall the temperature of any COLD water be increased by more than 5° F above natural receiving water temperature.

2.2.2 Water Quality Objectives

The Basin Plan (NCRWQCB, 2005b) identifies both numeric and narrative water quality objectives for the Scott River. Those pertinent to the Scott River TMDLs are listed in Table 2.1.

2.3 SALMONID POPULATIONS & PERIODICITY

Many of the beneficial uses most impaired by and sensitive to excessive sediment loads and elevated water temperatures are related to the cold water salmonid fishery. These uses include the commercial and sport fishing (COMM); cold freshwater habitat (COLD); rare, threatened, and endangered species (RARE); migration of aquatic organisms (MIGR); and spawning, reproduction, and/or early development of fish (SPWN) beneficial uses. The following sections provide some background information on the status of salmonid populations, the locations of salmonid habitat, and salmonid periodicity within the Scott River watershed.

2.3.1 Salmonid Populations

Anadromous fish populations currently utilizing the Scott River basin include fall chinook and coho salmon, and fall and winter steelhead trout (Hardy and Addley, 2001, p.12; Klamath River Basin Fisheries Task Force [KRBFTF], 1991, p. 4-10 and 4-11). Data indicate that the fall chinook population within the Scott River basin has experienced a decline since at least the

1960s (Hardy and Addley, 2001, p.12). Available data for coho and fall and winter steelhead runs are not entirely reliable for determining long-term trends, however both species are considered to have experienced declines from historic numbers throughout the Klamath River basin (Brown and Moyle, 1991, p.6, 36; Brown et al., 1994; CDFG, 2002, p.1; Hardy and Addley, 2001, p.12-13). Historically, there were summer steelhead and spring chinook runs in the Scott River, however those runs no longer occur in this basin although a few random summer steelhead have been observed in the Scott River (KRBFTF, 1991. p. 2-87, 2-99, and 4-15; USFS, 2000b, p.3-9; USFS, 2000a). This review focuses on adult return populations.

Information on the numbers of coho salmon and steelhead trout in the Scott River basin is limited. In the early 1960s, the California Department of Water Resources (CDWR) estimated 2,000 coho and 20,000-40,000 steelhead in the Scott River basin (CDWR 1965, as cited by Scott River Watershed Council [SRWC], 2004, p.6-5). An inventory of salmon and steelhead conducted by the California Department of Fish and Game (1965, p.373) estimated 800 coho, and 5,000 steelhead in the basin in 1965. There are data on juvenile coho numbers in the French Creek drainage, discussed below. No other population estimates could be found for coho and steelhead in this basin. Information on coho and steelhead numbers were found for various years from 1982-1991 (Shaw et al., 1997) however, no population estimates were made from this information. In addition, adult spawner population estimates were developed for selected reaches in French, Miners, Shackleford, and Mill Creeks by the Siskiyou County Resource Conservation District in 2004-2005. Depending on the method used to calculate estimates, adult coho population estimates in these select reaches total 713 or 940 adult fish (SRCD, 2005c, p.5). Due to the lack of spawner abundance estimates in other recent years, it is not possible to use these results to indicate trends in reaches of these creeks or in the watershed as a whole.

In the absence of quantitative data it is assumed that the trends in coho salmon and steelhead trout within the Scott River basin are similar to trends within the larger Klamath Basin (Hardy and Addley, 2001, p.12). Despite this lack of quantitative data, it is clear from the information available that coho and steelhead populations within the Klamath basin and statewide have undergone a dramatic decline from historic levels (Brown and Moyle, 1991, p.6 and 36; Brown et al, 1994; CDFG, 2002, p.1; Hardy and Addley, 2001, p.12 and 13). The National Marine Fisheries Service (NMFS) listed the Southern Oregon/Northern California Coastal (SONCC) Coho Salmon Evolutionarily Significant Unit (ESU), which contains the Scott River basin, as threatened in 1997 (NMFS, 2004). The California Department of Fish and Game (CDFG) commission proposed the listing of this ESU as threatened in August of 2004, and this proposal will become effective upon approval by the Office of Administrative Law (CDFG, 2004b). Brown et al. (1994) state that California coho populations are probably less than 6% of what they were in the 1940s, and there has been at least a 70% decline since the 1960s. Coho salmon occupy only 61% of the SONCC Coho ESU streams that were previously identified as historical coho salmon streams (CDFG, 2002, p.2).

Historically, sustainable populations of spring chinook were present in the Scott River watershed but these stocks are either no longer present or occur very infrequently in low numbers (USFS, 2000b, p. 3-9). There have been occasional sightings of spring chinook in the Scott River, although the only true run in the Klamath basin exists in the Salmon River (KRBFTF, 1991, p 4-12). Snyder (1931, p. 19) wrote that the spring chinook migration in the Klamath basin, "was once very pronounced," but "has now come to be limited as to the number of individuals, and is of relatively little economic importance." The cause of the disappearance or depletion of the early spring migration in the Klamath River is attributed by some to heavy sediment loads unleashed by hydraulic mining operations (KRBFTF, 1991, 4-2), while others cite over fishing both in the river and at sea, and irrigation (Snyder, 1931, p.33).

Fall chinook salmon are the predominant run in the Klamath River basin and are the only chinook run believed to currently exist in the Scott River basin. The Scott River produces approximately 9.2% of the natural fall Chinook salmon in the Klamath River basin (SRWC, 2004, p.6-1). An historic population estimate from CDFG (1965, p. 373) estimated that there were 8,000 fall chinook in the Scott River basin in 1965. Fall chinook salmon spawning escapement has been monitored by the CDFG annually since 1978 (Figure 2.1). Since this time, spawning populations have ranged from 445 fish in 2004, to a high of 14,477 fish in 1995. Fall chinook numbers remained high in 1996 (12,097) and then decreased to between 3,327-6,253 from 1997-2002, but rebounded again in 2003 to 12,053 fish.

Juvenile coho salmon surveys have been conducted in French Creek in most years from 1992 to the present, in conjunction with an intensive road rehabilitation effort conducted in this drainage in the early 1990s. Effects of this effort on V*, a measure of instream sediment conditions, are discussed in Section 2.4.2.7. Juvenile coho salmon have been found regularly in several French Creek reaches as part of annual September electroshock monitoring initiated in 1992 and overseen by Department of Fish and Game fisheries biologist Dennis Maria. These surveys have been conducted each year since 1992 except for 1998. Since 1992 the surveys have been done in the same five reaches, except for 1996 when one reach was not surveyed. These survey data (Figure 2.2) provide the single best data set on coho salmon in the Scott River system.

Coho return as adults three years after they are spawned. Thus a fry hatched from the 1999 spawn, if it survived, returned as a spawning adult in 2002. We designate 1992, 1993, and 1994 as Brood Years 1, 2, and 3. When each brood year is looked at separately trends are apparent:

- Brood Year 2 (1993, 1996, 1999, 2002) is by far the strongest of the three with data through 2002.
- Brood Years 1 and 3 are much weaker than Brood Year 2
- All Brood Years show positive trends with Brood Years 1 and 3 now showing numbers and trends similar to those shown by Brood Year 2 approximately ten years ago.
- Given that Brood Years 1 and 3 were the best ever documented in 2004 and 2005, it can be reasonably anticipated that the juvenile survey taken in September of 2005 will also be strong.

2.3.2 Salmonid Habitat

A habitat survey performed by the CDFG (1965, p. 373) found that there were 59 miles of habitat in the Scott River basin suitable for chinook, 126 miles suitable for coho, and 174 miles of habitat suitable for steelhead in 1965. A more current survey by Hardy and Addley (2001, p.13) estimates that there are 59 miles of fall chinook, 88 miles of coho, and 142 miles of steelhead habitat in the basin. Stream diversions have reduced the amount of available salmon and steelhead habitat in the Scott River basin, and may have been the primary cause for the loss of the summer steelhead and spring chinook runs in this basin (KRBFTF, 1991, 2-99).

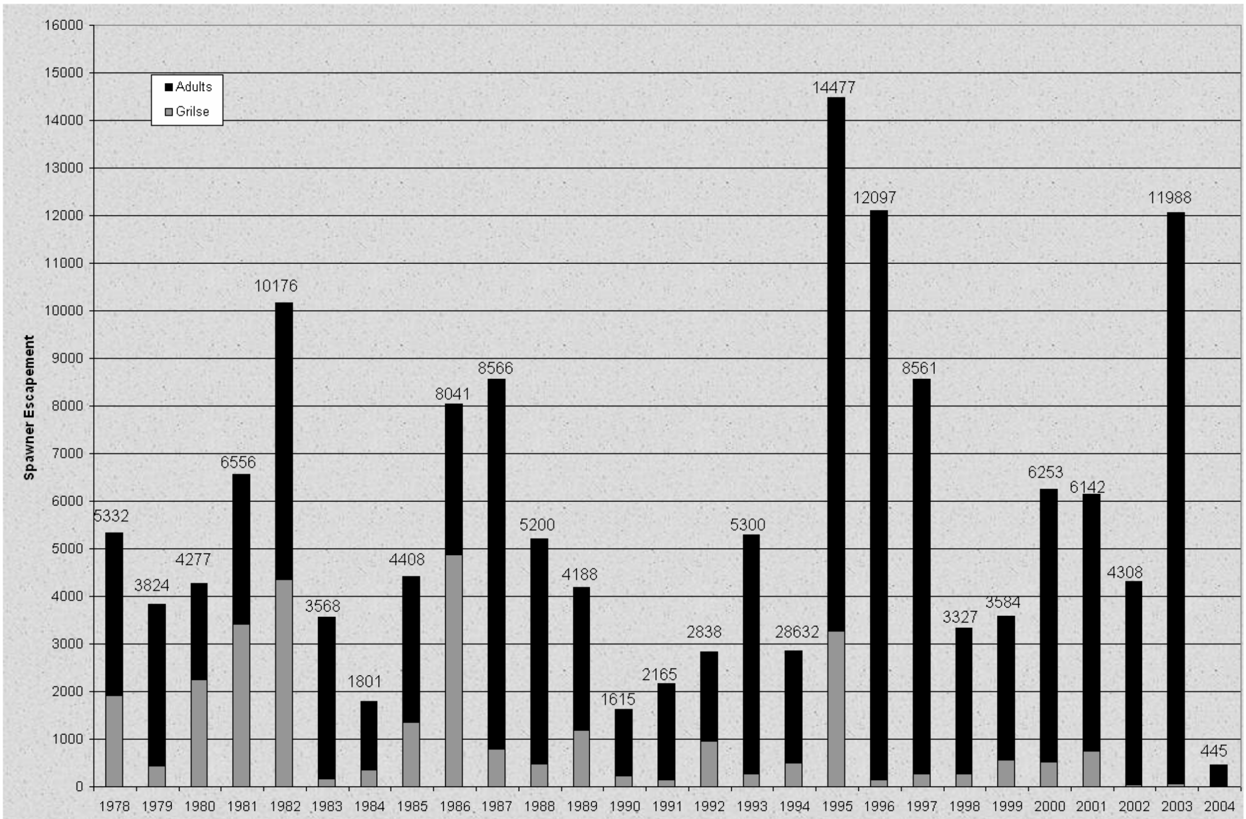

Figure 2.1. Scott River Fall Chinook Spawner Escapement (Source: CDFG data)

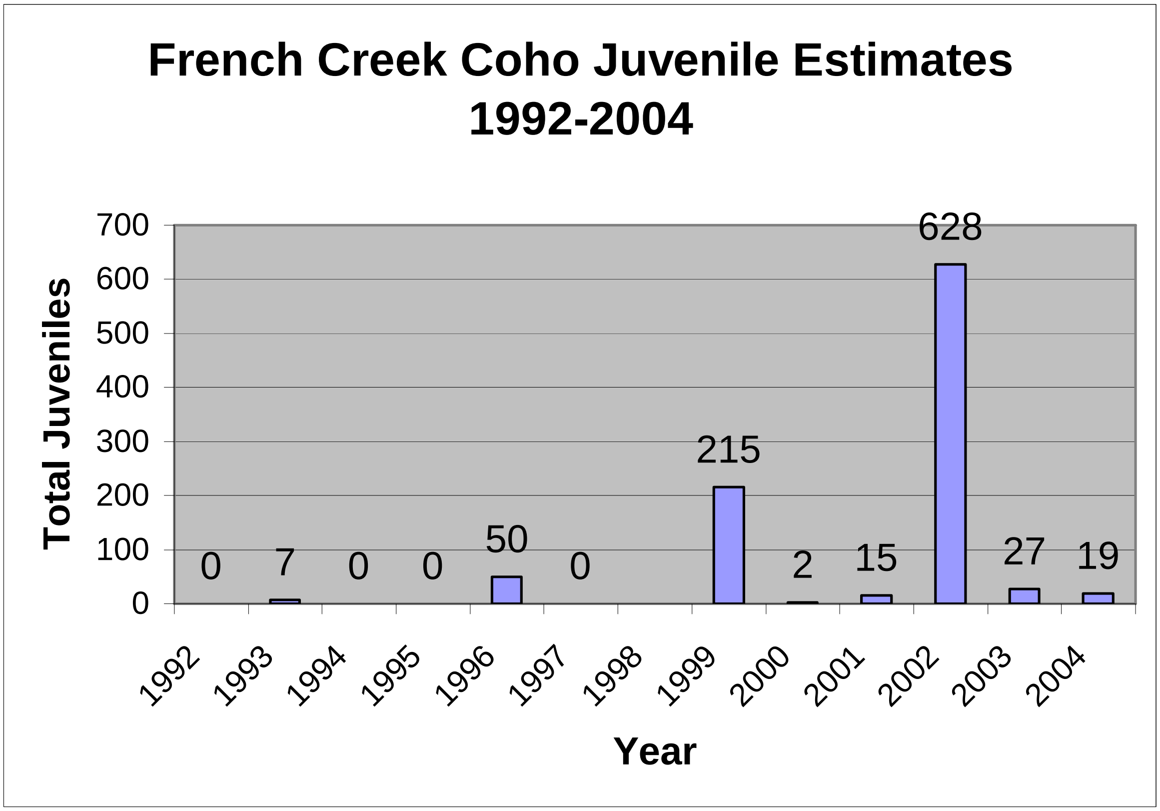

Figure 2.2. Juvenile coho estimates from electroshocking surveys on five reaches of French Creek from 1992-2004.

2.3.3 Salmonid Periodicity

Six runs of anadromous salmonids use the Klamath River, four of which are found in the Scott River basin. Fall run chinook, coho, and fall and winter run steelhead all are found in the Scott River basin, while spring chinook and summer steelhead runs are not currently present except for a few random summer steelhead. Together these four runs result in year round utilization of the Scott River basin by various life stages of salmonids (Figure 2.2).

Periodicity (presence of salmonids at varying life stages throughout the year) information for the runs is fairly easy to interpret with the exception of data for the fall and winter run steelhead. At times references do not distinguish between fall and winter steelhead, some calling all fish winter run steelhead (see for example Leidy and Leidy, 1984), while others only refer to fall fish (see for example Hardy and Addley 2001, p.12). In other references the discussion of fall and winter run steelhead is combined (see for example KRBFTF, 1991, p. 4-11; SRWC, 2004, p.6-18). Finally, some documents discuss the fall and winter steelhead separately (Shaw et al., 1997). For this reason, periodicity information for fall and winter steelhead in this document are combined into one group. Information from the above literature sources, Chesney (2000, p. 1-5, 19-27, and 33-37, 2002, p. 23-38, 2003. p. 21-39, 2004, p. 21-37), and the SRWC (2004, p. 6-3, 6-4, 6-17, and 6-18) were used to produce Figure 2.3.

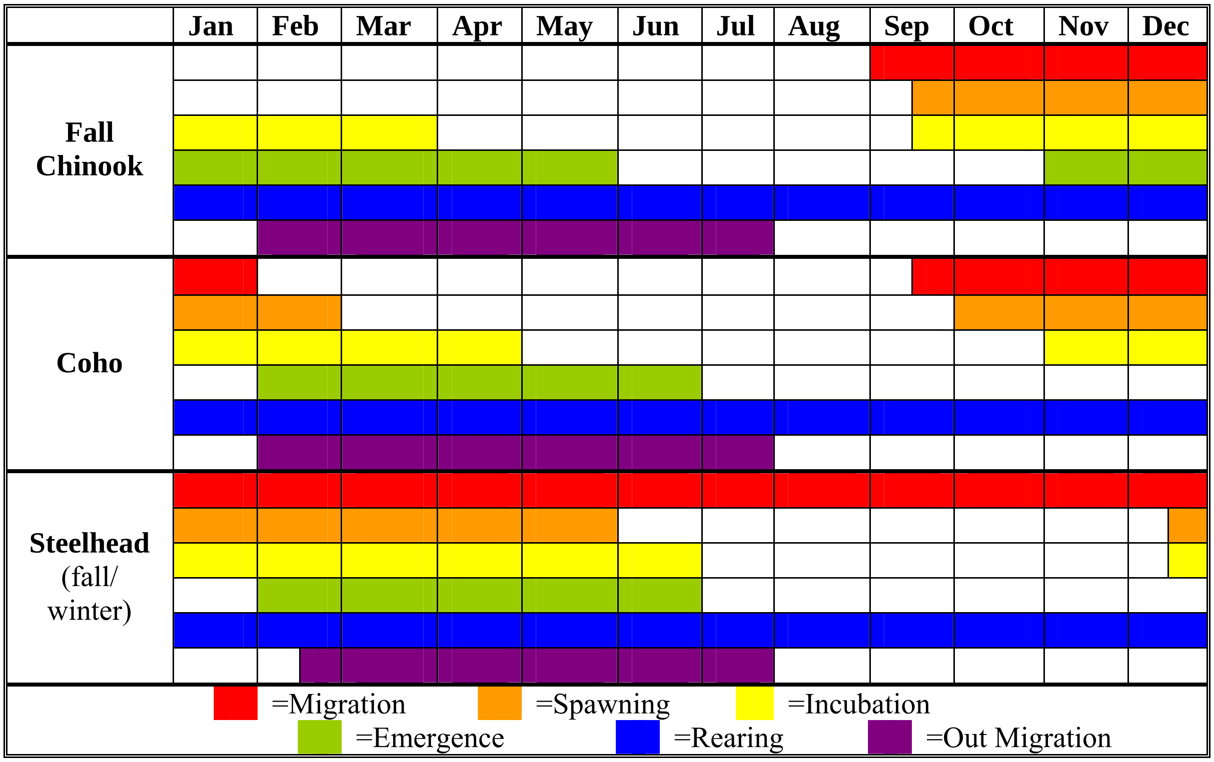

Figure 2.3. Salmonid Periodicity in the Scott River Watershed.

2.4 SEDIMENT PROBLEM STATEMENT

The primary adverse impacts produced by excessive sediment supply in the Scott River and its tributaries are adverse effects on the cold-water salmonid fishery. Excessive sediment fills pools, reducing available habitat. Fine sediment, which constitutes most of the additional sediment load, fills and buries the gravels that salmonids require to spawn. In addition, the influx of fine sediments reduces the number of macroinvertebrates available for food during salmonid rearing. Excess sediment produces wider, shallower channels which are subject to solar heating and contribute to the non-attainment of temperature objectives.

2.4.1 Sediment Desired Conditions

This section identifies desired conditions for salmonid freshwater habitat and upslope settings. These indicators are interpretations of the water quality standards presented in two categories, instream conditions and watershed conditions.[1] For each parameter, a desired condition value is identified. These parameters, and their associated desired condition values, although not directly

[1] Turbidity is the only exception as turbidity is a water quality objective listed in the Basin Plan.

enforceable, have proved to be a useful reference in determining the effectiveness of a TMDL and implementation measures toward attaining water quality standards.[1]

The instream desired conditions relate to the quality and size distribution of sediment and are important as measures of stream health. The watershed desired conditions focus on the environment upslope of the streams and reflect either predictors of or protection against future degradation of water quality. Watershed parameters focus on imminent threats to water quality that can be detected and corrected before sediment is delivered to the stream. Watershed parameters are often easier to measure than instream parameters and identify conditions that are needed in the watershed to protect water quality as it relates to sediment conditions.

Desired conditions values of both instream and watershed parameters are set at levels associated with well-functioning stream systems. Instream parameters reflect present conditions, but these conditions may take years or decades to respond to changes higher in the watershed. Watershed parameters reflect processes upslope from the streams in the watershed at the time of measurement, and may respond relatively quickly to induced changes. The linkages relating production of sediment upslope, delivery of that sediment to a stream, and what happens to that sediment in the stream are complex. Time lags between production and delivery of sediment, instream storage, and times and processes of transport through the system are not always well known. Accordingly, watershed desired conditions potentially can be achieved sooner than instream desired conditions, and can serve as checks on the progress toward achievement of water quality standards.

No single parameter adequately describes water quality with relation to sediment; instead, a suite of instream conditions and a suite of watershed conditions are identified. Because of the inherent variability associated with stream channel conditions, and because no single indicator applies in all situations, attainment of the desired conditions is evaluated using a weight-of-evidence approach. Experience shows that the parameters, when considered together, provide good evidence of the condition of the stream and of progress toward attainment of sediment-related water quality standards.

2.4.1.1 Instream Desired Conditions for Sediment

Tables 2.2 and 2.3 list the instream salmonid habitat desired conditions for the Scott River TMDL and their respective desired condition values. In several cases, desired conditions are expressed as improving trends, because information on watershed processes is not adequate to develop thresholds specific to the Scott River watershed. These parameters and their application are discussed by Fitzgerald (2004), which also includes a discussion of the literature on these indicators, their importance in characterizing instream conditions suitable for salmonids, and desired condition values for the indicators.

2.4.1.2 Watershed Desired Conditions for Sediment

Table 2.4 lists the watershed desired conditions for the Scott River TMDL and their respective desired condition values. More information on each parameter is found in the following sections. Watershed desired conditions are indicators of potential future sediment contributions to the stream system. The information on watershed desired conditions includes reported conditions taken from several publicly funded inventories including surveys in French Creek (Sommarstrom et al., 1990), Etna Creek (Resource Management, 2003), Moffett Creek (SHN Consulting Engineers & Geologists, 2003), Shackleford and Mill creeks (Siskiyou Resource Conservation District, 2003), and others. In several cases, desired conditions are expressed as improving trends, because information on watershed processes is not adequate to develop thresholds specific to the Scott River watershed.

Stream Crossings with Diversion Potential or Significant Failure Potential

Desired Condition: <1% of all stream crossings divert or fail as a result of a 100-year or smaller flood

Most roads, including skid trails, cross ephemeral or perennial streams. Crossings are built to capture the stream flow and safely convey it through, under, or around the roadbed. However, stream crossings can fail, adding sediment from the crossing structure (i.e., fill), or from the roadbed, directly into the stream. Stream crossing failures are generally related to culverts that are undersized, poorly placed, plugged, or partially plugged. When a crossing fails, the total sediment volume delivered to the stream usually includes both the volume of road fill associated with the crossing and sediment from collateral failures such as debris torrents that scour the channel and stream banks.

Diversion potential is the potential for a road to divert water from its intended drainage system across or through the road fill, thereby delivering road-related sediment to a watercourse. The potential to deliver sediment to the stream can be eliminated from almost all stream crossings by eliminating inboard ditches, outsloping roads, or installing rolling dips (M. Furniss, pers. comm., in USEPA, 1998). Generally, less than one percent of stream crossings have conditions where modification is inappropriate because it would endanger travelers or where modification is impractical because of physical constraints (D. Hagans, pers. comm., 1998, in USEPA, 1998).

Table 2.2
Instream Desired Conditions for Sediment*

Parameter	Desired Condition	Applicability	Monitoring/Sampling Notes
Benthic Macroinvertebrate Assemblage	≥ 18 Index Score per the Russian River Index of Biological Integrity (IBI). See Table 2.3 for the Russian River IBI.	1st, 2nd, and 3rd Order Streams.	Monitoring and calculation should occur in the spring according to the protocols found in the *California Stream Bioassessment Procedure* (CA Department of Fish and Game, 2003).
Embeddedness	Increasing trend in the number of locations where gravels and cobbles are ≤ 25% embedded.	All wadeable streams and rivers.	Monitoring should occur according to the protocols found in the *California Salmonid Stream Habitat Restoration Manual, Third Edition* (Flosi et al., 2004).
Large Woody Debris (LWD)	Increasing trend in the volume and frequency of LWD and key pieces of LWD.	Streams and rivers with bankfull channel widths > 1m.	Monitoring should be done according to the protocols found in the *California Salmonid Stream Restoration Manual, Third Edition* by Flosi et al. (2004), or in the Washington State *Method Manual for the Large Woody Debris Survey* (Shuett-Hames et al., 1999).
Pools –	Increasing trend in	Wadeable streams and rivers with	Monitoring should occur periodically during

Table 2.2
Instream Desired Conditions for Sediment*

Parameter	**Desired Condition**	**Applicability**	**Monitoring/Sampling Notes**
Backwater Pool Distribution	the number of backwater pools.	channel morphology that supports the development of backwater pools. Steep, v-shaped valleys with little floodplain connection generally do not exhibit this type of habitat and are exempt from this index.	the low-flow period and after a heavy winter storm according to the protocols found in the *California Salmonid Stream Restoration Manual, Third Edition* (Flosi et al., 2004).
Pools – Lateral Scour Pool Distribution	Increasing trend in the number of lateral scour pools.	Wadeable streams and rivers with channel morphology that supports the development of backwater pools. Steep, v-shaped valleys with little floodplain connection generally do not exhibit this type of habitat and are exempt from this index.	Monitoring should occur during the low-flow period, after a heavy winter storm, once every five to ten years according to the protocols found in the *California Salmonid Stream Restoration Manual, Third Edition* (Flosi et al., 2004).
Pools – Primary Pool Distribution	Increasing trend in the number of reaches where the length of the reach is composed of ≥ 40% primary pools.	All wadeable streams and rivers.	Monitoring should occur once every five to ten years during the low-flow period and after a heavy winter storm according to the protocols found in the *California Salmonid Stream Restoration Manual, Third Edition* (Flosi et al., 2004). Reported data should include length and depth of pools, and the number of primary pools.
Percent Fines	≤ 14% fines < 0.85 mm in diameter. ≤ 30% fines < 6.40 mm in diameter.	Wadeable streams and rivers with a gradient < 3%.	Monitoring should use a McNeil sediment core sampler similar to the specifications found in *Success of Pink Salmon Spawning Relative to Size of Spawning Bed Materials* (McNeil and Ahnell, 1964), except the diameter of the sampler's core should be at least 2-3 times larger than the largest substrate particle usually encountered. Monitoring should occur according the protocols found in *Stream Substrate Quality for Salmonids: Guidelines for Sampling, Processing, and Analysis* (Valentine, 1995), and use the methodology for the redd or pool/riffle break sampling universe. A 0.85 mm a 6.40 mm sieve should be used during sample processing. The wet volumetric method is recommended with the use of the wet volumetric method and the dry gravimetric method on 10% of the samples.
Thalweg Profile	Increasing variation in the thalweg elevation around the mean thalweg profile slope.	Streams and rivers with slopes ≤ 2%.	Monitoring should occur during the low-flow period, after a heavy winter storm, once every five to ten years. The monitored stream segments should be at least 20, but usually 30 to 40, times as long as the average bankfull channel width. Points that should be surveyed include the thalweg, all breaks-in-slope, riffle crests, maximum pool depths, tails of pools, and surface water elevation. Acceptable monitoring protocols include the Channel

Table 2.2 Instream Desired Conditions for Sediment*			
Parameter	**Desired Condition**	**Applicability**	**Monitoring/Sampling Notes**
			Geometry Survey of *Water in Environmental Planning* (Dunne and Leopold, 1978).

* Adapted from Fitzgerald, 2004.

Table 2.3 Russian River Index of Biological Integrity				
Biological Metric	**Score**			**How to use the Russian River Index of Biological Integrity**
	5	**3**	**1**	
Taxa Richness	> 35	35-26	< 26	Obtain a sample of benthic macroinvertebrates following the state standard procedures in *California Stream Bioassessment Procedure. Protocol Brief for Biological and Physical/Habitat Assessment in Wadeable Streams* (CA Dept. of Fish and Game, 2003). There must be at least three replicate samples collected at each monitoring location. The samples should be processed by a professional bioassessment laboratory using the Level 3 Taxonomic Effort. Determine the mean values for the six listed biological metrics, compare them to the values in the columns, and add the scores listed in the column headings. The total score will be between a low of 6 and a high of 30. Determine biotic condition of the monitoring location from the following categories: Excellent 30-24; Good 23-18; Fair 17-12; Poor 11-6
% Dominant Taxa	< 15	15-39	> 39	
EPT Taxa	> 18	18-12	< 12	
Modified EPT Index	> 53	53-17	< 17	
Shannon Diversity	> 2.9	2.9-2.3	< 2.3	
Tolerance Value	< 3.1	3.1-4.6	> 4.6	

1.Taken from *Measuring the Health of California Streams and River. A Methods Manual for: Water Resource Professionals, Citizen Monitors, and Natural Resources Students* by Harrington & Born (1999).

Table 2.4 Watershed Desired Conditions for Sediment				
Parameter	**Desired Condition**	**Comments**	**Purpose**	**References**
Watershed	Monitoring recommendations: prior to winter			
Diversion & Stream Crossing Failure Potential	≤ 1% of crossings divert or fail in 100 yr storm.	Measured prior to winter.	Estimate of potential for reduced risk of sediment delivery from hillslope sources to the water body.	Weaver and Hagans, 1994; Flanagan et al., 1998.
Hydrologic Connectivity of Roads	Decreasing length of connected road to ≤ 1%.	Measured prior to winter.	Estimate of potential for reduced risk of sediment delivery from hillslope	Ziemer, 1998; Flanagan et al., 1998; Furniss et al., 2000.

Table 2.4 Watershed Desired Conditions for Sediment				
Parameter	**Desired Condition**	**Comments**	**Purpose**	**References**
			sources to the water body.	
Annual Road Inspection & Correction	Increasing proportion of road to 100%.	Roads inspected and maintained, decommissioned or hydrologically closed prior to winter. No migration barriers.	Estimate of potential for reduced risk of sediment delivery from hillslope sources to the water body.	USEPA, 1998.
Road Location, Surfacing, & Sidecast	Decreasing length next to stream, increased % outsloped, and hard surfaced roads	See text	Minimize sediment delivery.	USEPA, 1998.
Activities in Unstable Areas	Avoid or eliminate.	Subject to geological / geotechnical assessment to minimize or show that no increased delivery would result.	Minimize sediment delivery from management activities.	Dietrich et al., 1998; Weaver and Hagans, 1994; PWA, 1998.
Disturbed Areas	Decrease	See text.	Measure of chronic sediment input.	Lewis, 1998.

Hydrologic Connectivity

Desired Condition: decreasing length of hydrologically connected roads to $\leq$1%
A hydrologically connected road drains water directly to the adjacent stream, which increases the intensity, frequency, and magnitude of flood flows and suspended sediment loads in the stream. This process can destabilize the stream channel and produce a devastating effect on salmonid redds and growing embryos (Lisle, 1989). The hydrologic connectivity can be reduced by outsloping roads, creating road drainage that mimics natural drainage as much as possible, and other factors (M. Furniss, pers. comm., 1998 in USEPA, 1998; Weaver and Hagans, 1994). The reduction of road densities and the reconstruction of roads to reduce the miles of inboard ditches, for example, can reduce the amount of water that is directly delivered to watercourses, as well as associated sediment load.

Annual Road Inspection and Correction

Desired Condition: increasing proportion to 100%
U.S. EPA's analysis indicates that in watersheds with road networks that have not experienced excessive road-related sedimentation, roads are either (1) regularly inspected and maintained; (2) hydrologically maintenance free (i.e., they do not alter the natural hydrology of the stream); or (3) decommissioned or hydrologically closed (i.e., fills and culverts have been removed and the natural hydrology of the hillslope has largely been restored). Roads that do not meet one of these conditions are potentially large sources of sediment (D. Hagans, pers. comm., 1998, cited in USEPA, 1998). In general, road inspection should be done annually and could in most cases be accomplished with a windshield survey. The areas with significant potential for sediment delivery should be corrected before the onset of winter conditions. This desired condition calls for an increase in the proportion of roads that are either (1) inspected annually and maintained before winter, (2) hydrologically maintenance free, or (3) decommissioned or hydrologically closed.

Road Location, Surfacing, & Sidecast

Desired Condition: decrease road length next to streams and increase proportion of out-sloped or hard surfaced roads This indicator is intended to address the highest risk sediment delivery from roads that are not covered in other indicators. Roads in inner gorges and headwall areas are more likely to fail than roads in other topographic locations. Other than along ephemeral watercourses, roads should be removed from inner gorge and potentially unstable headwall areas, except where alternative road locations are unavailable and the road is clearly needed. Road surfacing and use intensity directly influence sediment delivery from roads. Rock surfacing or paving is appropriate for frequently used roads. Sidecast on steep slopes can trigger earth movements, potentially resulting in sediment delivery to watercourses. These factors reflect the highest risk of sediment delivery from roads, and should be the highest priorities for correction (Flanagan et al., 1998).

This desired condition calls for several conditions: (1) elimination of roads alongside inner gorge stream reaches and in potentially unstable headwall areas, unless alternative road locations are unavailable and the road is clearly needed, (2) road surfacing, drainage methods, and maintenance should be appropriate to the road's use patterns and intensities, and (3) sidecast or fill on slopes of greater than 50 percent grade, and potentially unstable slopes that could deliver sediment to a watercourse, should be stabilized or re-graded to fifty percent grade or less.

Activity in Unstable Areas

Desired Condition: avoid or eliminate, unless detailed geologic assessment by a Certified Engineering Geologist concludes there is no additional potential for increased sediment loading
Unstable areas are those areas that have a high risk of landsliding, and include steep slopes, inner gorges, headwall swales, stream banks, existing landslides, and other locations identified in the field. Because of the high risk of landsliding inherent in these features, any activity that might trigger an erosional event should be avoided, if possible, and kept to a minimum if unavoidable. Such activities include road building, timber harvesting, yarding, terracing for vineyards, etc.

Analysis of chronic landsliding in the Noyo River basin indicated that landslides observed on aerial photographs largely coincide with predicted chronic risk areas including steep slopes, inner gorges, and headwall swales (Dietrich et al., 1998). Several other studies have shown that landslides are larger or more common in some harvest areas, particularly in inner gorges (Graham Matthews & Associates, 2001). Weaver and Hagans (1994) also suggest methods for eliminating or decreasing the potential for road-related sediment delivery.

Disturbed Areas

Desired Condition: decrease in disturbed area, or decrease in disturbance index
The areal extent of disturbed areas is an indication of increased sediment loads, particularly chronic sediment discharges that are not associated with large storms or floods. Studies in Caspar Creek (Lewis, 1998) indicate a statistically significant relationship between disturbed areas and the corresponding suspended sediment discharge rate (Lewis, 1998; Mangelsdorf and Clyde, 2000). In addition, studies in Caspar Creek indicate that clear cutting causes greater increases in peak flows (and, by extension, increased suspended sediment loads) than does selective harvest (Ziemer, 1998). As with the "hydrologic connectivity" desired condition, increases in peak flows, annual flows, and suspended sediment discharge rates negatively affect the potential survivability of salmonid eggs in redds (Lisle, 1989).

Available information is not sufficient to identify a threshold below which effects on the Scott River watershed would be insignificant. Accordingly, the desired condition calls for a reduction in the amount of disturbed area or in the disturbance index. In this context, "disturbed area" is defined as the area covered by urban development or management-related facilities of any sort, including: roads, landings, skid trails, fire lines, timber harvest areas, animal holding pens, and agricultural fields (e.g., pastures, vineyards, orchards, row crops, etc.). The definition of disturbed area is intentionally broad to include managed agricultural areas, such as pastures and harvest areas, where the management activity (e.g., logging or grazing) results in removal of vegetation sufficient to significantly reduce rainfall interception and other soil protection functions. Agricultural fields or harvest areas in which adequate vegetation is retained to perform these ecological functions are not considered disturbed areas. Dramatic reductions in the amount of disturbed area can be made by reducing road densities, skid trail densities, clearcut areas, and other management-produced bare areas.

Human intervention can affect both the frequency and the intensity of fires, but staff have not made an attempt here to address this complex issue. For the purpose of this study, fire is assumed to be a natural process and is not taken into account.

Road density is also considered by many researchers to be an important indicator of the potential for sediment delivery to streams. Roads create impervious surfaces which result in increased surface runoff and peak flows. A watershed analysis performed as part of a long term strategy for Lassen National Forest Land (Armentrout et al., 1998) cited a road density of 2.5 miles of road per square mile of land as a watershed management objective indicating overall system conditions on at the subwatershed scale. The Scott River TMDL Action Plan does not propose road density as a specific desired condition for the Scott River watershed, although a decreasing trend in road densities would be beneficial. Information on road density by subwatershed is presented in Chapter 3.

2.4.2 Instream Sediment Conditions in the Scott River Watershed

Available data on instream sediment conditions mostly represent the mainstem Scott River, several tributaries in the canyon reach (Tompkins, Boulder, and Canyon creeks) and several westside tributaries (Shackleford-Mill, Etna, French, and Sugar creeks). Available data on instream sediment conditions on the mainstem Scott River through Scott Valley show a consistent pattern of impairment, through with indications of improving trends for some parameters. Westside tributaries show mixed conditions, with some parameters exceeding desired conditions, some meeting desired conditions, and some with stable or improving trends in fine sediment values. For canyon tributaries, available data are generally indicative of sediment impairment.

A summary of instream sediment conditions in the Scott River watershed is listed in Table 2.5, which also includes desired conditions values taken from Table 2.2. A more detailed discussion of instream sediment conditions for individual parameters is found in the following sections. These sections are presented in alphabetical order. The order is not intended to convey relative importance of any individual parameter.

2.4.2.1 Benthic Macroinvertebrate Assemblages

Quigley (2001) conducted a macroinvertebrate survey at five localities on the mainstem Scott in October, 2000 and April, 2001. The sites are:

a) Red Bridge, just below where the South Fork and the East Fork meet and upstream of the dredge tailings.
b) ISSCR (T44N R9W Sec 26), in the middle part of Scott Valley downstream of the dredge tailings and in the major agricultural area.
c) Meamber (T44N R10W Sec 26), eight miles downstream of Fort Jones, just upstream of the mouth of the canyon. This site was chosen to show the cumulative impact of upstream farming practices.

Table 2.5
Instream Sediment Conditions in the Scott River Watershed

Parameter	Desired Condition	Applicability	Assessment of Available Data
Benthic Macroinvertebrate Assemblage	≥ 18 Index Score per the Russian River Index of Biological Integrity (IBI). See Table 2.3 for the Russian River IBI.	1st, 2nd, and 3rd Order Streams.	Quigley concludes that benthic data indicate degraded water quality through the valley during the summer months, although conditions improve over the course of the winter.
Embeddedness	Increasing trend in the number of locations where gravels and cobbles are ≤ 25% embedded.	All wadeable streams and rivers.	Data limited. Results from 1989 for Scott River and streams in the canyon reach show high percent of locations exceed 25% embedded. Scott River results indicate watershed-scale impairment for this indicator.
Large Woody	Increasing trend in	Streams and rivers with bankfull	Data collected for Siskiyou RCD available but

Table 2.5
Instream Sediment Conditions in the Scott River Watershed

Parameter	Desired Condition	Applicability	Assessment of Available Data
Debris (LWD)	the volume and frequency of LWD and key pieces of LWD.	channel widths > 1m.	cannot be evaluated against LWD key piece criteria.
Pools – Backwater Pool Distribution	Increasing trend in the number of backwater pools.	Wadeable streams and rivers with channel morphology that supports the development of backwater pools. Steep, v-shaped valleys with little floodplain connection generally do not exhibit this type of habitat and are exempt from this index.	No data.
Pools – Lateral Scour Pool Distribution	Increasing trend in the number of lateral scour pools.	Wadeable streams and rivers with channel morphology that supports the development of backwater pools. Steep, v-shaped valleys with little floodplain connection generally do not exhibit this type of habitat and are exempt from this index.	No data.
Pools – Primary Pool Distribution	Increasing trend in the number of reaches where the length of the reach is composed of ≥ 40% primary pools.	All wadeable streams and rivers.	Available data on both the mainstem Scott and tributaries do not meet the desired condition in any reach measured.
Percent Fines	≤ 14% fines < 0.85 mm in diameter. ≤ 30% fines < 6.40 mm in diameter.	Wadeable streams and rivers with a gradient < 3%.	Available data indicate stable or improving trends in the 0.85 mm indicator and that the desired condition is generally met. The 6.4 mm desired condition is generally not met, including in the mainstem from French Creek to Shackleford Creek, and in French, Sugar, Canyon and Tompkins Creeks. The 6.4 mm desired condition was met in Etna Creek.
Thalweg Profile	Increasing variation in the thalweg elevation around the mean thalweg profile slope.	Streams and rivers with slopes ≤ 2%.	Data not adequate for assessment.

d) Johnson Bar (T45N R 10W Sec 21), just above the mouth of the Scott River. This site is in the first spawning reach available to Chinook salmon in the fall.
e) Below the mouth of Middle Creek (T44N R11W), below the mouth of Canyon and Kelsey Creeks. Site chosen to show influence of water contributed by free-flowing canyon tributaries that mitigate some of the effects of agriculture.

The biotic indices used by Quigley (2001, p. 6) are:

Taxa Richness - This reflects the number of distinct taxa within a sample. The more diverse the sample, the healthier the habitat indicated. Taxa richness values decrease as the diversity of the sample decreases.

EPT Taxa - Number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). These are the most common taxa of intolerant invertebrates. This number also decreases with disturbance of habitat.

Tolerance Value - This value is a measure of the number of species considered tolerant to pollution. As the health of the habitat decreases, this value increases.

%Dominance - Measures the dominance of the single most abundant taxon. As the habitat quality gets worse, the most tolerant species will increase in numbers, and the % Dominance value will increase.

Modified EPT and Shannon Diversity indices were also reported.

Quigley (2001, p. 8) concludes that samples collected for the project demonstrate degraded water quality through the valley during the summer months, although conditions improve over the course of the winter.
Another measure of the biological health of a stream is the Russian River Index of Biological Integrity (Table 2.3). This measure uses the same biological metrics as the work of Quigley and combines all the metrics into a single score. If the work of Quigley (2001) is considered to be background information, future studies might build upon it by using the Russian River Index of Biological Integrity. Ongoing work on macroinvertebrates by the State Water Board and researchers at Utah State may also provide indicators appropriate to the North Coast.

2.4.2.2 Embeddedness Conditions

The U.S. Forest Service has compiled embeddedness figures for the Scott River and four tributaries within the Klamath National Forest (Table 2.6). The Scott River, with an average of thirty-five percent embeddedness and fifty-four percent of sites exceeding the desired condition value of ≤ 25% embeddedness, showed that the basin as a whole was impaired at the time the measures were made in 1989. Results for Tompkins and Canyon Creeks indicated high embeddedness values at most sites, and average values above the desired condition. Two tributaries, Shackleford and Mill Creeks, showed only mild impairment.

Quigley (2003) reports data on embeddedness from 4 mainstem locations and 24 locations on 8 tributaries (Boulder, Emigrant, French, Mill/Shackleford, Miner's, Sugar and Wildcat Creeks). Results indicate generally high values except in Miner's Creek, Wildcat Creek, the tailings reach, and some locations in French Creek.

Table 2.6
Embeddedness of Gravels in the Scott River & Four Tributaries*

USFS Survey #	Name of Stream	# of Measure-ments	Average % Embeddedness	Range of % Embeddedness	# >25% Embedded	% >25% Embedded
39	Scott River	239	35	0-95	128	54
119	Tompkins Creek	12	33	0-50	10	83

101	Canyon Creek	25	48	0-75	23	92
33	Shackleford Creek	46	13	5-40	2	4
25	Mill Creek	12	10	10-50	1	8

* Data supplied by the USFS. Data gathered in 1989.

2.4.2.3 Large Woody Debris (LWD) Conditions

No systematic analysis of LWD conditions in the Scott River watershed is currently available. Table 2.7 shows an accepted procedure for determining LWD effectiveness. A protocol such as is shown in Table 2.7 would be an appropriate beginning to evaluate the status of LWD in the Scott River and tributaries.

2.4.2.4 Pool Distribution and Depth Conditions

Habitat data cited in the Noyo River Total Maximum Daily Load for Sediment (USEPA, 1999, p. 38-39) all indicate that pool frequency and/or pool depth may be factors limiting the success of salmonids. Deep and frequent pools are necessary as summer rearing habitat, particularly for coho salmon, which are less able than steelhead trout to compete for food supplies in the absence of deep pools (Harvey and Nakamoto, 1996).

Flosi et al. (2004, p. V-15) reported:

> DFG habitat typing data indicate the better coastal coho streams may have as much as 40 percent of their total habitat length in primary pools. In first and second order streams a primary pool is defined to have a maximum depth of at least two feet, occupy at least half the width of the low-flow channel, and be as long as the low-flow channel width. In third and fourth order streams the criteria is the same, except maximum depth must be at least three feet.

A review of habitat typing data collected since 1993 indicates that the better coho streams in California generally have about 40 percent of their total habitat length in primary pools (USEPA, 1999, p. 39). Using this criterion, the numeric desired condition for pool frequency/depth requires that at least forty percent of the total habitat length be in three-foot-deep pools.

Table 2.7
LWD Key Piece Volume Criteria
(taken from Schuett-Hames et al., 1999; modified with results from Fox, 2001)

Min. Diameter in meters	Minimum Length of LWD in meters			
	BFW > 0 to < 5	BFW 5 to < 10	BFW 10 to < 15	BFW 15 to < 20
0.20	32			
0.25	21			
0.30	15	36		
0.35	11	26		
0.40	8	20		
0.45	7	16	38	
0.50	6	13	31	
0.55	5	11	26	
0.60	4	9	22	32
0.65	3	8	19	28
0.70	3	7	19	24
0.75	3	6	14	21
0.80	2	5	12	18
0.85	2	5	11	16
0.90	2	4	10	15
0.95	2	4	9	13
1.00	2	4	8	12
1.05	2	3	7	11
1.10	2	3	7	10
1.15	1	3	6	9
1.20		3	6	8
1.25		3	5	8
1.30		2	5	7
1.40		2	4	6
1.55		2	4	5
1.60		2	3	5
1.70		2	3	4
1.80		1	3	4
2.00			2	3
2.40			2	2
2.80			1	2
3.40				1

Meter/Feet conversion: meters x 3.281 = feet

Minimum LWD Volume to Qualify as a Key Piece

BFW (m)	Volume (m^3)
0 to < 5	1
5 to < 10	2.5
10 to < 15	6
15 to < 20	9
20 to < 30	9.75
30 to < 50	10.5*
50 to 100	10.75*

* Wood piece must have an attached root wad.

Procedure:
1. Select segment bankfull width (BFW) category.
2. Measure diameter of candidate pieces and round to nearest 0.05 m (5 cm)
3. Follow matrix across to find the minimum length requirement.

Key Log Example:
1. Segment has an average BFW of 12 m (use BFW column of 10 to < 15 m).
2. Candidate log diameter is measured/ estimated to be 0.53 m (round to 0.55 m).
3. Log must be a minimum of 26 m long (measure/estimate log length to assess if it is a key piece).

Key Rootwad Example:
1. Segment has an average BFW of 4 m (use BFW column of 0 to < 5 m).
2. A rootwad Key Piece must have a minimum diameter of 1.15 m and length of 1 m.

The Siskiyou RCD (2003) recorded pool occurrence in five reaches of the Scott mainstem and five tributaries. The five reaches of the mainstem ranged from nine percent to thirty percent pools by length and averaged twenty percent. Twenty reaches recorded on the five tributaries ranged from zero percent to fifteen percent pools by length, and averaged six percent pools. This study did not specify depth of pools and some pools may have been less than three feet deep.

Quigley (2003) included data on pools in four reaches of the Scott mainstem and twenty-four reaches on eight tributaries. In this study, the four reaches of the mainstem ranged from nine percent to thirty-four percent pools by length (with the highest value in the tailings reach), and by reach from forty-seven percent to 100 percent of these pools were three feet deep or deeper. In the twenty-four tributary reaches, values ranged from zero percent to twenty percent pools by length.

2.4.2.5 Percent Fines Conditions

In this section, the discussion is broken out by drainage first. Within each drainage discussion, results related to the 6.4mm desired condition are discussed first, followed by results related to the 0.85 mm desired condition. Most of this discussion is based on results presented in Sommarstrom and others (1990) and Sommarstrom (2001), reporting on sampling performed in 1989 and 2000. All samples in both years were collected with a McNeil sampler.

Mainstem Scott River

Sediment size was analyzed from twelve sites in the mainstem Scott River distributed from River Mile (RM) 23.5 to RM 55.7 (in 1989 and 2000. This part of the river is of low gradient and passes through the open agricultural part of Scott Valley Analyses showed more than 30 percent fines <6.3 mm at 9 of 11 sites in 1989 (one site not sampled) and at 10 of 12 sites in 2000. In 1989 the fraction <6.3 mm ranged from 26.8 percent to 92.7 percent; in 2000 that size category ranged from 18.3 percent to 84.3 percent. A comparison of the two sample sets shows increases at 4 sites, decreases at 3 sites, and values about the same at 4 sites. Sediment in the mainstem Scott does not reach the desired condition of $\leq$ 30 percent fines < 6.4 mm in the reach between French Creek and Shackleford Creek. Sommarstrom and others (1990) showed that much of the sand-sized sediment is generated in the areas of decomposed granitic soil in areas on the west and south sides of the watershed, and that disturbance of these areas by management greatly increases their sediment contribution.

At the same sites on the mainstem Scott River, analyses showed more than 14 percent fines <0.85 mm at four of 11 sites in 1989 (one site not sampled) and at 2 of 12 sites in 2000. In 1989 the fraction <0.85 mm ranged from 6.4 percent to 21.6 percent, but in 2000 the range of that size category ranged had decreased to 4.0 percent to 16.8 percent. The biggest improvements were measured in the reach between Etna Creek and Moffett Creek.

Etna Creek

In 2000, samples were collected at one site in Etna Creek, two in French Creek, and one in Sugar Creek, for comparison to sites sampled in 1989. The Etna Creek site, at the Highway 3 bridge, showed the fraction ≤ 6.3mm to be 28.3 percent in 1989 and 16.9 percent in 2000. These values meet the desired condition of ≤ 30 percent in both years and show an improving trend. The fraction ≤ 0.85mm was 5.1 percent in 1989 and 7.4 percent in 2000. These values met the desired condition of ≤ 14 percent in both years.

French Creek

In 1989, three locations were sampled in French Creek. Two of the three samples exceeded 30 percent sediment <6.3mm and did not meet the desired condition of ≤ 30 percent < 6.4mm. Sommarstrom (2001) reported sampling of locations at the Highway 3 and Miner's Creek Road bridges over French Creek. At both locations the fraction of sediment ≤ 6.3mm exceeded 30 percent in 1989 and 2000. All of the three locations sampled in 1989 showed < 14 percent sediment < 0.85mm, meeting the desired condition of ≤ 14 percent. Samples from the two locations resampled in 2000 also met the desired condition.

Sugar Creek

Samples were collected near the mouth below the Highway 3 bridge in 1989 and 2000. The fraction of sediment ≤ 6.3mm was 30.8 percent in 1989, and 33.8 percent in 2000. The fraction ≤ 0.85 mm was < 14 percent in both locations in both years, though slightly higher in 2000.

Canyon Creek

Lester (1999) analyzed sediment from nine sites in Canyon Creek, which drains an area containing some granitic soils. Lester did not use a 6.4 mm screen, but instead used 4.75 mm and 8 mm screens. These data show >30 percent sediment ≤6.4 mm at four of 12 sites and >14 percent fines ≤0.85 mm at none of 9 sites. This creek appears somewhat impaired in regard to fine sediment.

Tompkins Creek

Lester (1999) analyzed sediment from nine sites in Tompkins Creek, which drains an area containing some granitic soils. These data show >30 percent sediment ≤6.4 mm at four sites and >14 percent fines ≤0.85 mm at one site. In summary, results at the locations sampled appear to indicate improving trends from 1989 to 2000 for the fraction <0.85 mm, but show continued patterns of exceedance and no clear trend of improvement for the fraction <6.4 mm.

2.4.2.6 Thalweg Profile Conditions

No systematic information on thalweg profiles is available in the Scott River watershed. One study by University of California Davis (2003) surveyed reaches in Mill Creek (4), Emigrant Creek (3), French Creek (5), Sugar Creek (5), and the East Fork (5). Example results of longitudinal profiles and cross sections are presented, though comparisons through time are not made. Sommarstrom and others (1990, p. 3-9 to 3-14) measured cross sections at 15 locations from above Callahan to the Scott River gage station near Fort Jones. The report (Figure 3-10) compares cross sections at the Highway 3 bridge from 1956 and 1989, and finds the thalweg elevations are similar.

2.4.2.7 V* Conditions

Before 1992 excess fine sediment was acknowledged to be a significant problem in French Creek. V* analyses were done in French Creek yearly from 1992 to 1997 and again in 1999 and 2001 (Figure 2.4). The number of pools sampled each year ranged from 11 to 13.

More than sixty percent of the French Creek drainage basin is underlain by DG, which ravels and contributes abundant sediment to streams (e.g. Sommarstrom, 1992). By the early 1990s management activities had disturbed large areas in the basin. In 1992 a major restoration and reclamation effort began that included, among other steps, repairing and redesigning road crossings, outsloping roads, and decommissioning some roads. A major decline in fine sediment in the following years appears to be the direct result of that initiative. In 1997, a major storm led to flooding and abundant sediment contribution. However, the V* values rose to only about fifty percent of what they had been in 1992. The restoration work that began in 1992 appears to be quite effective in decreasing the sediment contribution to French Creek.

The U.S. EPA, in the South Fork Trinity River and Hayfork Creek TMDLs (U.S. EPA, 1998a, Table E-2), includes a mean V* desired condition value of ≤ 0.10 for tributaries that drain watersheds composed of the metamorphic and intrusive basement of the Klamath Mountains geologic province, which includes the Scott River watershed. The U.S. EPA states that background values of 0.10 to 0.15 would be expected for Klamath Mountains geology (Lisle, USFS, pers. comm., 1998, as cited in U.S. EPA, 1998a, Table E-1). Assuming that a mean V* value of ≤ 0.10 represents healthy background conditions in the Scott River watershed, data from French Creek indicate improving trends in V*, and values that meet or are near to meeting the ≤ 0.10 value. There are no data available for the mainstem Scott River or other tributaries.

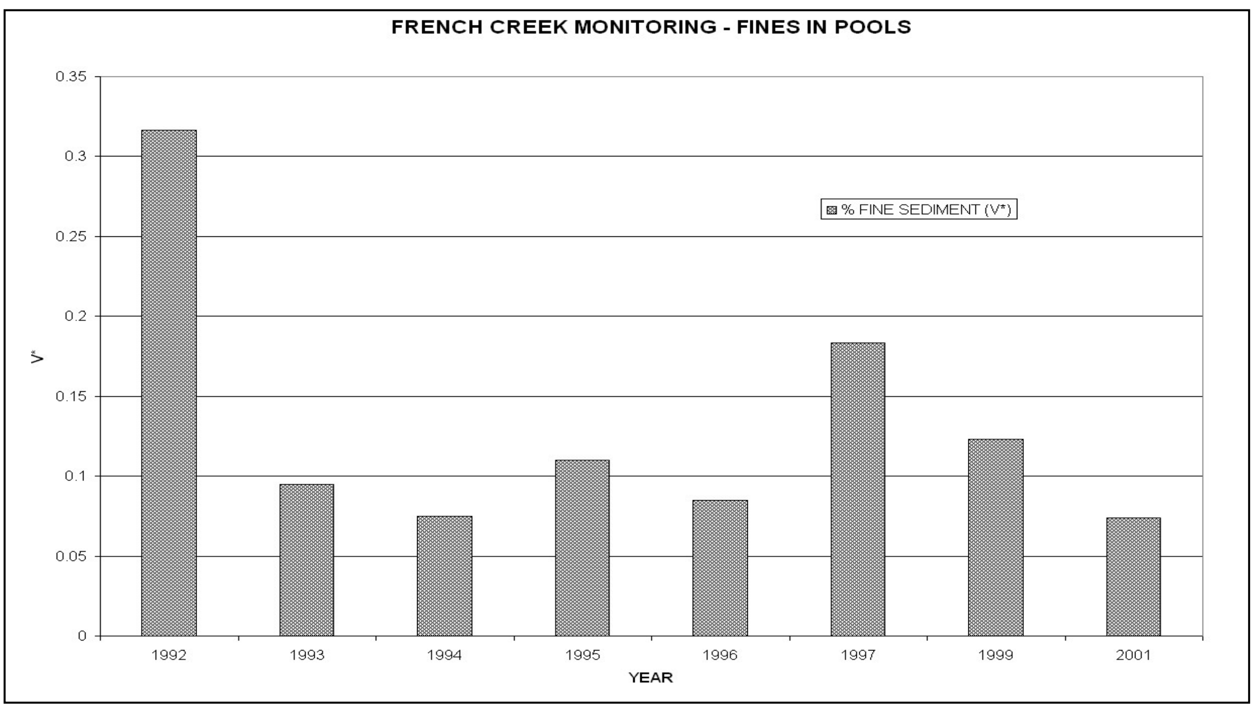

Figure 2.4. French Creek Monitoring Results – Fine Sediment in Pools (V*)

Juvenile coho surveys done in French Creek from 1992, the time of the French Creek Project, are discussed in Section 2.3 and indicate an increasing trend in coho coincident with the beginning of improvement in sediment conditions in the stream.

2.4.3 Watershed Sediment Conditions in the Scott River Watershed

The hydrology and surface conditions in the Scott River watershed have been affected over time by several intense management activities. The upslope conditions in the Scott River watershed have been altered by human activities in many ways, some of them reversible and some, such as effects of some aspects of mining activities, virtually irreversible. The following sections describe some of these processes, the conditions they create, and recently documented trends.

2.4.3.1 Stream Crossings with Diversion Potential or Significant Failure Potential

The USFS has done a road sediment source inventory that includes sites in the Scott River watershed (USFS, 2001). Diversion potential was estimated at 38% of channel crossing sites in the Lower Scott survey area (mostly in the West Canyon subwatershed, as defined in chapter 3), and at 36% in the Upper Scott survey area (all in the West Headwater (South Fork) subwatershed).

A road erosion inventory in the Shackleford and Mill Creek watersheds (SHN Consulting Engineers & Geologists, 1999) mapped 107 miles of forest roads on private timberlands. The road density is approximately 8.9 miles per square mile. Culverts, crossings, gullies, slides, and road surface erosion were inventoried and evaluated for past erosion and possible future erosion. Sites and road segments farther than ¼ mile from a fish-bearing stream were not considered. Features surveyed included 164 culverts, 186 crossings, 82 gullies, and 50 slides. Estimated volume of past erosion, not including mass movement, was 19,700 cubic yards. This inventory identifies 487 features in the four point-source categories, of which 121 are evaluated as high or medium-high priority for treatment.

The follow-up Shackleford-Mill Road Erosion Reduction Project (Siskiyou Resource Conservation District, 2003) treated 30 miles of roads to reduce sediment production. The program hydrologically decommissioned 6.9 miles of road and improved the remainder to reduce sediment contribution. Measures consisted primarily of storm-proofing road segments and crossings, and out-sloping roads. The 219 sites treated had the potential to deliver 73,000 cubic yards of sediment.

A road survey in the upper Etna Creek drainage and adjacent areas in Clark Creek, North Fork French Creek, and upper French Creek (Resource Management, 2003) examined approximately 100 miles of road. The area has had extensive timber harvest, and harvest continues, but we do not know the most recent harvest history. Generalizations summed up in this study are:

- 91% of past erosion has been on 25 percent of the road miles.

- Only 20-30% of smaller culverts in the area (12, 18, 24 inch) pass for a 100-year flow design; however small errors in drainage area calculations or assumptions regarding infiltration can have large effects on results, so more investigation is needed.
- Culverts 36" and larger passed 100 year flow design at 50% and higher.
- New road construction and ongoing maintenance techniques are effective.
- Effective use of low water crossings and bridges reduced diversion potential and increased the number of crossings passing 100-year flows.

The Preliminary Road Maintenance Action Plan calls for a) specific erosion site plans, b) company 5-year planning schedule, c) company road maintenance procedures, d) workable cooperative road agreements. The report notes and prioritizes specific problem sites.

2.4.3.2 Hydrologic Connectivity

SHN (1999) recommends upgrading major segments of roads in the Mill and Shackleford Creek drainages. The SHN (1999) road inventory does not record whether a road segment has inboard ditches, but their map of Erosion and Crossing Locations shows many culverts that are not in natural drainages, suggesting an extensive inboard ditch system and little outsloping. They do not describe the culverts and to what degree they are "shotgunned."

The USFS has done a road sediment source inventory that includes sites in the Scott River watershed (USFS, 2001). The results indicate hydrologic connectivity values of 12.3% and 21.8% in the upper and lower Scott survey areas, respectively.

2.4.3.3 Annual Road Inspection and Correction

The USFS and timber companies maintain roads on a project basis, repairing and upgrading roads in limited areas on a project rather than on a widespread annual basis. Over time, the trend is toward an increasing proportion of outsloped roads, although a large proportion of roads remain in ditch-and-culvert design. One timber company is currently embarking on a long-term road management plan as part of a Habitat Conservation Plan. Other private roads appear to be maintained on an as-needed basis. The SHN study (SHN 1999, p. 14) survey notes that many road segments have had little or no annual maintenance for years.

2.4.3.4 Road Location, Surfacing, & Sidecast

The road erosion inventory of Shackleford and Mill Creek watersheds (SHN Consulting Engineers and Geologists, 1999) does not quantify the miles of road adjacent to streams, but the included map shows gravel surface roads in inner gorges within 600 feet of both Shackleford and Mill Creeks. In this heavily roaded area many logging roads lie on lower slopes and in headwall areas. The inventory document recommends much upgrading of culverts and crossings, and sets priorities, but does not address outsloping of roads.

Information on road proximity to streams was developed as part of the sediment source analysis and is presented in Chapter 3.

2.4.3.5 Disturbed Areas

The earliest major disturbance in the Scott River watershed was placer mining for gold, which started at Scott Bar in 1850 and soon spread throughout much of the watershed. The story of this mining, summarized by the Scott River Watershed CRMP Committee (1995), is a story of placer mining that included deep dredging and hydraulic mining. Resulting sediment plumes impeded fish surveys as late as 1934, and in 1934 a federal fishery biologist reported that upstream of Callahan food and spawning grounds had been destroyed. During development of mining, extensive ditches were constructed. Later, these ditches were used for developing agriculture. Much of the agriculture is grazing and hay cropping, which does not qualify as disturbed areas under the present definition. Timber harvest began along with mining, and continues on an industrial scale to the present. Logging roads are a major source of sediment, and they contribute a particularly large amount in areas of decomposed granite (DG) soils (Sommarstrom et al., 1990; Sommarstrom et al., 1999).

2.5 TEMPERATURE PROBLEM STATEMENT

This section describes the freshwater temperature requirements for salmonids, recommended criteria for summer salmonid rearing, desired conditions, and temperature conditions in the Scott River watershed.

2.5.1 Salmonid Temperature Requirements

Temperature is one of the most important factors affecting the success of salmonids and other aquatic life. Most aquatic organisms, including salmon and steelhead, are poikilotherms, meaning their temperature and metabolism are determined by the ambient temperature of water. Temperature therefore influences growth and feeding rates, metabolism, development of embryos and alevins, timing of life history events such as upstream migration, spawning, freshwater rearing, and seaward migration, and the availability of food. Temperature changes can also cause stress and mortality (Ligon et al., 1999).

Much of the information reported in the literature characterizes temperature requirements with terms such as “preferred” or “optimum” or “tolerable.” Preferred temperatures are those that fish most frequently inhabit when allowed to freely select temperatures in a thermal gradient (McCullough, 1999). An optimum range provides for feeding activity, normal physiological response, and normal behavior (without symptoms of thermal stress) (McCullough, 1999). A tolerable temperature range refers to temperatures at which an organism can survive.

Most interpretations of water temperature effects on salmonids and, by extension, water temperature standards, have been based on laboratory studies. Many studies have also looked at the relationship of high temperatures to salmonid occurrence, abundance, and distribution in the field.

As discussed above, several species of anadromous fish utilize the Scott River watershed at some point within in their life cycle, including various salmonid species. A complete review of the literature pertaining to the temperature requirements for the various life stages of steelhead trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*) and chinook salmon (*O. tschawytscha)* is presented in *The Effects of Temperature on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stag, Implications for Klamath Basin TMDLs* (Carter, 2005*)*. When possible, species-specific requirements were summarized by four life stages: migrating adults, spawning, embryo incubation and fry emergence, and freshwater rearing. Some of the references reviewed covered salmonids as a general class of fish, while others were species specific.

2.5.1.1 Temperature Metrics

It is useful to have measures of chronic and acute temperature exposures for assessing stream temperature data. An USEPA document*, Temperature Criteria for Freshwater Fish: Protocol and Procedures* (Brungs and Jones, 1977) discusses development of criteria for assessing temperature tolerances of fish for several different life stages. Two measures of exposure are developed and applied: maximum weekly average temperature (MWAT) as a measure of chronic exposure and short-term maximum temperature as a measure of potentially lethal effects.

The MWAT is the maximum value of the mathematical mean of multiple, equally spaced, daily temperatures over a 7-day consecutive period (Brungs and Jones, 1977). In different words, this is the highest value of the 7-day moving average of temperature. Brungs and Jones developed MWAT metrics for the growth phase of fish life, as growth appears to be the life stage most sensitive to modified temperatures and it integrates many physiological functions. They also developed life stage MWAT metrics for spawning.

Sullivan and others (2000) review sub-lethal and acute temperature thresholds from a wide range of studies, incorporating information from laboratory-based research, field observations, and risk assessment approaches. The authors report calculated MWAT metrics for growth ranging from 14.3° C to 18.0° C (57.7^{o} F to 64.4 ^{o} F) for coho salmon, and 14.3° C to 19.0° C (57.7^{o} F to 66.2^{o} F) for steelhead trout. The risk assessment approach used by Sullivan and others (2000) suggest that an upper threshold for the MWAT of 14.8° C (58.6^{o} F) for coho and 17.0° C (62.6^{o} F) for steelhead will reduce growth 10 percent from optimum, and that thresholds for the MWAT of 19.0° C (66.2^{o} F) for both coho and steelhead will reduce growth 20 percent from optimum.

While these thresholds relate to reduced growth, temperatures at sub-lethal levels also can effectively block migration, inhibit smoltification, and create disease problems (Elliot, 1981). Further, the stressful impacts of water temperatures on salmonids are cumulative and positively

Table 2.8
Recommended Criteria for Summer Maximum Water Temperatures

Use	**Criteria**	
	7-DADM	**MWAT**
Salmon / Trout "Core" Juvenile Rearing (*Salmon adult holding prior to spawning may also be included in this use category*).	16°C / 60.8°F	14.5°C / 58.1°F
Salmon/Trout Migration	18°C / 64.4°F	16.1°C / 70.0°F

plus Non-Core Juvenile Rearing.		
Salmon/Trout Migration.	20°C / 68.0°F	17.7°C / 63.9°F

Notes:
1) "Salmon" refers to chinook, coho, sockeye, pink, and chum salmon. "Trout" refers to steelhead and coastal cutthroat trout.
2) "7-DADM" refers to the Maximum 7-Day Average of the Daily Maximums.
3) Source: U. S. Environmental Protection Agency (2003a, p.25).

correlated to the duration and severity of exposure. The longer the salmonid is exposed to thermal stress, the less chance it has for long-term survival (Ligon et al., 1999).

Jobling (1981) reported that the upper lethal limit, that is, the temperature at which death occurs within minutes, ranges from 27° C to 30° C (80.6 F to 86.0° F) for salmonids. Sullivan and others (2000) report acute threshold values, that is, temperatures causing death or total elimination of salmonids from a location, that range from 21.0° C to 25.5° C (69.8° F to 77.9° F) for coho, and 21.0° C to 26.0° C (69.8° F to 78.8° F) for steelhead.

The MWAT is used as the primary statistical measure for interpretation of stream temperature conditions in the summary of stream temperature data in the Scott River watershed. USEPA Region 10 has issued guidance regarding temperature criteria protective of cold water fish for various species and life-stages. These values are included here to aid with interpretation of watershed data. Because USEPA values are presented for the maximum 7-day averages of daily maxima (7-DADM), an MWAT equivalent value is included in Table 2.8 using correlation equation developed using temperature data from the Scott River watershed. The values in Table 2.7 are used for comparison to measured stream temperatures to characterize the temperature quality of surface waters in the Scott River watershed.

2.5.2 Temperature Desired Conditions

2.5.2.1 Effective Shade

Desired condition: Adjusted Potential Effective Shade Conditions from Riparian Vegetation
Effective shade is defined as the percentage of direct beam solar radiation attenuated and scattered before reaching the ground or stream surface from topographic and vegetation conditions. The desired shade conditions are those that result from achieving the natural mature vegetation conditions that occur along stream channels in the watershed, approximated as adjusted potential shade conditions as described in Section 4.5.1. The distribution of adjusted potential shade values is presented in Figure 4.29. A second approach to identifying the potential shade conditions at a site is detailed below.

To determine potential shade conditions provided by riparian vegetation for a particular stream reach in the watershed requires correlation of vegetation type, stream aspect, and active (unvegetated) channel width with effective shade. These relationships are functions of vegetation type, channel geometry, topography, and solar position.

Two models used to predict shade given channel characteristics as input were tested for use in estimating potential shade on a reach-by-reach basis. ODEQ has developed an Excel-based spreadsheet that allows calculation of effective shade as a function of vegetation height, stream aspect, active channel width, stream buffer width and buffer density. The spreadsheet is based on equations presented by Boyd (1996) and expanded for TMDL applications. USGS (Bartholow, 1999) also has a shade model.

The ODEQ spreadsheet, named SHADE, was selected for use in developing desired condition shade curves for different vegetation types occurring along riparian corridors of the Scott River and its tributary streams because it is better adapted for TMDL applications and has been used in the development of an approved temperature TMDL (ODEQ, 2000).

Effective shade desired conditions for the vegetation classes occurring in the watershed were set at 90% of the potential vegetation height for the class. Effective shade curves are presented for Douglas Fir (DFR) and Mixed Hardwood-Conifer (MHC) forest (40m), Klamath Mixed Conifer (KMC) and Ponderosa Pine (PPN) forest (35m), and Oak Woodland (20m) (Figures 2.5, 2.6 and 2.7) as an indicator of riparian conditions relative to a potential condition. Buffer widths are assumed to be 30m. The curves were developed for the July 22 solar path. The curves presented in Figures 2.4, 2.5 and 2.6 constitute the numeric targets for the temperature TMDL.

2.5.2.2 Thermal Refugia

Desired condition: Increased volume of thermally stratified pools
The desired condition is an increased volume of thermal refugia. Thermal refugia are sites that provide cold water habitat. The depth and degree of stratification is partly a function of stream flow and is expected to vary depending on site conditions. Thermally stratified pool volume can be expected to increase as existing stratified pools become deeper and shallow pools become deep enough to stratify in response to reduced sediment supply. Thermal refugia are also commonly found at the mouths of cold tributaries.

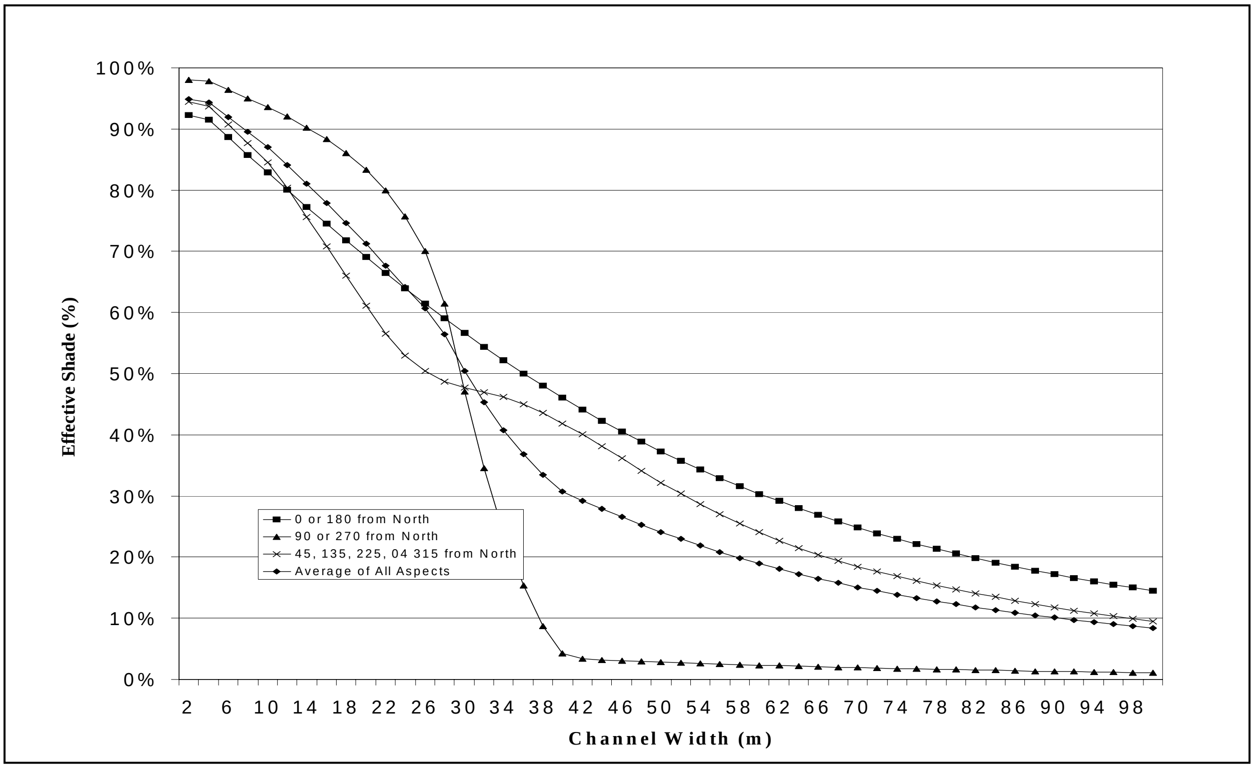

Figure 2.5: Effective Shade vs. Channel Width, Douglas Fir Forest (DFF) and Mixed Hardwood – Conifer Forest, Buffer Height = 40m

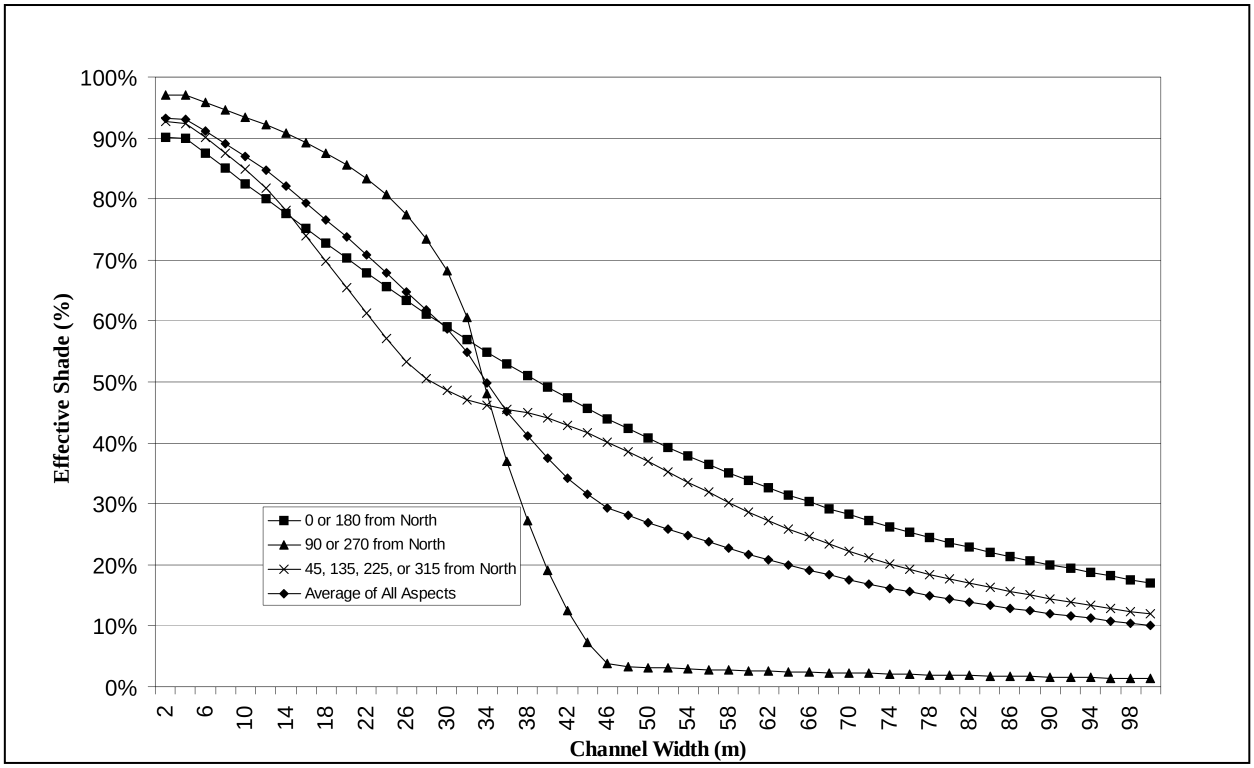

Figure 2.6 Effective shade vs. channel width, Klamath Mixed Conifer Forest (KMC) and Ponderosa Pine Forest (PPN), buffer height =35m

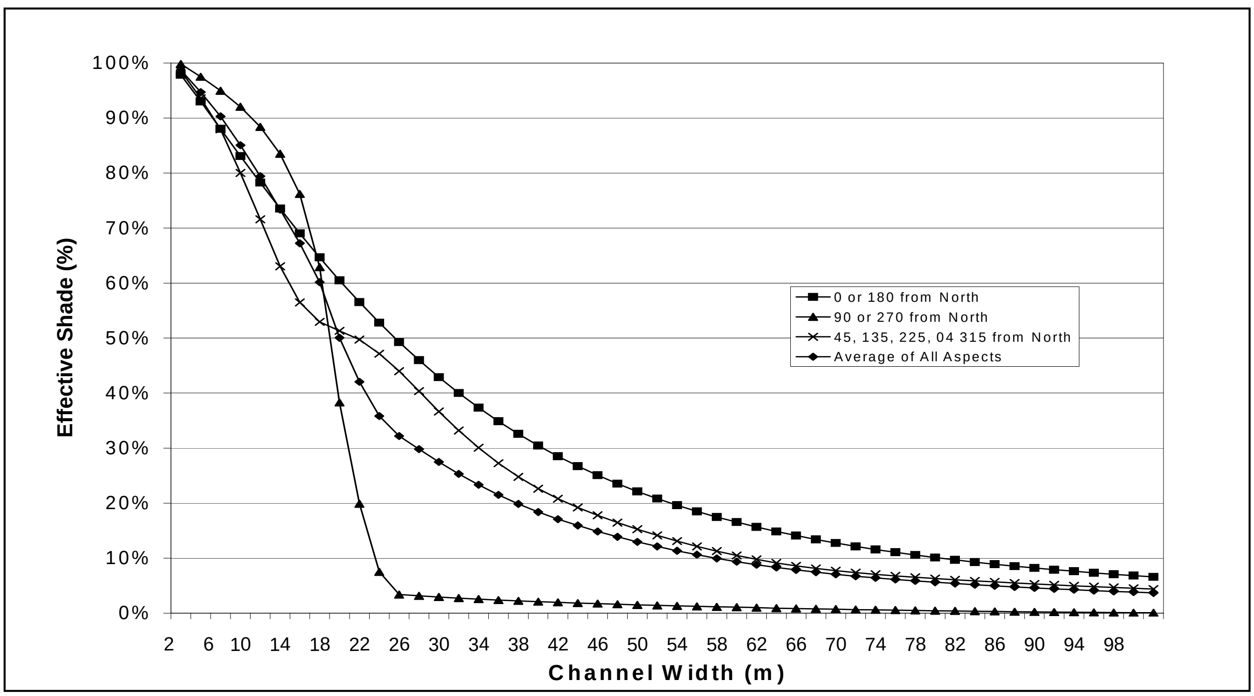

Figure 2.7. Effective shade vs. channel width, Oak woodland, buffer height =20m

2.5.3 Temperature Conditions in the Scott River Watershed

Unlike sediment-related objectives, stream temperature is a directly measurable water quality parameter and requires no indicator for interpretation of the water quality objective.

2.5.3.1 Summary of Temperature Conditions

Stream temperature data collected in the Scott River watershed since 1995 indicate that conditions vary throughout the watershed. A few generalities can be drawn based on these data:

1. Summer temperature conditions in the mainstem of the Scott River do not support suitable rearing habitat for salmonids.
2. Summer temperature conditions in the East Fork of the Scott River do not support suitable rearing habitat for salmonids.
3. Summer temperature conditions in the South Fork of the Scott River support suitable rearing habitat for salmonids in some years.
4. Summer temperature conditions in the upper reaches of many tributary streams in the Scott River watershed support rearing habitat for salmonids. These tributary streams include Lower Mill, Kelsey, Canyon, Boulder (canyon), Sniktaw, Shackleford, Mill (Shackleford tributary), Kidder, Etna, Etna-Mill, Clark, French, Sugar, Jackson, Fox, Boulder (west headwaters), Rail, and Kangaroo Creeks
5. Summer temperature conditions in the lower reaches of some tributary streams in the Scott River watershed, including Kelsey, Shackleford, Kidder, Patterson (west side), French, Wildcat, Etna, and Big Carmen Creeks do not support suitable rearing habitat for salmonids.
6. Summer temperature conditions in the upper reaches of Moffett Creek and Sissel Gulch do not support suitable rearing habitat for salmonids.

Stream temperatures vary considerably throughout the Scott River watershed in response to geomorphic and hydrologic characteristics. Quigley and others grouped streams in the Scott River watershed into six areas with similar geomorphic and hydrologic characteristics: the East Headwaters (East Fork watershed), West Headwaters (South Fork watershed), Scott Valley, Eastside, Westside, and Canyon. Water Board staff has summarized stream temperature conditions using the same groupings, except that the valley category has been replaced by the mainstem of the Scott River.

2.5.3.2 Scott River Mainstem

The temperatures in the Scott River are too high for suitable salmonid habitat conditions from the confluence of the East and South Forks to the mouth at the Klamath River. Starting at the confluence of the East and South Forks, the Scott River begins relatively warm. At river mile 55 the MWAT ranged from 20.4^{o} C (68.7^{o} F) to 17.1^{o} C (62.8 ^{o} F) in the years monitored (Table 2.9). The lowest MWAT measured in the Scott River was 17.0^{o} C in the tailings reach, near the upstream end of the river during 1998. The highest MWAT measured in the Scott River was 23.9 at Roxbury Bridge, near the mouth of the river, in 2003.

2.5.3.3 West Headwaters / South Fork Scott River

The West Headwaters of the Scott River, which consists of the South Fork Scott River and its tributaries, are located in the southwestern extremity of the Scott River Watershed. The West Headwaters have beneficial temperature conditions for salmonids, though the temperature rises into the unsuitable range in some years near the mouth of the South Fork of the Scott River (Table 2.10).

2.5.3.4 East Headwaters

The East Headwaters of the Scott River, which consists of the East Fork Scott River and its tributaries, are located in the southeastern extremity of the Scott River Watershed. The East Fork Scott River has temperatures that are warmer than the South Fork (Table 2.11). The East Fork MWATs are in the unsuitable range for salmonids. The middle and upper reaches of many of the perennial tributaries have temperatures cool enough to support salmonids.

2.5.3.5 Westside Tributaries

The Westside sub-basin tributaries have a wide range of measured MWAT temperatures (Table 2.12). Temperatures at three sites are suitable for salmonid habitat, while other sites have unsuitable temperatures, and yet others have suitable temperatures in some years and unsuitable temperatures in other years.

2.5.3.6 Eastside Tributaries

There is very little data for the eastside tributaries. There is only data available for two sites, both in the upper reaches of the Moffett Creek drainage (Table 2.13). Data from these two sites indicate that temperature conditions are unsuitable for salmonid habitat in most years.

2.5.3.7 Canyon Tributaries

The Canyon sub-basin tributaries exhibit a wide range of temperatures, from 10.9^{o} C in Patterson Creek, to 20.0^{o} C in Deep Creek (Table 2.14). The majority of measured tributary stream temperatures in this sub-basin indicate these tributaries are not fully supportive of salmonid habitat.

Table 2.9: Stream MWATs, Scott River Mainstem, 1995 – 2004

River Mile	LOCATION	Maximum Weekly Average Temperature (C)									
		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
0.5	at Steelhead Bridge		22.8								
0.5	at Roxbury Bridge									23.9	
6.5	at McGuffy Creek		21.9	22.9	**21.8**						
10.8	at Townsend Gulch									22.6	
13.2	at Deep Creek			21.8						22.5	
14.3	below Kelsey Creek									22.2	
15.8	below Canyon Creek		21.2		**21.1**					22.4	
16.1	above Canyon Creek			22.7						23.3	
18.8	at Jones Beach		22.4		**22**					23.3	
21.6	at USGS Gaging Station	20.2			**21**					22.7	
	above Shackleford Creek							*18.6*			21.6
22.6	below Meamber Gulch								*21.2*		21.3
	at Meamber Creek 1					**19.8**	21.8				
	at Meamber Creek 2			23.1						22.5	
24.9	at Meamber Bridge								*21.4*	22.5	
25	at Meamber School			21.0		**19.8**					
31.9	at Eiler Ranch			21.7	**21.1**	**19.9**	22.5				
31.9	below Kidder								*23.7*	23.3	23.3
32.5	above Kidder Creek									23.6	
33.1	at Highway 3 Bridge			22.8		**21.2**					
35.1	at Island Road			23.1		**21**	23.6			23.2	
39.4	near Black Bridge								*22.0*	21.9	
41.5	at Eller Lane			22.1	**20.5**	**19.9**	22.5				
41.8	at Sweazey's Bridge									21.0	
42.3	above Sweazey's Bridge									20.3	
42.6	below Etna Creek			20.6	**20**		20.6				
42.9	above Etna Creek			20.7	**19.7**		17.2	*18.0*	*17.6*		
44.6	at Horn Lane			19.5			19.4				
47.9	below French Creek			20.9	**18.2**	**18.7**	19.1	*19.7*	*19.0*	20.3	
48.2	above French Creek			20.8	**19.7**	**18.5**	19.8	*20.9*	*20.0*	20.3	
50.2	at Fay Lane			19.6	**19.2**		20	*19.3*		20.2	19.7
50.2	above Fay Lane (bottom)									19.3	
50.2	above Fay Lane (surface)									20.1	
52.8	Alexander				**17**	**19.9**					
53.2	at Alexander's (bottom)									20.2	
53.2	at Alexander's (surface)									21.0	
53.6	Scott River tailings						20.3				19.8
54.5	at Red Bridge				**18.3**	**17.1**					
54.5	Scott River in tailings									20.4	

High discharge years are in **bold,** low discharge are shown in *italics* .

Table 2.10: Stream MWATs, West Headwaters Sub-Basin, 1996 - 2004

LOCATION	Maximum Weekly Average Temperature (C)								
	1996	1997	1998	1999	2000	2001	2002	2003	2004
South Fork at Baker's			**16.3**	**13.8**	17.3	*17.8*	*17.3*	17.4	
South Fork at Blue Jay Creek			**14.8**	**13.5**	15.4	*15.9*	*15.3*	15.9	15.6
Boulder Creek	16								
Fox Creek	14.9								
SF Scott at road 40N21Y								15.8	
Jackson Creek	14.6								

High discharge years are in **bold,** low discharge are shown in *italics* .

Table 2.11: Stream MWATs, East Headwaters Sub-Basin 1998 – 2004

LOCATION	Maximum Weekly Average Temperature (C)						
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
E.F at Callahan	**14.4**	**19.4**	21.6	*21.9*	*21.8*	22.1	21.8
Grouse Creek		**16**	18.5				
E.F at Masterson Road	**21**		21.4	*20.9*	*21.7*	22.7	21.5
Kangaroo Creek		**11.6**	12.3				
Rail Creek 1	**16**	**15.1**	17.3	*16.7*	*17.9*	17.7	17.3
Rail Creek 2				*17.0*			
Rail Creek 3			17.4				
Upper East Fork below Houston Creek						17.0	

High discharge years are in **bold,** low discharge are shown in *italics* .

Table 2.12: Stream MWATs, westside tributaries of Scott River, 1996 – 2004

LOCATION	Maximum Weekly Average Temperature (C)					
	1996	**1997**	**1998**	**1999**	**2000**	**2003**
Mill Creek - Scott Bar	16.2	16.5	**16.3**	**15.2**	17.1	
Upper Mill Creek					14.2	
Tompkins Creek		16.9	**17.6**			17.6
Tompkins Creek - Potato		17.3				
Middle Creek at Mouth						18.5
Deep Creek Mouth						20.0
Lower Kelsey	16.8	17.4	**16.6**			17.8
Upper Kelsey	10.9					
Lower Canyon		15.4	**15.2**			15.8
Upper Canyon	15.5	15				
Lower Boulder Creek	14.4	14				

High discharge years are in **bold,** low discharge are shown in *italics* .

Table 2.13: Stream MWATs, eastside tributaries of Scott River, 1997 – 2001

LOCATION	Maximum Weekly Average Temperature (C				
	1997	**1998**	**1999**	**2000**	**2001**
Sissel Gulch			**16.3**	18.6	*16.9*
Moffett Creek	16.9	**16.8**	**15.8**	17.6	*17.5*

High discharge years are in **bold,** low discharge are shown in *italics* .

Table 2.14: Stream MWATs, tributaries of canyon section of the Scott River, 1996 – 2003.

	Maximum Weekly Average Temperature (C)					
LOCATION	**1996**	**1997**	**1998**	**1999**	**2000**	**2003**
Mill Creek - Scott Bar	16.2	16.5	**16.3**	**15.2**	17.1	
Upper Mill Creek					14.2	
Tompkins Creek		16.9	**17.6**			17.6
Tompkins Creek - Potato		17.3				
Middle Creek at Mouth						18.5
Deep Creek Mouth						20.0
Lower Kelsey	16.8	17.4	**16.6**			17.8
Upper Kelsey	10.9					
Lower Canyon		15.4	**15.2**			15.8
Upper Canyon	15.5	15				
Lower Boulder Creek	14.4	14				

High discharge years are in **bold,** low discharge are shown in *italics* .

CHAPTER 3. SEDIMENT

Key Points

- The sediment source analysis addresses both natural and human-caused sources of sediment.
- Road-generated sediment rates calculated from road inventories and modeling in the South Fork subwatershed were applied to other parts of the watershed.
- Granitic bedrock and decomposed granite soils were considered separately in the road-generated sediment estimates.
- Large mass-wasting features were inventoried for the entire watershed from aerial photos.
- Streamside sediment source estimates were based on inventories of stream banks and streamside features contributing sediment in sample reaches.
- Streamside sample reaches were identified using a stratified random sampling approach. The results were then extrapolated to other stream reaches based on geology.
- The largest sediment sources are from streamsides and are the result of multiple interacting human activities.
- Results show current sediment delivery is 167% of natural sediment delivery.
- The TMDL is set at 125% of natural sediment delivery.
- The sediment TMDL for the Scott River watershed is 560 tons of sediment per square mile per year.

This chapter describes the sediment source analysis, study methods, sediment TMDL, sediment load allocations, and margin of safety for the Scott River watershed. Please note that all figures and tables for this chapter are located at the end of the Staff Report.

3.1 STUDY METHODS

3.1.1 Sampling Approach and Rationale

The sediment source inventory and analysis is divided into three components:

- Road-generated sediment as calculated based on modeling (SEDMODL2) and road inventories.
- Large mass-wasting features inventoried on aerial photos.
- Streamside sediment sources as calculated from inventories of stream banks and discrete erosion and mass-wasting features contributing sediment.

Because not all stream reaches can be inventoried, a sample of stream banks was inventoried based on a stratified random sampling approach.

3.1.2 Subwatersheds Used in Compilation

For the purpose of the TMDL analysis, the Scott River watershed was divided into seven subwatersheds, each of which has more continuity of characteristics within it than it has with the other subwatersheds. The sub-watersheds, shown on Figure 3.1, are as follows:

- **West Canyon.** Steep rugged mountains. Mostly sedimentary and metamorphic bedrock with smaller areas of mafics and only a small area of granite. Greatest concentration of landslides in the Scott is in the western portion of this area. Mostly high precipitation except lower slopes of the mountains.

- **East Canyon – Scott Bar Mountains**. Steep rugged mountains, almost all sedimentary and metamorphic bedrock. Only one landslide mapped. Mostly drier than West Canyon except in highest Scott Bar Mountains.

- **Eastside**. Moffett Creek drainage. Steep country, but not as high as mountains that ring the rest of Scott Valley. Mostly sedimentary and metamorphic bedrock with a little mafic bedrock in the mountains and a little Quaternary in the valley bottom. No significant landslides were mapped or observed on aerial reconnaissance. Least precipitation of the seven subwatersheds.

- **East Headwater**. East Fork and Noyes Valley Creek drainages. Steep, rugged mountains, more than half sedimentary and metamorphic bedrock, but has largest area of mafic bedrock and a little granitic bedrock. One upland valley has Quaternary glacial deposits, other Quaternary deposits too small to map at scale shown. Few landslides. High country is intermediate in precipitation between the Westside/West Headwater area and the Eastside.

- **West Headwater - South Fork Drainage**. Steep, rugged mountains. Largely granitic and mafic bedrock, small amount of sedimentary and metamorphic bedrock. High precipitation in the high country and lower precipitation at lower elevations. Has several landslides and several hydraulic mining sites. High precipitation in the high country and lower precipitation at lower elevations.

- **Westside**. Steep, rugged mountains. Mixed bedrock geology but has largest areas of granitic bedrock, which produces unique problems. Landslides widely distributed in the steep country, particularly in granitics, but not great concentrations of landslides. High precipitation in the high country and lower precipitation at lower elevations.

- **Scott Valley and Eastern Valley Side**. Valley bottom is low relief, low precipitation, and underlain by Quaternary alluvium. Eastern valley side has low precipitation like the valley bottom, and much of the drainage does not reach the Scott, so it is a low sediment contribution area.

3.1.3 Combined Geologic Units

The geologic material and structure underlying a particular area is a primary factor in determining not only sediment delivery under natural conditions but also sediment delivery in response to human activities. For this reason staff chose bedrock composition as the factor on which to stratify sampling. The GIS geology coverage used (Saucedo et al., 2000) shows not less than twelve geologic units mapped in the Scott. Because applying all of these units would create too many strata for a practical sampling program, similar mapped units were combined. For the purposes of the streamside sampling program, staff aggregated the mapped units into four geologic units:

- Quaternary Deposits
- Granitic Bedrock
- Mafic and Ultramafic Bedrock
- Sedimentary and Metamorphic Bedrock

3.1.4 Description of Geologic Units

3.1.4.1 Quaternary Deposits

This unit is primarily unconsolidated gravel, sand, and soil that make up the floor of Scott Valley and the lower reaches of some tributary valleys. For the most part this unit forms flat or gently sloping land, as the land surface is the surface on which these materials were deposited. For this reason, the main means of erosion over most of the area of this unit is not slope processes but rather bank erosion of streams and occasional gullying. The primary management-related sediment delivery over most of the unit is associated with crop production, livestock management, and dredging legacy. Small areas within this unit include glacial deposits in the high valleys of the Scott Mountains, and landslide deposits.

3.1.4.2 Granitic Bedrock

This unit is exposed in the mountains paralleling the west side of Scott Valley. The suite of granitic rocks ranges in composition from granite to granodiorite (Mack, 1958, p. 24), and is generally fine grained and weathers to noncohesive and highly erodible soil. In the Klamath Mountains and the Sierra Nevada of California this decomposed granite soil is known as DG, both in the scientific literature and in popular parlance. During weathering of the granitic rock, cohesion between grains is lost, leaving the material as a mass of separate grains ranging in size from fine sand to small pebbles and lacking enough clay to bond it together. Consequently, the DG is highly susceptible to dry ravel, rill and gully erosion, debris slides, and debris torrents (Kellogg, 1992, p. 64). In addition, disturbance of the surface, or an increase in the degree of slope, tends to accelerate these processes. The problems of stability and sediment contribution associated with DG are sufficiently severe, widespread, and costly that a conference dedicated to these problems and their solutions was convened in Redding, California in 1992 (Sommarstrom, 1992).

3.1.4.3 Mafic and Ultramafic Bedrock

This unit is largely serpentine along with minor basalt, peridotite, and gabbro (Jennings, 1977). These rocks occur in parts of the Marble Mountains in the northwest part of the watershed, in the Scott Mountains in the southeast, and in a disconnected belt that runs from the south part of the Scott watershed to the northeast part. Some outcrops are the original igneous rock, but most are partly or wholly altered to serpentine. Much of the area underlain by mafic and ultramafic rocks is steep mountains. The rocks weather to form soil that is finer-grained and more clay-rich than soil formed on granitic rocks. The result is less tendency toward dry ravel, sheetwash, and rillwash. Some limited areas of sheared bedrock are vulnerable to landsliding.

3.1.4.4 Sedimentary and Metamorphic Bedrock

This unit makes up more than half of the area of the Scott River watershed and includes sedimentary rocks of many lithologies, mostly of Mesozoic age; metamorphic rocks of low to medium grade including amphibolite, greenschist, blueschist, and metavolcanics; and some Tertiary metavolcanics (Wagner and Saucedo, 1987). Although these suites of sedimentary and metamorphic rocks vary in geomorphic expression and potential for sediment contribution, in general they have more in common among themselves in terms of soils formed, structural strength, and slope stability than either suite has with the granitic or mafic rocks. For that reason the sedimentary and metamorphic rocks form a natural grouping in the context of this study.

3.1.4.5 Extent of Geologic Units

Table 3.1 summarizes the areal extent of geologic units in the Scott River watershed. The GIS geology coverage (Figure 3.2) has proved satisfactory for the job at hand. Field observations in October and November of 2003 and May-July of 2004 at computer-generated random stream sample locations showed no significant differences between geologic units shown on the GIS coverage and geologic units observed on the ground.

Table 3.2 summarizes the distribution of the geologic units in the seven subwatersheds used in this analysis. Granitic rocks, which are a major sediment contributor, especially when disturbed, underlie twenty-eight percent of the Westside subwatershed, forty-eight percent of the West Headwater subwatershed, and lesser amounts of the West Canyon and East Headwater subwatersheds. The East Canyon and Eastside subwatersheds are underlain mostly by sedimentary and metamorphic rocks. The highest proportion of mafic and ultramafic rocks occur in the East Headwater subwatershed where they underlie forty-three percent of the area. The Scott Valley subwatershed contains most of the Quaternary deposits in the Scott, as they cover most of the valley floor, but this subwatershed also is underlain by a substantial area of sedimentary and metamorphic rocks, primarily on the east side of the valley and in the hills at the north end of the valley. A discontinuous belt of mafic and ultramafic rocks trends northward from the Callahan area along the base of the mountains on the east side of the valley.

3.1.5 The Role of DG Soils

A significant portion of the Scott River watershed, 10.6 percent of the area (derived from Table 3.2), is underlain by granitic bedrock. The soils that form on this suite of rocks are widely recognized as some of the most erosive soils anywhere. This susceptibility to erosion not only applies to natural conditions but produces greatly accelerated and persistent erosion when the soil is disturbed, especially on steep slopes (Sommarstrom et al., 1990; USSCS, 1991; Sommarstrom, 1992).

The Granitic Sediment Study (GSS) of Sommarstrom and others (1990) is an evaluation of the role of DG soils in the Scott River watershed, and an estimate of the sediment contribution of DG in the watershed. The authors estimated the amount of sediment mobilized by different processes in different settings: sheetwash and rill erosion, road cuts, road fills, road surfaces, skid trails, streambanks, and landslides. They did not include a category defining soil creep, and staff interpret that they included soil creep processes in this highly granular soil in the sheetwash and rill erosion category. That study centered on contribution to the mainstem Scott River and recognized that much of the sediment mobilized is not transported immediately to the Scott but is stored on hillslopes and in swales, streambanks, and the channel bedload of tributaries.

In the GSS (Figure 2-11, p. 2-44), the authors estimated for each process the amount of sediment mobilized and the amount delivered to the Scott River. The proportion delivered ranges from five percent for sheetwash and rill erosion to 35 percent for stream bank erosion. For all processes combined, they estimated that 79 percent of mobilized sediment goes into storage and 21 percent is delivered to the Scott River. The GSS applied a different approach than the TMDL study, but the results can be compared in important ways.

The TMDL study is concerned not only with the Scott River, but also with the tributaries as they provide spawning and rearing areas for salmonids. Also, the TMDL study is less concerned with upslope processes and how much sediment is mobilized than with the interface between mountainside and stream system and how much sediment actually crosses into the stream system, including tributaries.

To assure uniformity of methods on all areas, staff applied the same system of field observations and data compilation to the DG areas as to the areas of other bedrock units. These results are presented first in the summary section.

However, DG produces sediment through a significantly different balance of processes than the other bedrock units. For example, roadcuts in DG are a dominant generator of sediment (Sommarstrom et al., 1990, p. 2-32), in contrast with other units. Also, DG is particularly susceptible to disturbance, and disturbed areas are slow to heal. For these reasons, staff did a separate calculation of the sediment estimate using the DG sediment contribution rates estimated in the GSS for areas of Granitic Bedrock, and rates from the TMDL study for the other bedrock units. These calculations are discussed in the individual inventory sections and are summarized in separate summary tables.

3.1.6 Effects of Multiple Interacting Human Activities (EMIHAs)

In published literature on forest management and surficial processes (e.g. Reid, 2001; Dunne et al., 2001), the term cumulative watershed effects is used to designate long-term cumulative and/or synergistic effects from multiple episodes of human activities. In addition, the term cumulative impacts is used in legal documents with its own specific meaning under the California Environmental Quality Act (CEQA) (Pub. Resources Code section 21000 et seq.). In order to avoid confusion or ambiguity, this TMDL document does not use the term cumulative effects and instead uses the term Effects of Multiple Interacting Human Activities (EMIHAs). In the following discussion, the published literature on cumulative watershed effects is referenced. Although this discussion is introduced in the Sediment TMDL chapter, the effects discussed may also affect other properties of a water body, including temperature conditions.

EMIHAs are changes in a watershed that affect processes in the watershed and are influenced by multiple human activities in the watershed. The multiple activities may be simultaneous or at different times, but they exert multiple influences on the processes in the watershed (Coats and Miller, 1981; Reid, 1993, 2001). Many EMIHAs are incremental and synergistic effects of multiple controlling factors, and the very fact of interaction creates difficulty in ascribing the cause of a particular effect to a specific action. One key concept is that the effects may not be concentrated at their point of origin and they may not be immediate.

EMIHAs take many forms. Reid (1993) discusses:

- Changes in hydrology including water input, runoff generation, water transport on hillslopes, water transport in channels, and water budgets.
- Changes in sediment generation and transport including erosion and sediment transport on hillslopes, gullies, and landslides; sediment delivery to streams; erosion, transport, and deposition in channels.
- Environmental change in organic material including changes in streamside vegetation, in-channel production of organic material, and in-channel transport of organic material.

Impacts of EMIHAs take many forms, a few of which are noted here:

- Impacts on fisheries due to changes including flow characteristics and channel morphology, water temperature, food availability, predation, and grain-size of the stream bed, combinations of which affect spawning and rearing success. These affect the commercial fishery as well as sport fishing.
- Water quality for agricultural, domestic, recreational, or industrial use.
- Other beneficial uses that are enumerated in Section 2.2.1.

A system to analyze and predict EMIHAs was developed by The University of California Committee on Cumulative Watershed Effects (Dunne et al., 2001). That report advocates a watershed approach that ideally would involve stakeholders in the watershed and time and resources to do modeling of many factors in the watershed and carry through to changes in policy and operations within a watershed. This TMDL study lacks the resources to apply such a broad approach, but neither can it ignore the presence and impacts of EMIHAs. What follows is a brief description of EMIHAs in the Scott River watershed and the Regional Water Board staff's approach to them. The methodologies used for identifying streamside sediment delivery features attributing sediment delivery to EMIHAs are discussed in more detail in Section 3.4.3.

3.1.7 Sources of Information

Information for this Sediment TMDL comes from a variety of sources. The Siskiyou Resource Conservation District (RCD) contributed information on environmental and habitat conditions and made their library of published reports and consultant reports available.

Timber Products Corporation and Fruit Growers Supply Company have allowed use of road inventory data in the South Fork Scott River watershed and permitted access to timberlands in that watershed. Resource Management, a consulting company in Fort Jones, analyzed road inventory data supplied by timber companies and the United States Forest Service (USFS). Regional Water Board staff field checked random samples of the road inventory data. VESTRA Resources produced the landslide inventory using an aerial photo survey.

Regional Water Board staff researched sediment contributions and trends using field studies, reports from other government agencies, consulting reports, and published literature. The USFS contributed data on road inventories and landslides and consultation on conditions in the watershed.

A Technical Advisory Group (TAG) consisting of stakeholders and representatives of other government agencies met at intervals with Regional Water Board staff to provide evaluation and guidance in the research and preparation of the TMDL. Dr. Sari Sommarstrom, also a member of the TAG, contributed her considerable expertise and local knowledge and access to her library.

California Department of Forestry and Fire Protection coordinated the road inventory and associated GIS work of Resource Management. Published scientific literature was used extensively and is referenced in this document.

3.1.8 South Fork Pilot Study

The South Fork Pilot Study was conducted in the South Fork Scott River (South Fork) as a demonstration project to illustrate the methods used in preparing a sediment TMDL with respect to gathering data and estimating sediment contribution to the stream system. The study was done at the request of Fruit Growers Supply, Inc. and Timber Products Company (the Companies) with the understanding that should the Companies find the methods to be appropriate and satisfactory they would grant access to Regional Water Board staff to gather specified data on other company lands throughout the Scott River watershed and would supply road inventory data for the companies' holdings in other parts of the Scott River Watershed to Regional Water Board staff. The Companies granted Regional Water Board personnel access to gather data along streams on company properties in the South Fork watershed. A Fruit Growers forester accompanied Regional Water Board staff in the field to observe sampling methods and field practice.

In addition, the Companies made their road inventory data in the South Fork watershed available to a third party, Resource Management Inc. (RM), for the purpose of calculating summaries and performing analyses of the data on behalf of Regional Water Board and the California Department of Forestry and Fire Protection (CDF). These data were used to estimate road surface erosion using SEDMODL2 (NCASI 2003) and provide summaries of other road-related sediment delivery sources in the South Fork. Under this agreement Regional Water Board staff did not take possession of the road inventory data. Regional Water Board staff field checked road-associated point sources of sediment in the company of RM staff.

After review of the South Fork Pilot Study, the Companies did not feel sufficiently confident in the process used in the Study, and declined to provide access to other company lands or associated data. Given time constraints in the TMDL consent decree schedule, Regional Water Board staff were not able to pursue resolution of the outstanding issues in the context of the South Fork Pilot Study. Instead, the road inventory data for the South Fork Pilot Study was used to calculate rates of sediment delivery per road mile in each geologic unit, and these rates were applied to other roads in the watershed. This process is discussed in Section 3.2.

3.2 ROAD RELATED SEDIMENT DELIVERY

3.2.1 Two Estimates Made

Road-related sediment was estimated in two ways. The first estimate treats roads on all geologic units in the same way. RM applied a computer model, SEDMODL2, to estimate contributions from road tread and cutslope on roads in the South Fork (West Headwaters) watershed in all four geologic units. As part of this process, RM applied information from road inventories on private land in the South Fork watershed to estimate contributions from road-related discrete features in that subwatershed. The inventories were conducted on about 5.5 square miles in the South Fork. Regional Water Board staff field checked many of these features as part of the South Fork Pilot Study (NCRWQCB, 2005b) to verify volume and to estimate age in order to estimate rate of contribution. Because this type of road inventory was not available in other subwatersheds, the rates estimated in the South Fork were applied to the rest of the subwatersheds in the Scott River watershed. Assumptions used in this application are:

- Distribution of road surface types (paved, unpaved) is similar
- Distribution of travel intensities on roads is similar
- Precipitation and storm intensity are similar
- Distribution of vegetative cover alongside roads is similar.

Variations occur in all of these factors, but in the context of the estimate many of the variations are opposite in effect. For example parts of the Westside Subbasin have more precipitation than the South Fork, which may deliver more sediment per road mile, but the Eastside Subbasin has less precipitation, and thus less runoff. The assumptions were based on the best information available.

Thus, the basic assumption is that the amount of sediment produced per mile of road in the geologic types in the South Fork subwatershed is the same as the amount of sediment produced per mile of road in those same units in the other subwatersheds. The assumption is made that road conditions on private land in the South Fork can be used to represent conditions along similar roads in the same geologic units in the other subwatersheds. Regional Water Board staff believe this is a reasonable assumption, based on observations of road construction and conditions in other subwatersheds.

The second estimate applies SEDMODL2 to roads in all geologic units except Granitic bedrock. For roads on granitic bedrock the sediment delivery rates applied are derived from the GSS in the Scott River watershed. The GSS found significantly higher DG sediment delivery from both anthropogenic and natural causes than did SEDMODL2. Sediment delivery from road-associated discrete sediment sources on granitic bedrock was treated as in the second estimate. All other geologic units were treated as in the first estimate.

In the four subwatersheds that include areas of granitic bedrock the difference between the first and second estimates of the sediment delivery processes from roads considered in SEDMODL2 range from nine percent to fifty-nine percent greater using the second estimate. The differences are approximately proportional to the proportion of the subwatersheds that is underlain by granite. Nonetheless, the estimate of total delivery of sediment from roads is relatively small in the big picture.

Because sediment generated on roads is not all delivered immediately to a stream, the distance of a road from a stream is a factor to consider in estimating sediment delivery. Both models include calculations based on the distance of roads from a stream. Table 3.3 presents the lengths of roads of different types and their distances from a stream through the whole of the Scott River watershed. For a more detailed comparison, Table 3.4 shows the same data divided out by subwatershed. These tables also include numbers of stream crossings, road miles, and road densities.

3.2.2 Discrete Sediment Sources (Road Inventory and Field-Check)

Inventories of discrete sources of sediment along roads are not presently available for most of the Scott River watershed. However, staff had access to an inventory of road-related erosion and sediment delivery completed by Resource Management (RM) in 2000 on all timber company roads in the South Fork subwatershed. That survey documented road-associated discrete sources of sediment including road-stream crossings, crossing failures, fill and cutbank failures, and gullies, along with the volume of each discrete sediment source. The purpose of the inventory was related to road maintenance, for which the age of features was not needed so age was not estimated. For that reason, and to evaluate the inventory, Regional Water Board staff, accompanied by RM staff, visited individual sites to verify volume and estimate age. The method is detailed in the South Fork Pilot Study (NCRWQCB, 2005b) and summarized below.

The RM road survey documented erosion at sixty-nine discrete features. Regional Water Board staff and RM personnel visited thirty of those features in 2004 and estimated age of erosion where possible. The remaining thirty-nine features were not visited, some because they had been repaired and some because time and resources did not permit total coverage. Of the thirty features visited, nine had been modified by repairs so that the age could not be estimated; staff estimated the age of the remaining twenty-one.

Of those twenty-one features, sixteen have estimated ages of less than fifteen years. Most of these are estimated to be within the 5-10 year age category. A major rain-on-snow event occurred in 1997, seven years before the field inspection, and, on the basis of anecdotal evidence and field estimates, staff attribute the major part of the erosion or failure of these features to that storm. The US Forest Service estimated runoff of the 1997 event in the Scott River to be equivalent to a 14-year recurrence interval event (de la Fuente and Elder, 1998, p. 10), and that event apparently caused more erosion than any other storm during the last 15 years. A flood risk evaluation in the area of Callahan prepared for the Siskiyou County Department of Public Works (Norman Braithwaite Incorporated, 1999) estimated a 30-year recurrence interval for the 1997 flood in that area. Staff chose to use the fourteen-year recurrence interval in our estimates.

Because the recurrence interval of this significant storm event brackets the age categories of a majority of the sites whose age staff could estimate, staff chose to isolate that time interval for the estimate of the rate of sediment contribution. The calculations of sediment input in the South Fork watershed in Section 3.1.8 are based on the volume of measured features divided by fourteen.

The estimated rate of sediment delivered from road-associated large and small features in the South Fork (exclusive of the anomalous features described below) was extrapolated to the other subwatersheds on the basis of road type and geologic units. This extrapolation is based on the assumption that similar road types, on similar substrate, at similar distances from the streams, will deliver similar amounts of sediment. While these assumptions surely vary in accuracy over different areas, staff believe, on the basis of field studies in many areas in the Scott, that conditions in different parts of the watershed have sufficient commonality to group in this way for the purpose of the watershed-wide TMDL study. Any land management decisions made in the future should be based on more detailed studies of the areas in question.

RM estimated the number of stream crossings using SEDMODL2. Water Board staff conducted a GIS exercise to estimate the number of stream crossings. RM and Water Board staff were within 97% agreement in the respective estimates. For that reason, the number of stream crossings estimated by RM were accepted.

In the RM South Fork road survey, the largest contributing features were all located within a single quarter-mile-long section of failing road. These few features accounted for seventy-five percent of the total contribution from road failures. Thus, these features are anomalous in context. For that reason they were not included in the group that was used to calculate the rates used to extrapolate to the South Fork watershed but instead were combined and treated separately as a single discrete feature added to the South Fork sub-watershed sediment summary.

Outside the South Fork, such anomalous features pose a problem in estimating sediment delivery. At present we cannot determine how many such features may have been unaccounted for in the other sub-watersheds, although some are large enough that VESTRA found and included them in the aerial photo landslide survey (Section 3.3). However, staff may have slightly underestimated anthropogenic sediment contributions because some anomalous features that were not large enough to be found on the landslide analysis may have not been counted.

The road dataset used was that developed for this project by VESTRA Resources, the contractor that performed the aerial photo analysis described in Section 3.3. During the field inventory, RM identified a few additional roads and added them to the dataset.

3.2.3 Granitic Substrate and Road-Associated Sediment – The DG Factor

The computer model used (SEDMODL2) takes into account road class, traffic volume, and a geologic erosion factor that is a multiplier to account for different rates of erosion on different substrates. However, the model does not specifically take into account the particularly high sediment contribution of the DG in the Scott River watershed and the tendency for elevated erosion rates to continue following disturbance.

Megahan (1992, p. 18), citing studies primarily in the Idaho Batholith, which has granitic rocks with weathering characteristics similar to those in the Scott, found that the highest erosion rates on cut banks occurred in the first two years. During this time rates decreased rapidly as the cut surfaces seasoned and litter and vegetation came to cover parts of them. After two years rates stabilized. Nonetheless, Megahan (1992, p. 18, 21) found that, “Erosion rates at this time were still accelerated, averaging about 50 times greater than undisturbed.”

Megahan (1992, p. 24) noted that, “While some road builders advocate constructing vertical cuts in granitic terrain, the data reveals that if you build them steeper, they are going to erode faster. Granitic road cuts will eventually end up at the natural angle of repose; it depends whether you want it now or later.”

The GSS in the Scott (Sommarstrom et al., 1990, p.5-3) also estimated that most of the road-associated sediment production was from cut banks. That study reached two conclusions that staff must consider in estimates for the TMDL:

- Average annual erosion for the entire road prism in granitic areas was 737 tons per mile, or 149 tons per acre of road prism. In the road prism the GSS includes cut slope, ditch, and fill slope as well as road surface. Erosion from the road surface alone averaged 11 tons per acre. The GSS cites these values (p. 2-31) as falling within the range reported by others on sandy loam soils.
- Sixty-four percent of road-associated erosion was found to come from the cut bank, which was the highest category of soil loss from all sources and made up 40 percent of the total.

Based on the GSS, the thickness of road surface eroded annually in the granitic area is calculated as follows:

1 acre = 43,560 sq ft.
11 tons / acre = 22,000 pounds per 43,560 sq ft
43,560 sq ft / 22,000 lb = 2 lb per sq ft. per year.
1 cu ft of sediment weighs 100 lb
2 lb per sq ft /100 lb per cubic ft = .02 ft thickness per year = .24 inch per year.

Most of the roads in the Scott were constructed before 1970, 35 years ago. Assuming they were all built in 1970, then:

35 yr x .24 inch = 8.4 inches of road surface lowering in 35 years. This rate of road surface erosion is significant, but considering the occasional resurfacing of eroded and failed parts of the road surface, it is reasonable.

To account for differences in erosivity of substrate, SEDMODL2 uses a multiplier that ranges from one for the least erosive rocks to five for the most erosive. In other words the model assumes that the most erosive rocks are on the order of five times as erosive as the least erosive rocks. Megahan (1992), Sommarstrom and others (1990) and others cited by these authors, as well as our field observations, suggest that the multiplier of five is substantially too low. Even with the model assuming no cover at all, SEDMODL2 estimated that only 23 percent of road-associated sediment generated on granite substrate comes from the cut bank.

The GSS was based on field studies and observations along many miles of road, and staff judged that its results must be considered within the area of DG soils. Accordingly, staff did a second estimate of road sediment contribution, applying the GSS rate of erosion in DG areas.

The GSS (Sommarstrom et al., 1990, Fig. 2-11) classified road-related sources into the categories of road cuts, road fills, and road surface. Taken together, these sources yielded an estimated 212,196 tons/year in their study area. Of that amount, an estimated 40,242 tons (19%) was delivered to the Scott River. The remainder went into storage in hillslope swales, hillslopes, channel margins, upper banks, alluvial fans, and channel bedload in tributaries.

The GSS approach is different from the TMDL approach in that the GSS authors were evaluating delivery to the mainstem Scott River, while the TMDL is evaluating delivery to the stream system as a whole, including tributaries. For that reason, the TMDL study cannot exclude the sediment that goes into storage in the channel bedload of tributaries.

3.2.4 Estimates of Road-Related Sediment Contribution

SEDMODL2 is a computer model developed to estimate the delivery of sediment to streams from roads using as parameters road width and type of surface, slope, geologic substrate, road use pattern, and distance of each road segment from a stream.

The creator of SEDMODL2, the National Center for Air and Stream Improvement (NCASI, 2004; and website accessed 4/4/05) describes SEDMODL2 as follows:

> …a GIS-based road erosion and delivery model designed to identify road segments with high potential for delivering sediment to streams. The model uses an elevation grid combined with road and stream information layers to produce what is essentially a computer-generated version of the Washington surface road erosion model. It estimates background sediment and generation of sediment for individual road segments, finds road/stream intersections, and estimates delivery of road sediment to streams.

SEDMODL2 was used to estimate contributions from road surfaces, cutbanks, and background. SEDMODL2 defines background as the contribution of sediment delivered to streams by soil creep. The soil creep contribution is included in Section 3.4 of this report.

For the stream network part of the model, RM first applied the GIS stream dataset from USGS 1:24,000 scale topographic maps. However, the stream network as observed on the ground during the inventories proved to be considerably denser than the USGS dataset. That is, a significant number of road/stream crossings were found where the stream dataset did not indicate a stream. RM then applied the Klamath National Forest (KNF) GIS stream network, as it is significantly denser, although it too was found to be under-dense relative to field observations. In some places RM field personnel found streams that were not shown even on the KNF coverage. In those cases, RM used a ten-meter digital elevation model to generate the stream course, and the stream feature was cut off just above the highest road/stream crossing identified in the watershed.

Tables 3.3 and 3.4 summarize parameters that go into the calculations of road-related sediment delivery in the Scott River watershed.

Table 3.3 shows the number of road-stream crossings and the miles of paved and unpaved roads at different distances from streams in the Scott River watershed. In SEDMODL2 the term direct delivery means that sediment from a road, once mobilized, is delivered directly to a stream; this happens primarily where the road surface, fill slope, and cut slope all meet at a stream crossing. Under all other conditions, fill slopes are assumed to not deliver sediment. For situations other than direct delivery, SEDMODL2 calculates percent sediment delivery from a road on the basis of distance from a stream. Distance categories are 0-100 feet, 100-200 feet, and greater than 200 feet from a stream.

Table 3.4 summarizes the number of road-stream crossings and miles of road at different distances from a stream sorted by geologic unit in each subwatershed. The information in this table serves as the basis for calculation of sediment contribution using SEDMODL2.

The next three tables (3.5, 3.6, and 3.7) develop the estimate of road-associated sediment.

Table 3.5 is in two sections. The upper section shows the estimated road-related sediment delivery rates in tons/road mi-yr from the South Fork Pilot Study (b 2005a) from roads on all geologic units. The South Fork is the area where the most detailed information was available. This table includes estimates of delivery from discrete features in the RM South Fork road survey and SEDMODL2 estimates of road tread and cut slope delivery. The lower section of the table is a separate estimate of road-associated sediment from granitic terrane derived from the GSS through the following procedure: The GSS estimate of total road-associated sediment generated was divided by the number of miles of road in the Granitic study area to derive an average rate of sediment mobilized in tons/road mile-yr. The proportion of mobilized sediment that is delivered to a stream is estimated by applying the delivery rates used in SEDMODL2 for direct delivery and delivery from distances from a stream of 0-100, 100-200, >200 feet.

The road survey-SEDMODL2 estimate and the GSS estimate use different categories to some extent, but the point to note is that delivery from cut banks is much greater in the GSS estimate. The rates for both estimates are carried forward to Table 3.6.

Table 3.6, in three sections, shows the estimated rates of road-associated sediment delivery in the Scott River watershed based on the rates estimated in the South Fork in Table 3.5. The upper section of Table 3.6 applies the estimated sediment delivery rates in the South Fork based on SEDMODL2 and the RM road survey (upper section of Table 3.5) to roads on all geologic units in the Scott River watershed. The middle section of Table 3.6 applies sediment delivery rate estimates on Granitic substrate in the South Fork from the GSS (middle section of Table 3.5). As seen in the right hand column in Table 3.6, the estimated sediment delivery from Granitic substrate using the GSS is about twice the tons/sq mi-year as what was estimated using SEDMODL2 and the road survey. Much of the increase comes from cut slopes.

Table 3.7, in five sections, shows the road-related sediment estimates broken out by geologic unit within each subwatershed. The upper section of the table shows estimates for Quaternary, Mafic, and Sedimentary/Metamorphic substrates. The Granitic contribution from the SEDMODL2-road survey estimate is summarized separately in the middle section for easy comparison with the GSS influenced estimate in the bottom section. In each subwatershed that has granitic rocks, the estimate that takes the GSS into account is a bit greater than twice the estimate that does not. The bottom section summarizes the road-associated sediment estimates. Despite a significant difference in estimated rates from Granitic substrate (Table 3.8), the difference in road-related sediment delivery rate from all units combined is increased only from 11 to 14 tons/sq mi-yr (Table 3.7), a 27% increase. The large difference in the estimates of Granitic contribution is minimized by the small percentage of the Scott River watershed underlain by granite and the large percentage underlain by Sedimentary/Metamorphic rocks, which have a relatively low contribution (Table 3.1).

3.3 AERIAL PHOTO LANDSLIDE SURVEY

Sediment delivery from landslides was estimated using photo interpretation from stereo aerial photos taken several years apart. Changes in presence or size and configuration of landslides between the photo sets were analyzed, and a proportion of the interpreted features were field checked to estimate volume and age. Additional information was used from USFS photo inventories that used 1992 and 1997 aerial photos. Four subwatersheds have significant sediment delivery from landslides: The West Canyon subwatershed delivers about 250 tons/sq mi-yr and the East Canyon, Westside, and West Headwater subwatersheds deliver in the range of 15-20 tons-sq mi-yr.

3.3.1 Methods

Landslides in the Scott River watershed were inventoried by VESTRA Resources using stereo aerial photos and compiled in ArcView GIS. VESTRA evaluated available photo coverages to obtain a baseline to evaluate changes in landslides through time. In this TMDL study the last 20 years are of most interest to use as a basis in understanding what processes are active at present.

No single set of existing aerial photographs covers the entire Scott River watershed, and private land and Forest Service land are photographed at different times and as separate projects. On both private and Forest Service land staff selected two coverages on the basis that (a) each coverage includes a large portion of the Scott River watershed, (b) they are recent, and (c) they are separated by an interval appropriate to the time scale of the study. The four coverages chosen (Figure 3.3) include three different types of photography and four different scales.

With these photo sets, 88.3 percent of the Scott watershed has coverage at two times, 8.1 percent has coverage at one time, and only 3.6 percent of the area is not covered. The areas of single coverage and no coverage are in the lower mountains in the Kidder Creek-Shackleford Creek area (Figure 3.3), an area where landslides are not a significant factor. The areas of most abundant landslides – West Canyon, Westside, and West Headwater subwatersheds – have excellent coverage with the Forest Service photos.

Results were compiled on digital ortho quarter-quads (DOQQs) based on 1993 aerial photography. Landslide features were identified and attributed using the following procedures.

3.3.2 VESTRA Aerial Photo Interpretation

Stereo pairs of the 1999 photos were examined under a mirror stereoscope for evidence of active or recent landslides. Features interpreted as possible landslides were marked as polygons, lines, or points, according to the following criteria:

- <u>Polygon</u> – Non-linear landslide feature larger than 1 acre.
- <u>Line</u> – Linear landslide feature – most are debris torrent scars in steep channels.

- Point – Landslide feature less than 1 acre in size. Pilot work indicated that features smaller than 1 acre cannot be consistently and repeatably identified and delineated; however, it is important to note their presence and density.

Landslide features were identified and marked on the newer photographs, then the location of each feature was reviewed on the older photos to determine whether it was present and if its boundary was different. If the boundary of a feature has changed, appropriate delineations were made on the newer photo record to modify polygons or line segments. The older photos were also reviewed for the presence of landslide features that may not be apparent on the newer photos.

Each landslide feature was attributed with codes representing status of vegetation in each set of photos, intersection with an anthropogenic feature, landslide type, and hydrologic connectivity. Presented in the following sections is a summary of results of this analysis.

Using the 1993 DOQQs as a base, polygons, points, and lines were digitized in a GIS coverage and attributed with their codes. As part of the South Fork Pilot Study, Regional Water Board staff and VESTRA staff were able to field check the photointerpretation on all sites but one in the South Fork (b 2005a). In the remainder of the Scott River watershed, approximately 15 percent of photointerpreted sites were field checked.

3.3.3 Estimation of Sediment Delivery Rates

In the aerial photo survey VESTRA assigned a causal effect based on categories of Harvest, Roads, Roads and Harvest, Fire, and Natural. Mining was not assigned a category but is noted in some comments. Staff estimated sediment delivery based on the VESTRA photo-interpreted slide features and the field verification as completed by VESTRA and Regional Water Board staff.

3.3.4 Volume Estimate of Slide Features

The volume of slide features and the rate of sediment contribution were estimated using a combination of photointerpretation, field observations, and extrapolation. It was not possible to investigate in the field every slide feature interpreted from the photos. Accordingly, a sampling of the photointerpreted features, which came to 26 percent, was visited in the field. The area and depth of each were measured or estimated in the field so that volume could be calculated. In addition, the age of each feature was estimated. The combination of depth and area allow calculation of volume, and the age estimate allows estimation of rate of mobilization of sediment.

3.3.4.1 Polygon Features

The area of polygon landslide features was estimated through digitizing on the DOQQs, and then a sampling of features was measured or closely estimated in the field. The average surface area of the polygon features measured in the field was 50 percent of the average as estimated in the digitized photointerpretation. The average of 50 percent was applied to the area of all polygon features in the photo survey. Average depth of the 10 polygon features measured in the field was 7 feet. This 7-foot average depth was applied to all polygon features in the photo survey.

3.3.4.2 Line Features

Line features were assigned no depth or width in the photointerpretation. Of line features surveyed in the field, the average depth was 4 feet, and the average width was 16 feet. The average length of the line features measured in the field was 42 percent of the average estimated in the photointerpretation. These average depth, width, and length percentages were applied in estimating volume of all linear features in the photo survey.

3.3.4.3 Point Features

Points were assigned no dimensions in the photointerpretation. The average estimated delivery from point features examined in the field was 25 tons/year. This contribution rate was applied to all point features in the photo survey.

3.3.5 Initial Estimate of Connectivity and Age

3.3.5.1 Connectivity

Using photointerpretation, VESTRA estimated whether or not each feature was hydrologically connected. When VESTRA field-checked the features, they evaluated the connectivity of each feature. Of the features they estimated to be fully connected, they found in the field that 68 percent were fully connected, 11 percent were partially connected, and 21 percent were not connected. Of the features they photointerpreted to be partially connected, they found 13 percent to be fully connected, 33 percent to be partially connected, and 54 percent not connected. Of the features they photointerpreted to be not connected, they found in the field that 70 percent were not connected, 20 percent were partially connected, and 10 percent were fully connected. These percentages were applied in estimating connectivity and rates of sediment contribution from photointerpreted landslide features (Table 3.9).

3.3.5.2 Age

VESTRA made field estimates of the age of features visited. Of these features, 72 percent were estimated to be approximately 18 years in age. The remaining 28 percent were estimated to be 30 years in age. Age was not estimated for the features that were identified only through the photo-interpretation process. Staff applied the age estimate percentages established in the field to the estimation of sediment delivery rates for all features that are calculated in section 3.6.

3.3.6 U.S. Forest Service Landslide Inventory

The U.S. Forest Service has done two aerial photo inventories of landslides on Forest Service land in the Scott River watershed. The first was done in 1992 using photos from earlier years, and the second was done in 1997 with new photos following the rain-on-snow flood event in the winter of 1996-1997.

3.3.6.1 1992 U.S. Forest Service Photo Inventory

The 1992 inventory in the Scott was part of a more widespread project on Forest Service land, using photos of several scales. Photos used ranged in date from 1971 to 1988 and covered all USFS holdings in the Scott. Flight lines and photo coverage spilled onto a small amount of surrounding properties, and the landslide inventory included all areas that had stereo coverage, including the small spillover to private land. In this survey 305 features were identified in the Scott River watershed. These features fall in four subwatersheds; Westside, West Canyon, West Headwater and East Canyon.

3.3.6.2 1997 U.S. Forest Service Photo Inventory

Following the 1997 storm event, a new set of color infrared photos at 1:40,000 scale was flown to evaluate resulting landslides and other changes in the Klamath National Forest, which includes Forest Service land in the Scott. On these photos, 192 features were identified in the Scott River watershed. Don Elder of the USFS reported that most of these appeared to be new rather than reactivated older features (Coates, 2006). Seventy four percent of the landslide features identified were field checked and dimensions measured. Associations were determined and delivery amounts estimated at the same time. Using a regression analysis derived from field checking more than 800 sampled slide features throughout Klamath National Forest, an area-volume relationship was determined and applied to the 26 percent of the features that were not visited in the field. Their size and association or non-association with human activity were estimated through the photo-interpretation process.

These 192 identified slide features fall in three subwatersheds; Westside, West Canyon, and East Canyon. Of the 192 features, USFS estimated that 52 features were natural, 57 were road-related, 2 were related to either harvest or fire greater than 20 years of age, and 81 were related to a harvest or fire within the last 20 years. The last two categories, classified without distinction between harvest and fire, are ambiguous as to whether human activity was involved in a given case, and for that reason they are of limited use in the TMDL study.

The USFS arrived at volumes mobilized and volumes delivered through field visits and the application of GIS estimation. The USFS estimated delivery percent for each feature and went on to estimate amount of sediment delivered. Sixteen of the slide features were estimated to have no delivery; for the remaining 177 features the estimated delivery values varied from 5 percent to 100 percent.

3.3.6.3 Discussion of USFS Landslide Inventory

Age of features was not estimated, except that those captured after the 1997 flood were directly related to the 1997 event. These features should be treated as discrete features in time and evaluated with that in mind. However, without further field work there is no way to quantify the continuing contribution from these features. Further study is required to evaluate their contribution to the system.

In comparing VESTRA and USFS inventories, staff noted that of the total 498 features mapped in the two USFS inventories, 250 do not appear to have a corresponding feature in the VESTRA GIS layer. Of the 192 features mapped in 1997 with volumes and associations, 79 do not appear to have a corresponding feature in the VESTRA GIS layer. One reason for this apparent discrepancy appears to be that the USFS was mapping many small features that VESTRA did not include in their inventory.

Of the 250 features in the USFS GIS layer that have no corresponding features in the VESTRA study, 78 are less than 0.5 acres, and 52 are between 0.5 and 1 acre in size. Thus 130 (52 percent), of these features are smaller than the one-acre size that VESTRA considered a minimum for repeatable estimation in their survey. Fifty-two (21 percent) of the USFS features are between one and two acres. Field-checked sites were on average 50 percent of the GIS size estimation. Applying a correction factor of .50 yields a figure of 182 features less than one acre out of the 250 features identified in the USFS inventory that did not appear in the VESTRA survey.

In summary, the USFS inventories picked out many landslides smaller than one acre that were not counted in the VESTRA inventory. In this investigation, landslide features less than one acre were accounted for in the streamside sediment surveys, described in Section 3.4.2. Problems in trying to apply this USFS inventory to the TMDL study arise because anthropogenic and non-anthropogenic features are not adequately distinguished, and lack of age estimates precludes estimating average delivery rates. Therefore, the USFS landslide inventory was not used to quantify landslide contributions.

3.3.7 Estimate of Sediment Delivery Rate

Delivery rate was estimated for the features examined by VESTRA in the field using calculations based on the percentages estimated through photo-interpretation and associated field work. These rates were then applied to all the features that were photo-interpreted but not field checked. The general equation is:

$$\text{Delivery} = (\text{Connectivity Value}) \times (\text{Volume-Size factor}) \times (\text{Age factor})$$

Table 3.9 is in two parts. The first part summarizes the numbers of slide features that are interpreted as delivering sediment. The first section shows results of field checking of 97 photo-interpreted landslide features. Field observation showed that 26 percent of these features are delivering sediment. The second part summarizes numbers of features that were not field checked and interpretation of hydrologic connectivity. Of 265 features, 151 (57 percent) are interpreted as partially or fully hydrologically connected.

Table 3.10 is in two parts. The first part summarizes estimates of sediment delivery from photo-interpreted landslide features that are associated with human activity. The second part summarizes estimates of sediment delivery from photo-interpreted landslide features that are not associated with human activity. The left columns in both parts show estimated tons/yr of sediment delivered from field-verified features. The right hand columns show estimated tons/yr delivered from features that have not been verified. Some sediment is counted as delivered from features that were photo-interpreted as not hydrologically connected. The reason for this goes back to the field-checked features, some of which were photo-interpreted as not hydrologically connected but were found in the field to be connected and delivering. This estimation is discussed in the section on Connectivity above. The estimates show a total of 66 tons/yr of sediment delivered from landslides of which 26 tons (39 percent) is attributed to human causes.

3.3.8 Summary of VESTRA Landslide Inventory

This survey shows that landslides are not a dominant source of sediment in the streams in most of the Scott River watershed. Table 3.10 estimates the landslide sediment delivery based on size, age, and hydrologic connectivity of features. Table 3.11 is a summary of human activity-related landslide delivery broken down by type of human activity and subwatershed.

3.3.8.1 West Canyon Subwatershed

The West Canyon Subwatershed has the largest human-associated contribution, and both roads and harvest are strongly associated with landslide delivery (Tables 3.10 and 3.11). This subwatershed is very steep mountains of the north end of the Marble Mountains. Ownership is primarily Forest Service. Landslides are more abundant than in any other subwatershed, particularly in the drainages of Kelsey Creek and Middle Creek (Figure 3.4). The estimated anthropogenic contribution of 254 tons/sq mi-yr (Table 3.11) is the highest in the Scott River watershed. This subwatershed has had considerable harvest activity, is densely roaded, and underwent severe fires in 1988.

3.3.8.2 East Canyon Subwatershed

The East Canyon Subwatershed has a low rate of sediment delivery from landslides, and that delivery is mainly associated with roads (Table 3.11). This subwatershed covers both the north and south flanks of the Scott Bar Mountains, which are steep, but not as high as the Marble Mountains to the west. Land ownership is largely a mix of National Forest and private timberlands, some in checkerboard pattern, with other private holdings more abundant in the southeast portion. The few landslides occur mostly near the west end of the Scott Bar Range above the great bend of the Scott River (Figure 3.4).

3.3.8.3 Eastside Subwatershed

The Eastside subwatershed has very low landslide delivery. Table 3.10 shows no delivery from non-anthropogenic sources and only a small delivery from anthropogenic sources, which is entirely associated with harvest (Table 3.11). This subwatershed is essentially the watershed of Moffett Creek and is the lowest and driest of the six mountainous subwatersheds. The north half of the area is a mixture of National Forest and private timberlands with inliers of other private lands. The south quarter of the area is largely private timberlands, and the middle parts are a mixture of private grazing land and timberland. No significant landslides were mapped in this subwatershed (Figure 3.4, Table 3.11).

3.3.8.4 East Headwater Subwatershed

The East Headwater Subwatershed was inventoried as having no major landslide delivery in spite of having a history of harvest and mining (Tables 3.10 and 3.11). This subwatershed is the drainage of the East Fork Scott River including Noyes Valley Creek. Surrounded on the south and east by high country of the Scott Mountains, this subwatershed is a mixture of environments. The northwest flank of the Scott Mountains, above the East Fork, are largely a checkerboard of Forest Service and private timberlands. The upper part of South Fork drainage and the drainage of Noyes Valley Creek are largely grazing land with inliers of private timberlands. Only a few landslides occur, primarily on the middle slopes of the Scott Mountains.

3.3.8.5 West Headwater Subwatershed

The West Headwater Subwatershed is the watershed of the South Fork Scott River, reported in detail in the South Fork Scott River Watershed Pilot Study for the Total Maximum Daily Load for Sediment (NCRWQCB, 2005b). The West Headwater Subwatershed has significant landslide delivery, of which about 60 percent is anthropogenic (Table 3.10). The largest anthropogenic contribution is from mining legacy on mafic bedrock along Slide Creek, which is discussed in some detail in the south Fork Pilot Study. As the tables in this report do not include a mining legacy category, this mining legacy is included under the Harvest category in Table 3.11. Landslide contribution per square mile is estimated at only 18 tons/year (Tables 3.10 and 3.11), a low rate considering the steep country and a history of human activity.

3.3.8.6 Westside Subwatershed

The Westside Subwatershed is second only to the West Canyon Subwatershed in total landslide sediment delivery per square mile (Table 3.10). The inventory showed the human activity-related landslide delivery to be significant at 20 tons/yr-sq mi falling about equally in the categories of Roads, Harvest, and Roads-and-Harvest (Table 3.10). This is the largest subwatershed and is underlain by significant areas of granite in the south and mafic rocks in the north (Figure 3.2). The higher country along the crest and east flank of the Marble Mountains is in federal ownership as National Forest and Wilderness. The middle and lower mountainous part is largely in timber company ownership. Both National Forest and private timberlands have been roaded and harvested. Landslide activity is widespread (Figure 3.4).

3.3.8.7 Scott Valley-Eastern Valley Side Subwatershed

The Scott Valley Subwatershed has negligible landslide delivery from either anthropogenic or non-anthropogenic sources (Tables 3.10 and 3.11). The floor of Scott Valley is an alluvial plain sloping gently toward the Scott River from each side. Surrounded by mountains, this valley receives much less precipitation than the surrounding high country. Low relief and dry climate combine to produce a terrain that does not produce landslides. In the north end of the valley Quartz Hill and Chaparral Hill rise above the plain, but they are low enough to participate in the drier climate of the valley bottom and this inventory found no landslides. The east flank of the valley, up to the divide between Scott Valley and Noyes Valley Creek in the south and Moffett

Creek in the north is included in this subwatershed because it too produces almost no landslides (Figure 3.4, Table 3.10).

3.3.8.7 Confirmation by SHALSTAB model

SHALSTAB, a computer model to evaluate risk of shallow landslides was applied in the Scott River watershed by Derksen (2005). This model shows the highest hazard ratings in the areas where the TMDL landslide inventory and USFS studies found the highest incidence of actual landslides (Section 3.3).

3.4 STREAMSIDE SEDIMENT DELIVERY

Streamside sediment delivery was estimated in three categories:

- Soil creep is the downslope migration of soil and rock under the influence of gravity. This is a natural process that probably is little affected by human activities and is considered as a natural background source. It was estimated using SEDMODL2.
- Small streamside discrete mass-wasting and erosion features are the result of lateral stream erosion and a variety of natural and human-influenced causes. These features include bank failure, gullies, small landslides, and other small features.
- Large streamside discrete mass-wasting and erosion features result from both natural and human-induced causes. They generally extend from the stream up onto the mountainside above and include landslides, debris flows, and sites of ongoing wasting. They tend to be long-term ongoing sediment sources.

3.4.1 Soil Creep Contribution

Three approaches were used to estimate sediment delivery associated with soil creep:

1) For comparative purposes, staff investigated the results of other authors who estimated soil creep in the nearby Trinity River and Eel River watersheds.
2) Staff applied to all geologic units the soil creep rate accepted in SEDMODL2 (NCASI, 2003), which includes a function to estimate the soil creep contribution to a stream system.
3) Staff applied the soil creep rate from SEDMODL2 in all geologic units except granitic bedrock and used the delivery rate from the Sommarstrom et al. (1990) granitic sediment Study to the areas of granitic bedrock.

Approach 3 seems to give the most credible estimate.

In their Trinity River Sediment Source Analysis, Graham Matthews and Associates (GMA, 2001, p. 79, Table 48) used a rate of 30 tons/sq mi-yr as a basis to estimate soil creep contribution (Table 3.12). They arrived at this rate by starting with the rate of 75 tons/sq mi-yr derived by Roberts and Church (1986) in the coastal areas. GMA took into account that in the coastal areas the geology is less stable and uplift rates are higher than in the Trinity and used 40 percent of the coastal rate, or 30 tons/sq mi-year, for the Trinity.

In the South Fork Eel River watershed, Stillwater Sciences (1999) used two methods to calculate creep in different geologic terranes. For Coastal Belt and Yager terrane they assumed that soil creep was shallow and used SEDMODL2. They considered it likely that their estimate of 9 tons/sq km-yr (23 tons/sq mi-yr) (Stillwater Sciences, 1999, Table 3.15) is an underestimate but believed that the effect on the overall budget was probably small. For areas in the Franciscan mélange matrix, they considered creep to be soil mantle creep, a deeper process, and applied a rate of 146 tons/sq km-yr (378 tons/sq mi-yr), which they derived from intensive study of one area within the mélange.

In the Scott River watershed, staff estimated the soil creep contribution to the stream system using parameters from SEDMODL2 and applying NRCS STATSGO data on soil strength, density, and depth. SEDMODL2 takes into account not only downslope soil movement from gravity but also downslope soil transfer from biological activity such as animal burrowing and soil attached to roots of fallen trees. Default parameters for SEDMODL2 are 36-inch soil depth, creep rates of 1 mm/year for slopes less than 30 percent and 2 mm/year for slopes greater than 30 percent, and contribution length equal to twice the stream length, to account for both banks.

A 10-meter digital elevation model (DEM) of the Scott River watershed shows 748.8 sq mi (92 percent of the watershed) as being steeper than 30 percent grade. The remaining 64.7 sq mi (eight percent of the watershed) that is lower than 30 percent grade lies almost entirely in the floor of Scott Valley (the Scott Valley Subwatershed).

Calculation of the soil creep contribution to a stream system using SEDMODL2 depends on the hydrography used. A higher density of hydrographic depiction will yield a higher estimate of soil creep contribution, because it shows a greater length of stream banks. The hydrography used to calculate soil creep contribution, the densest hydrography available, is a hydrography GIS layer developed by David Lamphear at Humboldt State University, College of Natural Resources and Sciences Institute for Forest and Watershed Management, as supplemented by RM on the basis of field studies. Lamphear digitized the USGS 1:24,000 scale blue-line streams into GIS. As RM was doing road survey work, they found that there were many more road/stream crossings than the USGS stream coverage would indicate. Accordingly they used the 10-meter DEM to supplement the stream coverage and show the streams that roads crossed as high in the watershed as the highest road crossing. While this may not capture the uppermost parts of many small streams, this is the best available data.

Slopes in much of the Scott River watershed average very steep. The 10-m DEM shows 92 percent of the slopes steeper than 30 percent grade. Furthermore, large areas have slopes between 50 percent and 100 percent grade. Accordingly, staff calculated soil creep assuming that the grade of all slopes is steeper than 30 percent.

The assumptions in this calculation are as follows:

Slope	All slopes steeper than 30% grade
Creep rate	2 mm/year
Soil depth	3 feet
Tonnage	1.35 tons/cubic yard

Table 3.13 summarizes the soil creep contribution estimates in the Scott River watershed by subwatershed. In the steep country of the subwatersheds surrounding Scott Valley, contributions range from 29 to 37 tons/sq mi-yr, and the Scott Valley subwatershed contributes only about 13 tons/sq mi-yr. In subwatersheds other than Scott Valley, because assumptions used for slope, creep rate, and soil depth are the same, differences in tons/sq mi-yr are the function of differences in stream miles per square mile.

In a second calculation, staff applied the SEDMODL2-derived soil creep rates to streams in the Sedimentary/Metamorphic, Mafic/Ultramafic, and Quaternary units, and applied the sediment contribution rates from the GSS to streams on Granitic substrate. Table 3.14 shows the results of this exercise minus the granitic contribution. The granitic contribution from Sommarstrom and others (1990) is included in the sediment contribution summary in Section 3.5.1. In Sommarstrom’s calculation, soil creep is not separated out from other streamside erosion processes. However, in the final calculations in section 3.5, soil creep is accounted for.

Sommarstrom and others (1990, p. 5-3) concluded that:

> Granitic terrane streambanks average 382 tons per mile per year. Nearly three times the average streambank erosion is estimated for Boulder and Fox Creeks because of large areas of upper bank scour. About 17 miles of granitic streams in the Study Area are gutted on their upper banks. In most cases, this occurred with the 1964 flood. There has been only limited revegetation of these banks since 1964, as viewed in historic and current aerial photos. This activity appears unrelated to timber harvest as it generally occurs in upper watershed areas where little if any harvesting has occurred.
>
> Total erosion is estimated to be about 340,450 tons per year. Road cuts constitute 40 percent of this amount, and streambanks 23 percent.

3.4.2 Streamside Mass Wasting and Erosion Features - Stratified Random Sampling

Random sampling is a standard and effective means to characterize a population. A simple random sample is applicable where a population is all governed by the same major factors. In the Scott, however, a number of different factors apply to different areas in the landscape. A more efficient system of sampling is to divide the landscape into more nearly homogeneous units and apply stratified random sampling. One accepted description of this process is:

“A stratified random sample is obtained by separating population elements into non-overlapping groups (strata) and selecting a simple random sample from each stratum”
(http://www.sph.uth.tmc.edu:8053/biometry/Elee/ph1745/doc/Strata.ppt accessed 4/6/05).

Stratified random sampling provides a systematic way to include in the sampling more than one important factor in sediment generation. A major factor that affects the inherent erodibility and rate of sediment contribution from a given locality in the study area is bedrock geology.

These aggregated geologic units are described in detail in the document, *Scott River Basin Sediment TMDL Stratified Random Sampling for Streamside and Road-Associated Sediment*

Contribution (Coates and McFadin, 2004). Table 3.1 summarizes the areal extent of these units in the Scott River watershed. This GIS geology coverage (modified from Saucedo et al., 2000) has proved satisfactory for the job at hand. Field observations in October and November of 2003 and May-July of 2004 at computer-generated random stream sample locations showed no significant differences between geologic units shown on the GIS geology coverage and geologic units observed on the ground.

Stream reaches for streamside sampling were chosen using GIS to select stratified random reaches along streams using the four geologic units as sampling strata (Figure 3.5). During sampling of sites on bedrock units, observations were recorded both of geology, to verify the GIS site selection, and of evidence of fire and timber harvest. During sampling of sites on Quaternary deposits, observations were recorded on presence or absence of riprap or levee, fencing of riparian corridors, adjacent land use, and other factors.

In selecting stream segments to sample, a digital elevation model was applied to define a minimum area of drainage into a stream before considering the stream valid for selecting a random sampling reach. A satisfactory minimum area was found to be one half square mile.

Within each sampled stream segment, each erosion feature that has contributed five cubic yards or more of sediment to the stream was inventoried. Such features include debris slides, gullies, stream bank failures, fill failures, road and skid-trail washouts, small landslides, and other features. Some features are not obviously associated with human activities while others are associated with skid trails, stream crossings, landings, road ditches, road cuts or fills, or other anthropogenic features. Association or lack of association with anthropogenic features was noted. The eroded void of the feature was measured or estimated, and the percent of that volume that entered the stream system was estimated. Age of the feature was estimated on the basis of freshness of scarps and sediment, age or maturity of vegetation within the feature, presence of the feature in aerial photos, or other relevant criteria.

In all, 63 segments with a total length of 21.3 miles were sampled. The total estimated length of streams in the watershed is 2,500 miles.

3.4.3 Effects of Multiple Interacting Human Activities in the Scott River Watershed

Most of the Scott River watershed has been affected by mining, timber harvest, or agriculture over the past one hundred fifty years and longer, and the effects from repeated episodes of human activities are evident in many areas.

Different parts of the landscape show abundant roads from both mining and timber harvest, skid trails of several ages, harvest units of several ages, evidence of mining both in the riparian zones and on mountainsides, and conversion from wetlands and forest to agricultural land. Past filling of channels and valley bottoms by sediment related to human activities has caused bank erosion. Downcutting into valley-bottom fill deposits generates further second-generation sediment. Sidecutting into banks resulting from aggradation adds large amounts of sediment to the channel and triggers gullying. Old roads and skid trails contribute varying amounts of sediment depending on design, age, and position in the landscape. Sediment is generated by landslides and debris flows are triggered, or reactivated, by human activities.

It is clear that both human activities and natural processes affect sediment contribution from both dispersed and discrete sources. At the present state of knowledge, however, it is not possible to determine with certainty for each sediment delivery feature the exact proportion of natural and human-activity-induced contribution. Lacking that certainty, Regional Water Board staff used the best available information to estimate the human-caused portion of sediment contribution by sediment delivery features that were not directly associated with a particular anthropogenic feature. Field observations and aerial photographs of several ages were used along with GIS coverages of disturbance, including extent and age of timber harvest, extent and date of fires, and extent of roads, to estimate the long-term effect of human activities on sediment contribution from features in each stream reach sampled.

The sources of information used in this process include:

- California Department of Forestry GIS coverage of timber harvest. This data goes back only to 1990 but is complete from 1990 to present.
- USFS GIS coverage of timber harvest. This data set includes pre-1990 information but does not include all timber harvest on Government land.
- USGS DOQQ Aerial photographs from 1993 and 1998.
- USFS Landslide data. (please refer to the data discussion in section 3.3.6)
- Vestra Landslide data. (please refer to the data discussion in section 3.3.8)
- USFS "Tweener" GIS coverage. This data documents erosional and mass wasting features that occur between road/stream crossings. This was compiled by the USFS from Road Sediment Source Inventories, 1999 to 2001.
- USFS "Damage_all" GIS coverage. This theme captures 1997 Flood damage to roads and other Forest facilities.
- USGS Mineral Resources Data System. Documents historical mining activities.
- Vestra-developed GIS roads coverage.
- USFS-developed stream layer.
- Field observations of human activity not documented elsewhere.

Water Board staff evaluated each of the above data sets in estimating the level of human contribution in each subbasin, upstream and upslope of the sediment sample survey reach. Also used were the USFS and CDF timber harvest records, which include the level of impact and age of the harvest, and additional harvest areas that staff digitized from the USGS aerial photographs in which impact and age of harvest was indeterminate. The Vestra and USFS landslide data used documented human-related or natural cause of slides. The impact of road-associated failures documented in the USFS "Damage_all" and "Tweener" coverages and those documented by Water Board staff during field work were included in the analysis. Analysis by Water Board staff incorporated all of these factors. The Human Contribution Factor assigned to each sample survey reach was based on the type, extent, and age of the activity and the proximity to the sample survey location.

Table 3.15 summarizes the estimates of EMIHAs for each stream reach sampled in the Scott River watershed. In this table:

- The stream reaches are the reaches selected by stratified random sampling.
- The Total Contribution column gives the contribution from streamside discrete features including bank failure, landslides, and gullies that were not associated directly with a proximate human activity in field examination.
- The Human-Activity Related Contribution column gives the estimate of proportion of sediment contribution resulting from human activity, in categories of 25 percent. A zero means that the estimate was closer to zero than to a quarter. A 0.25 estimate means that the estimate was closer to one-fourth than to zero or to one half, and so forth.
- Comments are primarily a narrative description of amount, age, and intensity of human activity adjacent to, and upstream of, the stream reach summarized from GIS coverages, aerial photographs, and field observations.

Four sampled stream reaches were selected as examples to illustrate the factors that were taken into account. Figure 3.6 shows the locations and relative sizes of the watersheds above these sample reaches. Each of these areas is shown in more detail in two figures to illustrate the factors taken into account. In each pair of figures, the first is an orthophoto or orthophoto mosaic with an overlay of timber harvest as depicted in CDF GIS coverage and additional timber harvest interpreted by Regional Water Board staff on aerial photos and/or in the field. Because the digital orthophoto quarter quads used come from both 1993 and 1998 photography, not all of the orthophoto coverage is the same age.

The second figure in each pair shows the same GIS and interpretive information as the first, but without the visual clutter (and verification) of the orthophoto. Note that while each figure of a pair is the same scale, different pairs are different scales. Figures 3.7 to 3.14 are examples of interpretation of different percentage categories of EMIHAs.

Example in zero percent category

Figure 3.7 (1993 and 1998 photography) shows a drainage basin of 2,800 acres upstream of the terminal point of stream reach M-09-04. This area is high in the Marble Mountains and heads at the divide between the Scott River and Salmon River watersheds. The GIS layers show timber harvest over 22 acres in 1978 and 111 acres in 1992 (total 133 acres, 5 percent of the area). Photointerpretation shows an additional 244 acres (9 percent of the area) harvested (Figures 3.7 and 3.8). Several roads lie within the area. Because only 14 percent of the area has been harvested and there is little evidence of other disturbance, staff estimated that anthropogenic contribution was closer to zero than to 25 percent.

Example in 25 percent category

Figure 3.9 (1998 photography) shows several factors used in interpreting anthropogenic sediment delivery. This small drainage basin covers 390 acres upstream of the terminal point for streamside sample reach S-05-04. GIS layers from CDF and DOQQs from 1993 and 1998 aerial photos were examined. The CDF GIS layers show pre-1997 timber harvest over 240 acres (61 percent of the area). On the DOQQs, Regional Water Board staff, interpreted thinned timber and skid trails to show an additional 64 acres of harvest in two areas in the head and on the north side of the basin, bringing harvest in the basin to 304 acres or 78 percent of the basin (Figures 3.9 and 3.10). The only permanent road within the basin is a short segment that crosses the headwaters. Although the area of harvest was high, 78 percent, the harvest practices were low impact, and staff estimated the anthropogenic contribution to be closer to one fourth than to one half.

Example in the 50 percent category

Figure 3.11 (1993 photography) shows the headwater area of North Fork French Creek and sample reach G-14-04. The available GIS coverage does not show timber harvest plans in this area, but interpretation of aerial photos shows a timber harvest area covering the mountainsides both north and south of the creek along the sampling area and other harvest areas higher in the basin (Figures 3.11 and 3.12). This is a granitic area (Figure 3.2) and the DG that makes up the surface is known to ravel extensively when disturbed. The photos (Figure 3.11) show a large amount of bare ground exposed in the harvest area, which is a steep slope. For these reasons, staff estimated anthropogenic contribution in this area to be in the 50 percent range.

Example in the 75 percent category

Figure 3.13 (1993 and 1998 photography) shows the drainage basin of North Fork Kelsey Creek, which has had extensive and intense management activities immediately upstream of the terminal point of sample reach M-18-04. Of the 11,110 acres in this drainage, USFS GIS coverage shows 2,060 acres (18.5%) as included in timber harvest plans. Most of these areas are immediately upstream of, and draining into, the sample area. Roads are abundant in the harvested area. Landslides are significantly more abundant in the harvest areas than in unharvested areas to the west and south, and aerial photos show association between several landslides and harvest activity (Figures 3.13 and 3.14). Because of the association with extensive disturbance, staff estimated anthropogenic contribution in this area to be in the 75 percent range.

The proportion of natural and anthropogenic contributions generated in Table 3.15 is applied to streamside large discrete features in Section 3.4.5 and to streamside small discrete features in Section 3.4.6. This application is based on the assumption that the contribution proportions and rates estimated for the randomly sampled areas are applicable throughout the Scott River watershed.

3.4.4 Estimation of Sediment Delivery from Small and Large Discrete Features

The sediment delivery per stream mile from both large and small features in all four geologic units was estimated using data from all random samples throughout the Scott River watershed. Then for the purpose of the TMDL study the delivery rate for each geologic unit, in tons/sq mi-yr, was applied in each subwatershed.

Streamside sediment sources were classified in two categories: streamside large discrete features and streamside small discrete features. The large features generally are long-term continuing sources of sediment and typically originate on, or extend up onto, the mountainside. The small-features category includes streambank failure, gullies, and a variety of other small failures that mostly deliver episodically to the stream.

While there can be some overlap in the middle ground, the large and small feature categories have fundamental differences in duration and mechanism. Most of the large features have much in common with the landslides that were inventoried by the aerial photo survey. Many in the large-feature category, however, are small enough that they would be marginal to be picked up in the aerial photo survey. In addition, some, although large enough to fit the criteria for the aerial photo survey, lie in steep inner gorges and are too obscured by trees and shadow to pick out on the photos. Also, in this extremely steep country, photo angle can be critical in finding and defining these features.

Some features, both large and small, are clearly associated with a specific anthropogenic feature such as a road or a road-stream crossing. These are counted simply as related to human activity.

3.4.5 Streamside Large Discrete Features

Ten features examined in the Scott River watershed meet the criteria of this category. Though small in number, these features are significant and generally long-term contributors to stream sediment. In Table 3.16, the average annual large-discrete-feature contribution per stream mile in the Scott River watershed is calculated on the basis of the random sampling along streams. Contribution from large features on granitic substrate is totaled separately from the other three geologic units for the purpose of comparison, as a separate calculation was done applying rates from the GSS to areas of granite.

In Table 3.17, the rates estimated in Table 3.16 are applied to individual sub-watersheds throughout the Scott River watershed, based on stream miles in Quaternary, Granitic, Mafic, and Sedimentary/Metamorphic substrates. The Scott Valley Subwatershed is not included as no large discrete features were found there and slopes are lower than in the areas where such features occur. In the bottom half of Table 3.17 is a summation of estimated large-feature sediment contribution. The first block shows tons per year for each subwatershed and for the Scott and tons/sq mi-yr per subwatershed and for the Scott including granitic substrate, based on SEDMODL2 and RM road survey rates for all geologic units. The second block shows results from the same sources, but without results from granitic substrate. These rates are carried forward to the summary in Section 3.5.

3.4.5.1 Feature 92 – A Special Case

Feature 92 of the air-photo landslide inventory, discussed in the South Fork Pilot Study (NCRWQCB, 2005b, Figure 2, Table 5), is not a landslide. It is a stream segment that has had extreme erosion. While this feature is not within one of the stratified random samples of stream segments, its very size puts it in a category that cannot be ignored. Staff visited one locality in the lower-middle portion of the feature and found it at that spot to be a steep-sided, downcutting gully as deep as 60 feet and as wide as 150 feet rim-to-rim. At that spot, it is essentially V-shaped in cross section, and the walls are so bare as to be conspicuous on aerial photographs. This is much larger than any other active gully, natural or anthropogenic, that staff have found in

the Scott River watershed. USFS data suggest that this feature originated in 1944 as a failure on steep upper slopes of the mountainside in an area that has not undergone mining or timber harvest. The feature has evolved over the years and created a debris flow channel extending from the upper flank of Craggy Peak down to East Boulder Creek.
Estimated dimensions and yield of Feature 92:

5,000 feet long
Avg. depth 30 feet
Avg. width 100 feet
V-shaped cross section = Avg. 1500 sq ft
1,500 sq ft (cross section) x 5,000 ft (length) = 7,500,000 cu ft
7,500,000 cu ft / 27 cu ft per cu yd = 280,000 cu yd
280,000 cu yd x 1.35 tons per cubic yard = 378,000 tons

Assuming an age of 60 years, then average yield has been 378,000/60 = 6,300 tons per year. But this needs some interpretation.

The total volume calculated above assumes that there was no prior depression where the gully now is, which is probably not true; water and sediment flowing downhill from the area of origin would follow the lowest course. The USGS 1:62,500 scale topographic map shows Feature 92 as the only blue-line stream incised into the west flank of Craggy Peak, suggesting that it existed as a stream course before the 1944 debris flow event. Assuming that the course of Feature 92 followed one of these shallow depressions to channel the water in the first place, staff decrease volume and tonnage by ten percent and arrive at a yearly average of 5,670 tons. Aerial photo analysis reveals that Feature 92 is a debris flow channel that has had at least two debris flows, probably in 1964 and 1997, in addition to the 1944 event that originated the channel, and any undocumented events that might have taken place between 1944 and the 1980 photos. However, debris flows are not the only source of erosion and sediment delivery. The V-shaped stream channel and steep, unvegetated gully walls indicate that downcutting of the channel and backwasting of the walls are ongoing processes.

Sediment is delivered from Feature 92 every wet season when the stream runs, but delivery has been punctuated by the episodic debris flow events, the timing of which is unpredictable. Seeking the average annual contribution over a long period, staff include the debris flow events as an integral part of the long term sediment delivery. 5,670 tons/yr divided by 43 sq mi = 132 tons/sq mi-yr in the South Fork Scott River subbasin. This figure is included in natural sediment delivery in Section 3.5.

3.4.5.2 East Boulder Creek – A Special Case

One reach of East Boulder Creek, G-06-04, has four large erosion features strung together along 300 m of stream course. This in an anomalous stream segment that is incising into glacial till deposits on the valley floor, and the features described are undercut banks on the outside of bends in the stream course. Although limited timber harvest has taken place upstream, and some legacy roads remain, no direct connection was seen between human activity and the downcutting. For the TMDL estimate, staff attribute it to natural causes. Staff combined the four described features into one causal feature, estimated sediment contribution for the last twenty years, and calculated the rate on that basis. This figure is applied in Table 3.22. The calculation is as follows:

$$(7255\ yd^3) \times (1.35\ tons/yd^3) / (20) / (43.91) = 11.15\ tons/sq\ mi\text{-}yr$$

3.4.6 Streamside Small Discrete Features

The rate of contribution per stream mile from streamside small discrete features throughout the Scott River watershed was calculated on the basis of stream survey data collected from all geologic units in 2003 and 2004 (Table 3.18). Delivery from features that are clearly associated with an anthropogenic feature were accounted for in the left of the table. To the right in Table 3.18 is delivery from features for which direct association with human activity is not obvious within the stream reach where sampling took place. A factor generated in Table 3.15 was applied to estimate anthropogenic contribution to take into account the effects of multiple interacting human activities in the watershed produced by many decades of human activity.

Table 3.19 presents the same calculation as Table 3.18 in areas of Quaternary, Mafic, and Sedimentary/Metamorphic substrate. However the delivery rate from granitic substrate is taken from the Granitic Sediment Study instead of from data collected in this study. The total delivery estimated by the two different approaches is so close as to be within the margin of error.

Estimates of sediment delivery per geologic unit per subwatershed are calculated in Table 3.20 for small discrete features that have no direct human-activity association. Estimates of rates of sediment delivery attributed to different human activities are summarized in Table 3.21.

3.4.7 Callahan Area Dredger Tailings

Gold dredging along a 4.7 mile reach of the Scott River below the town of Callahan from 1934 to 1948 created disruptions of channel processes as well as in surface and subsurface hydrology that persist today. Dredging in the river and adjacent terrace deposits went as deep as 50 feet below river level. This process not only left behind windrows of cobble gravel, but it disrupted the stratigraphy of the deposits greatly increasing permeability as fine material was washed out. Consequently a significant part of the river flows underground through this stretch and the surface flow dries up most summers (Hesseldenz et al., 1999; U.S. Forest Service, 1997). Lateral cutting of the river into the dredger tailings along the west side of the river delivers sediment into the channel, but the quantity of sediment delivered is not clear. Sediment discharged from the dredger tailings was not included in the TMDL calculation.

3.5 SEDIMENT ANALYSIS SUMMARY, TMDL, ALLOCATIONS, & MARGIN OF SAFETY

3.5.1 Sediment Source Analysis Results

The results of the sediment source analysis are summarized in Table 3.22 in tons per square mile per year from different natural and anthropogenic sources. The bottom section of Table 3.22 summarizes estimates of current natural and human-activity-related delivery and calculates the percentage of the total contribution above natural delivery. Sources of information for these calculations are as follows:

- Delivery from discrete features is taken from stream surveys.
- Delivery from landslides comes from the aerial photo survey with field checking.
- Road-related delivery is taken from SEDMODL2 and the RM road survey for Quaternary, Mafic, and Sedimentary/Metamorphic geologic units and from the Scott Granitic Sediment Study (Sommarstrom et al., 1990) in areas of Granitic substrate for reasons explained in Section 3.1.5.
- In Scott Valley, delivery from discrete features and soil creep was calculated only from observations in Scott Valley and not extrapolated from values in the mountainous subwatersheds.

3.5.2 Sediment TMDL

This TMDL is set equal to the loading capacity of the Scott River and its tributaries. The TMDL is the estimate of the total amount of sediment, from both natural and human-caused sources, that can be delivered to streams in the Scott River watershed without exceeding applicable water quality standards. Staff are assuming that there can be some increase above the natural amount of sediment without adverse effects to fish habitat. Staff postulate this because fish populations were thriving throughout the Klamath River watershed after human activities had begun to produce some sediment. For the Scott River, the sediment TMDL is set equal to 125 percent of natural sediment delivery, based on past experience in other Northern California watersheds.

For the Noyo River, the U.S. EPA (1999) used a reference time period to calculate the sediment TMDL. The TMDL was set at the estimated sediment delivery rate for the 1940s. Because salmonid populations were substantial during this time period, which was assumed to be a quiescent period between the logging of old growth at the turn of the century and logging of second growth in the middle of the 20th century, U.S. EPA postulated that there could be increases above the natural amount of sediment and still maintain healthy watershed conditions. Analysis of sediment sources during this period indicates that there was about one part human induced sediment delivery for every four parts natural sediment delivery (i.e. a 1:4 ratio, or a 25% increase).

The U.S. EPA reached similar results in the TMDL analysis of the Trinity River (USEPA, 2001). For that TMDL U.S. EPA used reference streams within the watershed to calculate TMDLs for all the subwatersheds of the Trinity. Again, the reference streams were subwatersheds in which there was some management accompanied by healthy watershed conditions. As with the Noyo, it appeared that in these watersheds fish populations could be supported under TMDLs set at a level equivalent to a 4:1 ratio.

Based on these analyses, staff have determined that setting the TMDL at 125 percent of natural sediment delivery is appropriate for the Scott River. Using the estimated natural sediment delivery rate of 448 tons/sq mi-yr (Table 3.22), the TMDL for the Scott River (rounded to two significant figures) is:

TMDL = Loading Capacity = (125%) x (448 tons/sq mi-yr) = 560 tons/sq mi-yr

Because of the natural variations in sediment delivery, the TMDL is to be evaluated as a ten-year, rolling average of total annual sediment yield. The ratio approach has several potential advantages. Stillwater Sciences (1999) indicates that looking at the ratio of human to natural sediment sources can detect the effects of land use changes better than an annual sediment loading alone, because the ratio may very with hydrology less than the annual sediment load. The ratio could be measured periodically and provide an indication of progress toward meeting sediment reduction goals. The ratio may also be less dependent upon spatial and hydrologic variability.

The approach taken focuses on sediment delivery, rather than on a more direct measure of salmonid habitat (i.e., instream conditions). Sediment delivery can be subject to direct management by landowners (for example roads can be well maintained and landslides mitigated).

While it would be desirable to be able to mathematically model the relationship between salmon habitat and sediment delivery, these tools are not available for watersheds with landslides and road failure hazards. Sediment movement is complex both over space and through time. Sediment found in some downstream locations can be the result of sediment sources far upstream; instream sedimentation can also be the result of land management from decades past. Nonetheless, management activities clearly can increase sediment delivery, and instream habitat can be adversely affected by increased sediment inputs. Therefore it is reasonable to link human activities to decreased stream habitat quality. The French Creek project, discussed in Section 2.4.2.7, demonstrates the linkage between upslope and instream conditions, and the potential for improvement in instream habitat that can result from upslope sediment delivery reductions.

The approach also relies upon the assumption that salmon populations can be self sustaining even with the yearly variation of natural rates of erosion observed in the 20th century. Although the sediment delivered to the streams varied, salmon adjusted to the natural variability by using the habitat complexity created by the stream’s adjustments to the naturally varying sediment loads.

3.5.3 Load Allocations

In accordance with EPA regulations, the loading capacity (TMDL) is allocated to the various sources of sediment in the watershed, with a margin of safety. That is:

TMDL = sum of the wasteload allocations for individual point sources
+ sum of the load allocations for nonpoint sources
+ sum of the load allocations for background sources.

The margin of safety in this TMDL is not added as a separate component of the TMDL. Instead it is incorporated into conservative assumptions used to develop the TMDL. As there are no point sources of sediment in the Scott River watershed, the wasteload allocation for point sources is set at zero.

In addition to ensuring that the sum of the load allocations equals the TMDL, the Regional Water Board considered several factors related to the feasibility and practicability of controlling various nonpoint sources of sediment. The load allocations for nonpoint sources reflect professional judgment as to how effective best management practices are in controlling these sources. For example, techniques are available for greatly reducing sediment delivery from roads (Weaver and Hagans, 1994). In the Scott River watershed, the effectiveness of mitigation measures with respect to roads has been demonstrated in the French Creek watershed and in improved road design in other areas since implementation of the Forest Practice Rules.

For the Scott River TMDL, source categories that are more controllable receive load allocations based on a higher percentage reduction from current levels. For example, road stream crossing failures are more readily controlled than road related mass wasting, particularly in weathered granite. Therefore, the load allocation for road stream crossing failures is based on a loading reduction of 75 percent, whereas the load allocation for road related mass wasting is based on a loading reduction of 42 percent.

The load allocations for the Scott River watershed are presented in Table 3.23. The allocations clarify the relative emphasis and magnitude of erosion control programs that need to be developed during implementation. The load allocations are expressed in terms of yearly averages (tons/sq mi-yr). They could be divided by 365 to derive daily loading rates (tons/sq mi-day), but the Regional Water Board is expressing them as yearly averages, because sediment delivery to streams is naturally highly variable on a daily basis. In fact, the Water Board expects the load allocations to be evaluated on a ten-year rolling average basis, because of the natural variability in sediment delivery rates. In addition, the Water Board does not expect each square mile within a particular source category to necessarily meet the load allocation; rather, the Water Board expects the average for the entire source category to meet the load allocation for that category.

3.5.4 Margin of Safety

The Clean Water Act, Section 303(d) and the associated regulations at 40 CFR §130.7 require that a TMDL include a margin of safety that takes into account any lack of knowledge concerning the relationship between the pollutant loads and the desired receiving water quality. The margin of safety may be incorporated implicitly by making conservative assumptions in calculating loading capacities, waste load allocations, and load allocations (USEPA, 1991). The margin of safety may also be incorporated explicitly as a separate component in the TMDL equation. For the Sediment TMDL analysis, conservative assumptions were made that account for uncertainties in the analysis.

Specific conservative assumptions used to account for margin of safety:

- Section 3.4.1. In estimating sediment delivery by soil creep it was recognized that the hydrography used directly affects the estimate of delivery from this source. Because no available hydrography GIS layer shows all streams, as evidenced in field studies, the delivery from this natural source is underestimated. This underestimate affects the allocation of anthropogenic sediment, as the allocation is calculated as a percentage of the natural delivery.

- Ages of small features tended to be estimated low. The majority of small features described and estimated were along streams and the majority of these are natural. This would tend to result in higher yearly rates of sediment delivery for these features and is therefore conservative. If features attributed to the 1997 flood event actually were initiated before this event, yearly rates of sediment delivery estimated for these features would be higher and are therefore conservative in the context of calculating the TMDL.

- The estimation of EMIHAs is a part of the margin of safety. Some anthropogenic features are not accounted for in their proper category. For example, the VESTRA-developed GIS layer of roads used under-represents roads and does not include skid trails. In some areas only major haul roads are included, which means that many temporary roads and skid roads that can increase erosion remain unaccounted for in that road survey. Addition of the EMIHA factor accounts for roads and skid trails that are not documented in the survey.

3.5.5 Seasonal Variation and Critical Conditions

The TMDL must discuss how seasonal variations were considered. Sediment delivery in the Scott River watershed inherently has considerable annual and seasonal variability. The magnitudes, timing, duration, and frequencies of sediment delivery events fluctuate naturally depending on intra- and inter-annual variations in storm patterns. Because the storm events and the mechanisms of sediment delivery are largely unpredictable year to year, the TMDL and load allocations are designed to apply to the sources of sediment, not the movement of sediment across the landscape, and to be evaluated on the basis of a ten-year rolling average. The Water Board assumes that by controlling the sources to the extent specified in the load allocations, sediment delivery will be controlled within an acceptable range for supporting aquatic habitat, regardless of the variability of storm events.

The TMDL must also account for critical conditions for stream flow, loading, and water quality parameters. Rather than explicitly estimating critical flow conditions, this TMDL uses indicators that reflect net long term effects of sediment loading and transport for two reasons. First, sediment impacts may occur long after sediment is discharged, often at locations downstream of the sediment source. Second, it is impractical to accurately measure sediment loading and transport, and the resulting short term effects, during high magnitude flow events that produce most sediment loading and channel modifications.

CHAPTER 4. TEMPERATURE

Key Points:

- This chapter presents an analysis of the factors that affect stream temperatures in the Scott River and its tributaries.

- Regional Board Staff identified five factors influenced by human activities in the Scott River watershed that have affected, or have a potential to affect stream temperatures. The five factors are: stream shade, stream flow via surface diversion, stream flow via changes in groundwater accretion, channel geometry, and microclimate.

- Regional Water Board staff investigated the effects of human activities using a stream temperature model. Stream temperature model applications were developed for the Scott River, South Fork Scott River, East Fork Scott River, and portions of Houston and Cabin Meadows creeks.

- The analysis of factors affecting the temperature of the Scott River and its tributaries indicate that human activities have resulted in significant increases in temperature in many areas of the watershed, small to modest increases in other areas of the watershed, and that removal of vegetation could cause temperature increases in the future.

- The mainstem Scott River has been drastically altered over the past 170 years. During that time the following changes have occurred:
    - The beaver population has been dramatically reduced.
    - The river has been straightened and levees have been built.
    - Flows have been diverted.
    - The extent and quality of riparian forests has been drastically reduced.
    - A number of periods of increased sediment loads have occurred.

- The primary human-caused factor affecting stream temperatures in the Scott River watershed is increased solar radiation resulting from reductions of shade provided by riparian vegetation.

- Groundwater inflows are also a primary driver of stream temperatures in Scott Valley. The temperature of the Scott River is affected by groundwater in two ways.

Key Points, continued:

First, groundwater accretion directly affects stream temperature by direct addition of cold water, changes in volume, and transit time. Second, the elevation of groundwater affects the ability of riparian tree species to thrive and reproduce, which indirectly affects stream temperatures by increasing exposure to solar radiation.

- Diversions of surface water lead to relatively small temperature impacts in the mainstem Scott River, but have the potential to affect temperatures in smaller tributaries, where the volume diverted is large relative to the total flow. Effects of surface diversions on stream temperatures may be significant when effects of human activities are considered cumulatively.

- Microclimate alterations have the potential to increase stream temperatures. The magnitude of such increases is small to moderate.

- This TMDL uses effective shade as a surrogate measure of solar loading.

- Current and potential effective shade estimates were developed at the watershed-scale using a computer model. The results of the modeling exercise provide an estimate of the loading capacity of the watershed, and were used to develop load allocations at the watershed level. The results should not be used to define load allocations at the site-specific level.

- The temperature TMDL for the Scott River watershed is the adjusted potential effective shade conditions for the date of the summer solstice, as expressed in Figure 4.34 and Table 4.10.

- Further study is required to better understand the interaction of groundwater and surface water.

- Stream temperature conditions are expected to benefit from actions taken to reduce sediment loads.

4.1 INTRODUCTION

This chapter presents the supporting technical analysis for the Scott River Temperature TMDL. The analysis investigates the factors that determine stream temperature conditions in the Scott River and its tributaries. The analysis was developed using the best available information.

The objective of this analysis is to evaluate and quantify the impacts of human activities on the temperature of the Scott River and its tributaries, and to provide an understanding of stream heating processes so that sources of the impairment can be effectively addressed. Specifically, the analysis addresses the following questions: "Have water temperatures been altered by human activities?", and "Have water temperatures been increased more than 5^{o} F?" These questions must be answered to evaluate current conditions in relation to the Water Quality Objective for Temperature (see Table 2.1).

Please note that all figures and tables for this chapter are located towards the end of this Staff Report.

4.1.1 Temperature Sources: Stream Heating Processes

Water temperature is a measure of the total heat energy contained in a volume of water. Stream temperature is the product of a complex interaction of heat exchange processes. These processes include heat gain from direct solar (short –wave) radiation, both gain and loss of heat through long-wave radiation, convection, conduction, and advection, and heat loss from evaporation (Brown, 1980; Beschta et al., 1987; Johnson, 2004; Sinokrot and Stefan, 1993; Theurer et al., 1984).

- Net direct solar radiation reaching a stream surface is the difference between incoming radiation and reflected radiation, reduced by the fraction of radiation that is blocked by topography and stream bank vegetation (Sinokrot and Stefan, 1993). At a given location, incoming solar radiation is a function of position of the sun, which in turn is determined by latitude, day of the year, and time of day. During the summer months, when solar radiation levels are highest and streamflows are low, shade from streamside forests and vegetation can be a significant control on direct solar radiation reaching streams (Beschta et al., 1987). At a workshop convened by the State of Oregon's Independent Multidisciplinary Science Team, 21 scientists reached consensus that solar radiation is the principal energy source that causes stream heating (Independent Multidisciplinary Science Team, 2000).

- Heat exchange via long-wave radiation at a stream surface is a function of the difference between air temperature and water surface temperature (Sinokrot and Stefan, 1993;

ODEQ, 2000). Long-wave radiation emitted from the water surface can cool streams at night. Likewise, long-wave radiation emitted from the atmosphere and surrounding environment can warm a stream during the day. During the course of a 24-hour period, heat leaving and heat entering a stream via long-wave radiation generally balance (Beschta, 1997; ODEQ, 2000).

- Evaporative heat losses are a function of the vapor pressure gradient above the stream surface and wind conditions (Sinokrot and Stefan, 1993). Evaporation tends to dissipate energy from water and thus tends to lower temperatures. The rate of evaporation increases with increasing stream temperature. Air movement (wind) and low vapor pressures (dry air) increase the rate of evaporation and accelerate stream cooling (ODEQ, 2000).

- Convection describes heat transferred between the air and water via molecular and turbulent motion. Heat is transferred from areas of warmer temperature to areas of cooler temperature. The amount of heat transferred by this mechanism is generally considered low (Brown, 1980; Sinokrot and Stefan, 1993).

- Conduction is the means of heat transfer between the stream and its bed. In shallow streams, solar radiation may be able to warm the streambed (Brown, 1980). Bedrock or cobbles on the streambed may store heat and conduct heat back to the water if the bed is warmer than the water (ODEQ, 2000). Likewise, water can lose or gain heat as it passes through subsurface sediments during intra-gravel flow through gravel bars and meanders. Bed conduction is a function of the thermal conductivity of the bed and the temperature gradient within the bed (Sinokrot and Stefan, 1993). A streambed that has absorbed radiant energy during the day will conduct that energy back to the stream at night.

- Advection is heat transfer through the lateral movement of water as stream flow or groundwater. Advection accounts for heat added to a stream by tributaries or groundwater. This process may warm or cool a stream depending on whether a tributary or groundwater entering the stream is warmer or cooler than the stream.

Each of the heat fluxes discussed above can be represented by mathematical equations. By adding the values of the fluxes for a particular location, the net of the heat fluxes associated with all of these processes can be calculated (Theurer et al., 1984; Sinokrot and Stefan 1993). The net heat flux represents the change in the water body's heat storage. The net change in storage may be positive, leading to higher stream temperatures, negative, leading to lower stream temperatures, or zero such that stream temperature does not change.

Of the processes described above, solar radiation is most often the dominant heat exchange process. In some cases and locations advection has a great effect on stream temperatures by diluting heat loads via mixing of colder water. Although the dominance of solar radiation is well accepted (Johnson, 2004; Johnson, 2003; Sinokrot and Stefan 1993; Theurer et al., 1984), some studies have indicated that air temperatures are the prime determinant of stream temperatures. These studies have based their conclusions on correlation rather than causation (Johnson, 2003). Air and water temperatures are generally well correlated, however correlation does not imply causation. Heat budgets developed to track heat exchange consistently demonstrate that solar radiation is the dominant source of heat energy in stream systems (Johnson, 2004; ODEQ, 2002; Sinokrot and Stefan, 1993). Stream temperature modeling conducted as part of this analysis (described below), confirms that solar radiation is the dominant heat exchange process in the Scott River watershed (Figures 4.1A-D). The analysis also demonstrates that heat exchange from air to water via convection is a minor component of the heat budget.

The conclusion that solar radiation is the dominant source of stream temperature increases is supported by studies that have demonstrated both temperature increases following removal of shade-producing vegetation, and temperature decreases in response to riparian planting. Johnson and Jones (2000) documented temperature increases following shade reductions by timber harvesting and debris flows, followed by temperature reductions as riparian vegetation became re-established. Shade loss caused by debris flows and high waters of the flood of 1997 led to temperature increases in some Klamath National Forest streams (de la Fuente and Elder, 1998). Riparian restoration efforts by the Coos Watershed Association reduced the MWAT of Willanch Creek by 2.8 ^{o}C (6.9 ^{o}F) over a six-year period (Coos Watershed Association, undated). Miner and Godwin (2003) reported similar successes following riparian planting efforts.

4.1.2 Stream Heating Processes Affected by Human Activities in the Scott River Watershed

Regional Water Board staff identified five factors influenced by human activities in the Scott River watershed have affected, or have a potential to affect stream temperatures. The five factors are:

- Stream shade
- Stream flow via changes in groundwater accretion
- Stream flow via surface diversion
- Channel geometry
- Microclimate

4.1.2.1 Stream Shade

Direct solar radiation is the primary factor influencing stream temperatures in summer months. The energy added to a stream from solar radiation far outweighs the energy lost or gained from evaporation or convection (Beschta and others, 1987; Sinokrot and Stefan 1993; Johnson, 2004). Because shade limits the amount of direct solar radiation reaching the water, it provides a direct control on the amount of heat energy the water receives.

Shade is created by vegetation and topography; however, vegetation typically provides more shade than topography. The shade provided to a water body by vegetation, especially riparian vegetation, has a dramatic, beneficial effect on stream temperatures. The removal of vegetation decreases shade, which increases solar radiation levels, which, in turn, increases stream temperatures. Additionally, the removal of vegetation increases ambient air temperatures, can result in bank erosion, and can result in changes to the channel geometry to a wider and shallower stream channel, all of which also increase water temperatures.

4.1.2.2 Groundwater

Ground water accretion affects temperatures in a number of ways. Most importantly, groundwater accretion provides a stream with a cold source of water that dilutes the thermal energy in the stream (advection). This dilution increases a stream’s capacity to assimilate heat. Additionally, groundwater accretion increases the volume of water, which increases the thermal mass and velocity of the water. Thermal mass refers to the ability of a body to resist changes in temperature. Basically, more water heats or cools slower than less water. Increases in velocity reduce the time required to travel a given distance, and thus reduces the time heating and cooling processes can act on the water. These principles are true for any stream, however because the Scott River gains so much of its volume from groundwater accretion in most years (see discussion in section 4.3.1.7), the processes that groundwater accretion influences are particularly effective at limiting stream temperatures.

Water use in Scott Valley is intense. The major human uses of the water are irrigation of alfalfa and other hay crops, irrigation of pasture, watering of livestock, and domestic needs. The great demand for water resulted in the adjudication of water rights in 1980. Unfortunately, the adjudication does not establish minimum instream flows for aquatic life. The US Forest Service does have a junior water right for instream fisheries and recreation flows downstream of Scott Valley, but the requirements are rarely met.

The Scott River Adjudication was the first in California to recognize the linkage between groundwater and surface water. In fact, new legislation was required (resulting in water code section 2500.5) to allow ground water resources to be included in the adjudication.

Unfortunately, the adjudication only recognized a narrow zone of the aquifer as being interconnected with surface water. The interconnected zone is defined in the adjudication as follows (Superior Court of Siskiyou County, 1980):

> Interconnected ground water means all ground water so closely and freely connected with the surface flow of the Scott River that any extraction of such ground water causes a reduction in the surface flow in the Scott River prior to the end of a current irrigation season.

The aquifer characteristics and groundwater-surface water dynamics of Scott Valley are poorly understood. The degree to which water use affects groundwater accretion cannot be determined from the available information. The analysis is complicated by the fact that, while groundwater pumping undoubtedly contributes to a drawn down aquifer, irrigation and leaky ditches must also contribute some amount of recharge.

The Scott River Adjudication allows for irrigators to switch from surface water to interconnected ground water, provided that any new wells are located at least 500 feet from the Scott River, or at the most distant point from the river on the land that overlies the area of interconnected groundwater, whichever is less. The only restriction placed on the use of interconnected groundwater is that the water pumped shall be used for irrigation of crops overlying the "Scott River ground water basin" in amounts reasonable for the acreage irrigated. The adjudication does not address groundwater use outside the interconnected zone.

A human-related factor not related to water use that has negatively affected the water table is the incision of the river channel. In 1938, the US Army Corps of Engineers constructed levees, and straightened and channelized the Scott River throughout the middle part of Scott Valley. Many landowners have subsequently rip-rapped the river banks, which has kept the river channelized. Additionally, the removal of a diversion dam in the mid 1980s resulted in a knick-point that has since migrated upstream and further lowered the channel bed. One effect of these channel changes is that with the stream channel lower, the water table drops faster and further during the dry season. Consequently, the aquifer is unable to store as much water compared to the un-incised channel condition. In essence, the river acts as a drain, and the channel incision makes it a more effective drain. A second effect is that the river does not flood as frequently, which reduces groundwater recharge.

There are a number of issues related to drawdown of the Scott Valley aquifer that do or may affect water quality and stream habitat:

1. Dewatered Channel. This is the most severe impact related to drawdown of the Scott Valley aquifer. In dry years the water table is lower than the bottom of the river channel and

consequently the river water percolates into the aquifer to the point that there is no continuous flow. The Scott River went dry for long stretches in 1924, 1977, 1991, 1994, 2001, 2002, and 2004. Pumping groundwater can contribute to drawdown of the aquifer. However, the river would likely go dry in severe droughts, even without pumping. (Channel dewatering can also be affected by channel aggradation as a result of increased sediment loads.)

2. Temperature Impacts. In normal water years the river is a gaining system. The ground water that enters the Scott River is relatively cold (approximately 58 ^{o}F) and has a cooling effect on the river. The temperature modeling results indicate that the amount of groundwater entering the Scott River has a profound effect on its temperature.

3. Migration Impacts. The depletion of groundwater also affects the ability of adult salmonids to access reaches of the river and tributaries they use for spawning during the fall of dry years. Adult chinook salmon often begin their migration prior to the beginning of the rainy season and before the end of the irrigation season. In dry years, river flows do no rebound even after irrigation ceases. During those dry years, there are insufficient flows to allow the fish to pass some stretches of the river in the canyon downstream of Scott Valley. The Scott River Watershed Council has identified fall flows as a limiting factor affecting salmonids in the Scott River watershed.

4. Riparian Impacts. The rapid lowering of the Scott Valley water table may interrupt the natural succession of riparian tree species and hinder the success of riparian planting projects. Basically, the issue is whether trees can grow roots fast enough to keep up with the drop in water table elevation. Riparian shade is critical for maintenance of natural stream temperatures.

The available data pertaining to ground water conditions in the Scott River mostly consist of a few reports that characterize the aquifer and subsurface sediments in broad terms. The only readily available data that provide a glimpse of recent groundwater conditions are water table measurements at five wells in Scott Valley. Analysis of these data shows that in general drawdown is greater in dry years. The water table measurements for one of the wells are presented in Figure 4.2.

4.1.2.3 Surface Water

Surface water diversions affect stream-heating processes by reducing advection, reducing thermal mass, and increasing travel time. The diversion of water often has a similar but opposite affect of that of groundwater accretion.

4.1.2.4 Channel Geometry

The geometry of a stream channel affects stream temperature processes in a number of ways, at multiple scales. The primary changes in channel geometry that affect stream heating processes are changes in width-to-depth ratios, sinuosity, and streambed complexity (e.g. side channels, deep pools, topographic relief). All of the stream heating processes described in section 4.1.1 are affected by channel geometry to some degree.

A stream's width-to-depth ratio influences stream heating processes by determining the relative proportion of the wetted perimeter in contact with the atmosphere versus the streambed. Water in contact with the streambed exchanges heat via conduction. Conductive heat exchange has a moderating influence, reducing daily temperature fluctuations. Water in contact with the atmosphere exchanges heat via evaporation, convection, solar radiation, and long-wave radiation. Heat exchange from solar radiation far outweighs heat exchange from evaporation, convection, and long-wave radiation, unless the stream is significantly shaded. The net effect of changes in width-to-depth ratios is that streams that are wider and shallower heat and cool faster than streams that are narrower and deeper.

The sinuosity (degree of meandering) of a stream channel can influence stream heating processes in alluvial areas by affecting the amount of intra-gravel flow (hyporheic exchange). In sinuous stream channels, a portion of the water flowing in the channel will pass through the sediments and short-circuit the meanders. The water that passes through the sediments loses heat to the earth through conduction, and re-enters the stream channel cooler than before.

The complexity of the streambed can also influence stream heating processes by affecting the amount of intra-gravel flow, and can lead to the existence of pockets of cold water through stratification of deep pools and hyporheic-fed side channels. Stream channels with greater complexity have deeper pools, more prominent riffles, and back-watered side-channels. The difference in elevation between a pool and riffle determines the amount of water passing through the riffle gravels. Thus, streams with prominent pool-riffle morphology exchange more heat via conduction than flat, simplified stream channels.

4.1.2.5 Microclimate

Microclimate is a phenomenon that results from the separation of air masses. In well-vegetated riparian areas, the mass of air directly over the stream is often effectively separated from the overlying air mass by vegetation, which limits the flow and mixing of air. This separation of air masses can lead to significant differences in air temperature, relative humidity, and wind speed between the near stream air and the overlying air. Removal of riparian vegetation can lead to increased air temperatures, decreased relative humidities, and increased wind speeds.

Air temperature, relative humidity, and wind speed both affect convection and evaporation processes. During warm periods convection typically warms a stream, whereas evaporation cools a stream. The amount of heat exchange that results from convection and evaporation depends on all three microclimate factors. Increased air temperature typically increases the rate of convective and evaporative heat exchange. Decreased relative humidity increases the rate of evaporative heat exchange, but decreases the rate of convective heat exchange. Increased wind speeds increase both evaporation and convection by transporting heat and water vapor away from the stream. It is possible that changes in vegetation inside and/or outside of the riparian area can result in microclimate changes that significantly influence stream temperatures.

4.2 METHODS

4.2.1 Sources of Information

Information used in the development of the temperature analysis came from a variety of sources. Much of the information used in the analysis was developed specifically for the analysis, either by Regional Water Board staff or by entities under contract.

Much of the data used in the development of the temperature model applications was collected during the summers of 2003 and 2004 by Regional Water Board staff. These data included:

- Eighty-nine flow measurements at thirty-two sites,
- Forty-three water temperature records,
- Thirty-four meteorological records,
- Bankfull geometry measurements at twenty sites,
- One hundred fifteen effective shade measurements.

Other supporting data and analysis were developed by the Information Center for the Environment (ICE) at UC Davis, under contract to the Regional Water Board. The analysis and data included a shade model developed for the Scott River watershed, and a Thermal Infrared Radiometry (TIR) survey by Watershed Sciences, LLC, funded through the same contract.

Regional Water Board staff coordinated temperature monitoring activities with the Siskiyou RCD and the USFS. These agencies collected and provided temperature data at thirty sites in the summer of 2003, in addition to a large amount of temperature data from previous years.

Other primary data used in the temperature analysis included habitat typing data provided by the Siskiyou RCD and US Fish and Wildlife Service, flow data obtained from the USGS and

California Department of Water Resources (CDWR), and meteorology data obtained from CDWR.

4.2.2 Approach and Model Selection

The approach used to evaluate and quantify the impacts of human activities in the Scott River and its tributaries relies on the use of computer simulation models. Stream heating processes are inherently complex and non-linear. The degree to which one factor can impact stream temperature is dependent on the state of the other factors involved, and vice versa, thus it is difficult or nearly impossible to quantify the impacts of a single factor without tools that can take into account all the factors at once and evaluate the non-linear relationships involved.

Many computer simulation models have been developed to approximate solutions to the non-linear differential equations that govern stream-heating processes. However, not all stream temperature models are suited for evaluating the particular factors that human activities affect in the Scott River watershed.

To evaluate the five factors identified, Regional Water Board staff selected the Heat Source temperature model. Heat Source is a computer model designed to simulate dynamic mass and heat transfer in streams and rivers. The model is designed to make use of high-resolution spatial data, as well as field measurements. Heat Source calculates a thermal budget at every calculation node along the stream length, and for each time step. The distance between calculation nodes and length of time steps are user-defined. In this analysis, the distance between calculation intervals was 100 meters (328 feet) in all simulations, and the length of time steps varied between one and five minutes. The Heat Source model reports results for every hour of the simulated period. For further information regarding Heat Source, refer to "Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0" (Boyd and Kasper, 2003). The Heat Source documentation is available at http://www.deq.state.or.us/wq/TMDLs/WQAnalTools.htmHeat Source.

The Heat Source model was chosen because it was designed to evaluate the five identified factors (and others) for the purpose of evaluating the effects of human activities. Also, the Heat Source model represents the state of the art in temperature models, has been peer-reviewed, and uses the same approach used to develop temperature TMDLs throughout the Pacific Northwest. Additionally, the Heat Source model has a well described methodology, was designed to make use of high-resolution data, and makes use of a commonly available software platform (Microsoft Excel) that makes it more broadly accessible and user-friendly for other potential users. Other temperature models, such as SNTEMP, Qual2E, and the TVA model, were considered but rejected because none of them simulate the complexity of stream heating processes as well as Heat Source. Also the other models considered have a cumbersome user interface in comparison to Heat Source.

Heat Source requires compilation of a great amount of spatial data. The Oregon Department of Environmental Quality developed the TTools to automate sampling and derivation of spatial data for use in the Heat Source temperature model. Regional Water Board staff also made use of the TTools ArcView extension to organize land cover data and measure channel widths, elevations, and spatial coordinates. TTools also calculates channel gradient, stream aspect, and the angle to the topographic and vegetation horizons. TTools and its calculation methods are described in detail in the Heat Source documentation (Boyd and Kasper, 2003). The parameters required by Heat Source are presented in Table 4.1.

Finally, the RipTopo model (described in Appendix A) was used to evaluate current and potential shade conditions in areas of the Scott River watershed where the Heat Source model was not applied. The RipTopo model uses the same general approach to estimating stream shade as the Shade-a-lator shade model, which is included with the Heat Source model package.

4.2.3 Collection and Use of Stream Temperature and Meteorology Data

Stream temperature and meteorology data were used to develop and calibrate computer simulation models of the selected river stream segments. Stream temperature and meteorology data from multiple sources were used in the source analysis. Regional Water Board staff and contractors, US Forest Service staff, and Siskiyou Resource Conservation District staff collected stream temperature data used in the analysis. Regional Water Board staff collected meteorology data at many locations. Data from the Callahan and Quartz Hill weather stations were also used.

Stream temperature data were specifically used to define boundary conditions and evaluate the accuracy of the models. Data describing air temperature, relative humidity, and wind speed also were used to define local weather conditions required as input to the model. Meteorology from the nearest or most appropriate source was used when site-specific data was unavailable (see Table 4.2).

4.2.4 Collection and Use of Infrared Imagery

The Regional Water Board funded a thermal infrared remote radiometry (TIR) survey of the Scott River and select tributaries (Watershed Sciences, 2004) in support of this study. On July 25 & 26, 2003, Watershed Sciences, LLC conducted aerial TIR surveys of the Scott River, East Fork Scott River, South Fork Scott River, Shackleford Creek, and the lower reaches of Kidder Creek. The imagery was collected using side-by-side video and infrared cameras. The survey yielded temperature measurements of approximately half-meter resolution, in images that captured an area approximately 140 m – 193 m (459ft - 635ft) on the ground, depending on flight altitude. The accuracy of TIR data was better than +/- 0.5°C (0.9°F), based on temperatures measured at the time of the flight. Watershed Sciences subsequently processed the thermal information into longitudinal profiles, a GIS database, and other data products. A complete description of Watershed Sciences' methods, measurement accuracy, and findings are available in their 2004 report (Appendix B).

The survey yielded a tremendous amount of information related to the temperature dynamics of the areas surveyed, as well as high-resolution color imagery. Regional Water Board staff used the thermal data to identify areas of groundwater accretion (the influx of groundwater to a stream), identify springs and seeps, identify stream diversions, calculate tributary flows, and validate the temperature models.

Areas of groundwater accretion are identified in the longitudinal temperature profiles as areas showing cooling or reduced rates of warming. Some examples of this are the pronounced cooling at the downstream end of Scott Valley, and the dip in temperature downstream of Young's dam. Springs and seeps are identifiable in the infrared imagery by their thermal contrast and, in some cases, cold water plumes. For model input, unmeasured tributary flows were often calculated using the mass balance equations shown below.

$$Q_{\text{upstream}} \times T_{\text{upstream}} + Q_{\text{tributary}} \times T_{\text{tributary}} = Q_{\text{downstream}} \times T_{\text{downstream}}$$
$$Q_{\text{upstream}} + Q_{\text{tributary}} = Q_{\text{downstream}}$$

(Q denotes flow and T denotes temperature.)

Given that the downstream flow is equal to the sum of the tributary and upstream flows, and the three temperatures are known from the infrared imagery, only one flow is required to solve for the remaining two values.

4.2.5 Rectification and Use of Color Imagery

Regional Water Board staff used the color imagery collected by Watershed Sciences, LLC to develop a spatial database of stream and riparian attributes. The color images captured during the TIR survey were merged into mosaics, which were then georeferenced, and rectified (aligned with digital maps) using digital orthophoto quads for reference. These rectified images were used to digitize the stream center, wetted widths, and riparian land cover extending 300 feet from the stream. The digitized stream and riparian features were then used to develop information for use in the Heat Source model using the TTools ArcView extension. Examples of rectified imagery are presented in Figures 4.3A –4.3D.

4.2.6 Mapping and Classification of Land Cover

Mapping included digitization of the stream center, stream banks, and land cover up to 300 feet on both sides of the stream. The land cover was digitized to capture visually like land cover types. Land cover types include: seventeen types of native vegetation, pasture, roads, structures, open water, and gravel bars. Vegetation characterizations included type (conifers, deciduous, and mixed), height, and density. Each land cover type was assigned a numeric code describing the species, density, and height of vegetation. Water board staff relied on low-level oblique aerial photos, and species and height measurements collected by staff during field surveys, during the assignment of the numeric codes. Vegetation densities where estimated from the aerial images. Examples of classified land cover are presented in Figures 4.3A –4.3D.

4.2.7 Collection and Use of Flow Data

Regional Water Board staff made 89 flow measurements at 32 sites as part of the data collection for this project. The majority of flow measurements were made using standard velocity-area methods using a tape and velocimeter, however in some cases flows were measured at culverts using a bucket and stopwatch or calculated from the geometry of the culvert and hydraulic principles. Regional Water Board staff also relied on stream gage data provided by USGS and CDWR. The flow data were used to estimate boundary condition flows and estimate rates of ground water accretion using standard mass balance techniques. Measured and estimated flows are presented in Table 4.3

4.2.8 Estimation of Stream Diversions

The Heat Source temperature model accounts for thermal effects of flow diversions. The amount of water diverted at Young’s dam was estimated based on information provided by the Scott Valley Irrigation District. Stream diversions were estimated based on the adjudicated water rights associated with a given diversion. Diversions in the East Fork Scott River were estimated based on comparison of upstream and downstream conditions and professional judgment.

4.2.9 Measurement and Estimation of Channel Geometry and Morphology

Regional Water Board staff measured bankfull channel dimensions at twenty locations. These data were collected using a laser rangefinder and digital clinometer. The bankfull cross-sectional areas and widths were plotted against the drainage area for each site to develop relationships of bankfull cross-sectional area to drainage area (Figure 4.4), and bankfull width to drainage area (Figure 4.5). Bankfull channel measurements were used to estimate the channel widths as part of the RipTopo shade modeling (described in Appendix A), and to estimate the potential channel width of the modeled streams.

Modeled stream widths were developed in two ways. Wetted widths corresponding to current conditions were digitized and measured using the rectified color imagery and mapped channel dimensions. Widths were sampled at 100 meter intervals, based on the digitized wetted channel margins, using the TTools ArcView extension. Potential widths were developed as described in section 4.2.10, below.

Dominant particle sizes were estimated from staff observations and limited channel typing information. The information describing dominant particle sizes is used in the Heat Source computational scheme to calculate streambed heat conduction and hyporheic exchange.

4.2.10 Development of Potential Condition Scenarios

Regional Water Board staff have developed depictions of potential shade, flow, and channel geometry for use in evaluating potential stream temperature conditions.

4.2.10.1 Shade

Potential shade estimates were developed through the use of two models. The first model, RipTopo (discussed in Kennedy et al., 2005; attached), was used to estimate current and potential shade conditions in streams throughout the watershed. The second model, Heat Source, was used to evaluate potential shade conditions in the mainstem Scott River, South Fork Scott River, East Fork Scott River, and Cabin Meadows/Houston Creek modeling scenarios. RipTopo evaluates potential shade conditions by calculating a shade value based on mature tree heights of the tree species present, and estimates of channel width based on drainage area. Potential shade conditions in the mainstem Scott River, South Fork Scott River, and East Fork Scott River are based on both the mature height of the tree species historically present, as well as the potential width of the channel. Potential shade estimates developed for the Cabin Meadows/Houston Creek scenarios are based on the assumption that current and potential channel widths are the same.

Regional Water Board staff reviewed aerial photos of relatively undisturbed areas taken in 1944 to evaluate whether predicted potential shade conditions are reasonable. The 1944 aerial photos generally show dense vegetation growing along streams. In many cases the vegetation obscures the streams, providing high levels of shade. Based on these and similar observations of mature vegetation encountered during field surveys, Regional Water Board staff feel that the 1944 aerial photos provide validation of the potential shade conditions predicted by the shade models. It is worth noting that many of the upland areas appear more open than current forest conditions, however.

4.2.10.2 Flow

Potential flow conditions were estimated based on full natural flow, with no diversions. Because of the uncertainty regarding potential groundwater accretion rates, Regional Water Board staff evaluated groundwater accretion at a range of values to understand the magnitude of the effects of groundwater on stream temperatures.

4.2.10.3 Width

Potential channel widths were developed using the bankfull relationships described in Section 4.2.9 and a typical width-to-depth ratio for a C-type stream (24) (Rosgen, 1996). Regional Water Board staff assumed:

- The top width of the potential low flow channel of the Scott River would be half the bankfull width, based on a comparison of the wetted widths measured from imagery captured on July 25th and 26th, 2003, to the bankfull widths predicted by the relationship of bankfull width to drainage area (Figure 4.5).
- The potential channel dimensions of the Scott River upstream of the Scott River canyon correspond to a "C" type channel. The Scott River is currently an "F" type channel in this reach (Quigley, 2003).
- The wetted channel widths of July 25th and 26th, 2003, are representative of the top widths of the low-flow channel.
- The low-flow channel width-to-depth ratios are similar to the bankfull width-to-depth ratios.

4.2.10.4 Sinuosity

A hypothetical depiction of the Scott River was developed to represent the river as it was prior to the straightening that occurred in 1938 (SRWC, 2004). The hypothetical stream channel was developed from Fay Lane to Fort Jones. The purpose of the exercise was to evaluate the effects of channel straightening on stream temperatures. Regional Water Board staff used orthophotos to identify remnants of the channel that existed prior to the straightening. In some areas the former channel was easily identified, but in other areas the former channel was not apparent or many former channels were evident. Consequently, much of the channel was developed based on the judgment of Regional Water Board staff. Although the resulting channel alignment and sinuosity does not precisely depict the historic stream channel, the analysis has value because it defines the magnitude of temperature change that could be expected from a more sinuous channel. The increased sinuosity of the hypothetical channel resulted in an increase in channel length from 31.7 kilometers to 34.4 kilometers.

4.2.10.5 Combined Factors

Regional Water Board staff evaluated the combined effects of individual factors affected by human activities on Scott River temperatures. The magnitudes of stream temperature change related to the individual factors affected by human activities (shade, groundwater accretion, surface diversions, channel geometry) were initially analyzed separately to distinguish the importance of each of the factors. However, it is important to understand how the interactions of the individual factors affect stream temperatures. Regional Water Board staff developed three scenarios to evaluate the interaction of individual factors, and to evaluate the expected benefits of the combination of potential restoration measures under various conditions.

The first scenario is meant to define the temperature regime of the Scott River when all potential conditions are met. The scenario assumes a riparian forest of cottonwood, potential channel widths, potential sinuosity, and no diversions. Rates of groundwater accretion were left as estimated for the July 28 – August 1, 2003 time period due to the uncertainty of potential accretion rates.

The second scenario is meant to define the temperature regime of the Scott River when potential vegetation conditions are achieved and rates of groundwater accretion are increased. The scenario assumes a riparian forest of cottonwood with groundwater accretion rates set as 150% of the rates estimated for the July28 – August 1, 2003 time period. Channel widths, sinuosity, and diversions were left as currently depicted.

The third scenario is meant to define the temperature regime of the Scott River in a dry year when potential vegetation conditions are achieved but groundwater accretion is reduced to 25% of the rates estimated for the July28 – August 1, 2003 time period. The purpose of this scenario is to evaluate whether the water quality standard for temperature could be met solely by the achievement of potential vegetation conditions in dry years.

4.3 MODEL APPLICATIONS

Stream temperature models were developed for the mainstem Scott River, the South Fork Scott River, the East Fork Scott River, and Houston and Cabin Meadows creeks. The details pertaining to the development of individual model applications are presented below.

4.3.1 Scott River Mainstem

The Heat Source temperature model was used to simulate the stream temperatures of the Scott River from Fay Lane (RM 50.2) to the mouth of the river, as shown in Figure 4.6. The tailings reach of the river was mapped but was not included in this model application. The tailings reach was not included because the river goes dry for a large stretch of the tailings reach as river water infiltrates into the subsurface, and the infiltrated river water re-emerges in multiple locations that have not been characterized.

4.3.1.1 Boundary Conditions

The boundary condition locations of the Scott River temperature model are listed in Table 4.2 and shown in Figure 4.6. The upstream boundary is at Fay Lane (RM 50.2). The flow at Fay Lane were estimated based on one or more flow measurements at Fay Lane during each simulation period, with daily flow values adjusted based on the relationship between the flows measured at Fay Lane and the summation of the East and South Fork gage flows. Hourly temperature data collected at the site were used to define temperatures at the upstream boundary.

Boundary conditions were defined for twelve tributaries, as shown in Table 4.2 and shown in Figure 4.6. Flows were estimated based on measurements, comparisons with other nearby streams, and TIR data. Seven of the twelve tributaries had temperature data for the modeled time periods Table 4.2. The temperature of Boulder Creek was estimated to be 1.5 ^{o}C less than the temperature of Canyon Creek, based on comparison of summer temperature data collected in the two creeks from 1995 through 1997. The other tributaries (McCarthy, Big Ferry, Mill, and Franklin Creeks) were characterized using the unaltered temperature records of nearby streams. Given the small magnitude of the tributary flows relative to the mainstem, the model results are insensitive to the temperatures of these tributaries.

4.3.1.2 Channel Geometry and Substrate Representation

The channel geometry and substrate of the Scott River were characterized based on channel mapping, habitat typing data, cross sections, channel type, and observations made by Regional Water Board staff.

The channel widths were developed based on the mapped wetted widths of the river on July 25, 2003, the date of the FLIR survey. The wetted widths were then sampled at 100-meter intervals and recorded in a database using the TTools ArcView 3.2 extension. The decision to map wetted channel widths rather than widths of the near-stream disturbance zone, as described in the Heat Source documentation, was based on the assumption that the wetted widths would provide a better representation of the channel when modeled as a trapezoidal channel. The morphology of the Scott River is generally such that a low-flow channel exists within the larger bankfull channel during the summer months.

The width-to-depth ratios were assigned based on typical ratios for the respective Rosgen channel types (Rosgen, 1996). The river channel in Scott Valley was treated as an “F” type channel and assigned a width-to-depth ratio of 28. The river channel in the canyon area (downstream of the valley) was treated as a “B” type channel and assigned a width-to-depth ratio of 17. Regional Water Board staff assigned Rosgen channel types based on habitat typing surveys conducted by the Siskiyou RCD (2003).

The dominant particle size and embeddedness values, used in the Heat Source model to calculate bed conduction and hyporheic exchange, are based on observations made by Regional Water Board staff and limited substrate information reported in habitat typing data collected by the SRCD and USFWS in the valley and canyon reaches, respectively. The bed particle size and embeddedness values are presented in Figure 4.7.

Stream gradients were calculated for each node based on a 10-meter digital elevation model (DEM) using TTools. A full description of the methodology employed by TTools for the gradient calculation can be found in the Heat Source documentation (Boyd and Kasper, 2003). Stream gradients are presented in Figure 4.8.

The Manning’s “n” channel roughness coefficients were the parameters used to calibrate the model. These values were initially approximated based on the values reported in USGS Water Supply Paper 1849 (Barnes, 1967). The values were then adjusted so that width, depths and velocities were similar to measured and observed values, and the amplitude of the calculated diurnal change in stream temperature were similar to the measured values. The final values of Manning’s “n” are presented in Figure 4.9.

4.3.1.3 Flow Simulation

Regional Water Board staff developed estimates of tributary inputs, groundwater accretion, and surface water diversions as part of the model development. The hydrologic depiction of the Scott River was developed using a mass balance approach. The methods used to define the flows at tributaries and upstream boundary are described in the boundary conditions section, above.

The groundwater accretion estimates were developed based on measured flows at ten locations distributed throughout the modeled reaches. The change in flow rate between measured points, after subtracting tributary inputs and adding diversion withdrawals, was attributed to groundwater accretion. The measured and estimated flows are presented in Table 4.3; modeled stream flows are presented in Figure 4.10. The estimated rates of groundwater accretion are presented in Figure 4.11. Groundwater accretion was estimated and assigned to two locations, both near the mouth of Canyon Creek, based on TIR data and field observations of fisheries biologists (S. Maurer, personnel communication, 9-23-04, described by McFadin, 2006). In some cases the distribution of the groundwater accretion was estimated based on temperature trends observed in the TIR-derived longitudinal temperature profile.

Surface water diversions were estimated for the Scott Valley Irrigation District (SVID) and Farmer's Ditch diversions. The SVID has a water right that allows for 42 cfs to be diverted from the river. However, the river was flowing less than 42 cfs in both of the modeled time periods. The SVID diversion was estimated as 90% of the flow of the Scott River, based on information provided by the SVID. The Farmer's Ditch diversion is upstream of the reach modeled, but was estimated to account for changes in flow that would occur at the upstream boundary as a result of reduced diversions. The Farmer's Ditch diversion was estimated as the difference between the flow measured at Callahan and the estimated flow at Fay Lane.

The flow routing was modeled using the Muskingum-Cunge method, with a storage factor of 0.2.

4.3.1.4 Shade Simulation

Regional Water Board staff developed estimates of current and potential stream shade as part of the model development. The shade estimates were developed using the Shade-a-lator shade model, which is included with the Heat Source model package, and the TTools pre-processor. The inputs to the Shade-a-lator model are the mapped land cover and associated height and density estimates, and the 10-meter DEM. The Shade-a-lator model calculates shade from both vegetation and topography. A full description of the Shade-a-lator methodology is provided in the Heat Source documentation (Boyd and Kasper, 2003).

The estimates of current shade are based on current near-stream vegetation. The estimated current and potential effective shade values are presented in Figure 4.12. A comparison of measured and modeled shade values is presented in Table 4.4.

The potential near-stream vegetation depiction in the canyon reaches was developed based on the distribution and type of current vegetation. The potential vegetation was represented as the mature height of the current vegetation, with open areas represented as the mature condition of the vegetation surrounding them.

In the Scott Valley, historical changes in the near-stream vegetation distribution have been extreme, thus the current vegetation mapping was not useful for depicting potential vegetation. The potential near-stream vegetation depictions in the Scott Valley reaches were developed based on historical photos, vestigial trees, literature, and an assessment of potential Scott River watershed riparian conditions (Appendix A). The available historical photos, taken in the early 1900s, show a continuous riparian forest bordering the Scott River. In most of the photos the trees appear to be Black Cottonwood, although a photo of the river near Fort Jones indicates the river was bordered by a shorter species, most likely willows. Given the uncertainty, Regional Water Board staff modeled shade for a range of potential vegetation conditions. Regional Water Board staff developed a depiction of potential vegetation conditions that represents the potential riparian tree species height, density, and distribution, based on information contained in the assessment of potential Scott River watershed riparian conditions prepared by UC Davis ICE (Appendix A), and Lytle and Merritt (2004).

4.3.1.5 Meteorological Data

Meteorological conditions were characterized using air temperature data from six sites, relative humidity data from five sites, and wind speed data from three sites, as shown in Table 4.2. These data were distributed along the length of the modeled reaches, as shown in Table 4.5. Solar radiation intensity data from the Quartz Hill weather station was used to estimate cloud cover.

4.3.1.6 Model Calibration and Validation

The first application of the model was developed to represent the stream temperature conditions for the August 27 – September 10, 2003 time period. This time period was chosen because it was the time period with the most complete input and calibration data, and relatively constant flows. Although the Heat Source model represents dynamic mass and heat transfer, the groundwater accretion is represented as a constant, which necessitated a period of relatively constant flow. The model performance for the August 27 – September 10, 2003 time period is detailed in Table 4.6A. Charts of measured and modeled stream temperatures are presented in Appendix C.

The model was calibrated by adjusting values of Manning's n. Manning's n (channel roughness) is routinely determined by solving for the coefficient when all the other hydraulic variables (wetted dimensions, slope, and flow) are known. Because it is not subject to direct measurement (i.e. channel roughness can't be measured, rather the effects of channel roughness are measured), and because it affects both wetted dimensions and travel time, it is a logical calibration parameter. In this analysis, the flows and wetted widths were known and some information describing velocities and depths was available, though they were not measured comprehensively. The remaining hydraulic variables, width-to-depth ratio and Manning's n, were the only missing variables required to describe the hydrodynamics of the river. Regional Water Board staff used the estimates of width-to-depth ratios suggested in the model documentation for the given channel types, for lack of better data. The remaining variable, Manning's n, was first approximated using best professional judgment so that initial model runs could be generated, then the variable was adjusted so that the modeled hydraulic conditions approached the measured hydraulic conditions. Although better results may have been possible by also adjusting the width-to-depth ratios, Regional Water Board staff decided to limit the subjectiveness of the calibration by limiting the calibration to only one parameter.

Once the calibration of the August 27 – September 10 model was complete, a second application of the model was developed for another time period. The second time period was chosen because it coincides with the date of many of the MWATs at sites in the Scott River and it is a relatively constant flow period between two spikes in the season's hydrograph. The model performance for the July 28 – August 1, 2003 time period is detailed in Table 4.6B.

There are differences in input values between the model applications representing the two time periods that go beyond the differences in observed conditions. Adjustments to input values were necessary because of data availability and changes in conditions between modeling periods. The first of these adjustments was in the number of calibration/validation data sets available. The July 28 – August 1 time period coincides with 17 data sets, whereas the August 27 – September 10 time period coincides with 20. Sixteen of the calibration/validation data sets were common to both time periods.

The second difference between the model representations of the two time periods was in the number of tributaries represented. The July 28 – August 1 time period simulates 12 tributaries, whereas the August 27 – September 10 time period simulates 10. The two tributaries, Big Ferry and Franklin Gulch creeks, were not included in the later time period because they had fallen below 1 cfs, an amount considered negligible when the river is flowing at 60 cfs.

The comparison of measured and simulated temperatures indicates that, on average, the model under-predicts temperatures from approximately Fay Lane to Fort Jones, over-predicts temperatures from Fort Jones to the USGS gage, and under-predicts again in the canyon. Upstream of Fort Jones the model results are out of phase with the measured temperatures by about two hours, with the simulated temperatures lagging the measured temperatures. The model results are in phase with the measured temperatures in the area near and below Fort Jones. The model is generally in phase with measured temperatures in the reach between Meamber Bridge and Jones Beach, but the model consistently predicts higher temperatures. Below Canyon Creek, the model results are generally in phase with measured temperatures, but the range of diurnal variation is higher in the simulated temperatures.

The model is out of phase with measured temperatures most likely because of differences between actual and simulated travel times. A discrepancy in travel times could be explained by any of the following factors:

1. Groundwater accretion was assumed to be evenly distributed between sites where flows were measured, which is not likely to be the case in reality.
2. The channel roughness coefficients (Manning's n) are mostly constant in the simulation. In reality the channel roughness would be expected to vary from reach to reach.
3. The width-to-depth ratios are mostly constant in the simulation. In reality the width-to-depth ratio varies from reach to reach.

The reason for the consistent bias at Meamber Creek and the USGS gage is most likely due to uncertainty in the magnitude and extent of groundwater accretion, which is known to be significant in the lowest part of the valley. The differences in measured and simulated temperatures below Canyon Creek may be due to differences between actual and modeled width-to-depth ratios, channel roughness, and Canyon Creek flows. The temperature of the Scott River in the lower canyon reaches is sensitive to the temperature and flow rate of Canyon Creek.

Despite the errors described above, Regional Water Board staff believe the model performance is adequate for evaluating the relative roles of management-related factors. This assessment is supported by the following facts:

1. The model predicts the same trends as seen in the measured temperature data during a wide range of weather, flow, and solar conditions.
2. The mean absolute error for the validation period ranged from 0.5 to 2.4 ^{o}C (0.9 to 4.3 ^{o}F), and averaged 1.1 ^{o}C (2.0 ^{o}F). Average bias of the daily average error for the validation period ranged from –1.9 to 2.1 ^{o}C (3.4 to 3.8 ^{o}F), and averaged -0.2 ^{o}C (-0.36 ^{o}F). The measures of error are similar to results of other stream temperature modeling efforts (Deas et al., 2003; Watercourse Engineering, 2003; ODEQ, 2002).
3. The performance of the model is similar in both time periods, which indicates the model performed consistently.

4.3.1.7 Results and Discussion

Groundwater Flow Scenarios

Regional Water Board staff evaluated the effects of groundwater accretion on Scott River temperatures. The Scott River Adjudication (Superior Court for Siskiyou County, 1980) recognizes the interconnection of groundwater and surface waters. Groundwater is the source of much of the irrigation water used in Scott Valley. Given the interconnectedness of groundwater and surface water, and the prevalent use of groundwater for irrigation, evaluating the effects of groundwater accretion on stream temperatures in the Scott River is necessary for evaluating impacts of management on stream temperature. Unfortunately, the Scott Valley groundwater resource has not been well studied. It is not possible to evaluate the degree to which ground water pumping has affected the rate of groundwater accretion at this time. It is possible, however, to evaluate the degree to which the rate of groundwater accretion affects stream temperatures.

To evaluate the degree to which the rate of groundwater accretion affects Scott River temperatures, Regional Water Board staff simulated Scott River temperatures with varying rates of groundwater accretion. The groundwater accretion rates measured in August of 2003 were used as a baseline condition. Regional Water Board staff varied groundwater accretion from 0% to 200% of the baseline condition in 25% increments. The resulting longitudinal profiles of temperature modeling results quantifying effects of groundwater accretion are shown in Figure 4.13.

The results illustrated in Figure 4.13 indicate that as groundwater accretion is reduced, both the rate of heating and cooling and maximum temperatures of the Scott River increase dramatically. As groundwater accretion decreases, the temperature of the river becomes more responsive to shade and cold tributaries. These results can be explained by the fact that groundwater enters the river at a cold temperature (57-67 ^{o}F), as well as the fact that a reduced rate of groundwater accretion results in a reduction of river flow. As flow volume increases, the rate of heating and cooling decreases. Simply put, more water takes longer to heat. It is logical then that because the majority of Scott River summer flow originates from groundwater, the rate of groundwater accretion greatly affects the total volume of the river, and thus, its rate of heating and cooling.

The results indicate that the temperature of the Scott River is very sensitive to the amount of groundwater entering the river. Given that groundwater is the source of the majority of the water that flows out of Scott Valley, this is not a surprising result. For instance, on August 27, 2003, the flow at Fay Lane was approximately 11 cfs, while at the same time the flow at Jones Beach was 34 cfs. Regional Water Board staff have estimated that tributary flows accounted for 2 cfs, while the rate of surface diversion was 17 cfs. This results in approximately 38 cfs discharged from the Scott Valley aquifer on that day. Although the amount of groundwater entering the river varies over the course of the season, flow measurements indicate that groundwater contributed the majority of the Scott River's flow at the downstream end of Scott Valley throughout the post-snow melt summer season. These conclusions are supported by the Scott River flow measurements reported in the State Water Resource Control Board's Report on Water Supply and Use of Water, Scott River Stream System (SWRCB, 1974).

Vegetation Scenarios

Regional Water Board Staff evaluated the effects of solar radiation (energy from the sun) on Scott River temperatures. Studies have confirmed that solar radiation is the single most important factor affecting water temperatures in rivers and streams (see discussion, page 4-2).

The two most common factors that affect the amount of solar radiation reaching a stream are shading by topography (mountains and canyons walls) and vegetation. The stream shade analysis takes into account both factors, and uses effective shade as an inverse surrogate for solar radiation. Effective shade is a measure of the percentage of direct beam solar radiation attenuated and scattered before reaching the ground or stream surface, and takes into account the differences in solar intensity that occur throughout a day.

Given the importance of shade in determining stream temperatures, and the fact that riparian vegetation provides shade, evaluating the effects of riparian vegetation on stream temperatures in the Scott River is necessary for evaluating impacts of management on the Scott River. Regional Water Board staff simulated the effects of riparian vegetation on stream temperatures by evaluating the degree of shading and resulting stream temperatures for a range of potential Scott Valley vegetation conditions. Vegetation conditions in the canyon reach of the river were modeled as the mature height of existing vegetation, except in the no vegetation scenario. The simulated potential riparian vegetation depictions are: no vegetation, willows, cottonwoods, ponderosa pines, and a depiction of potential vegetation conditions that represents the potential riparian tree species height, density, and distribution, based on information contained in the assessment of potential Scott River watershed riparian conditions prepared by UC Davis ICE. The average land cover heights depicted in the potential vegetation scenario for the Scott River mainstem are presented in Figures 4.14A and 4.14B for the left and right banks, respectively.

Figure 4.15 presents the longitudinal profiles of temperature modeling results, which quantify the effects of riparian vegetation on Scott River temperatures. The results indicate that riparian vegetation has great potential for reducing the temperature of the Scott River. All vegetation simulations indicate reductions in stream temperature, with the greatest reductions associated with the tallest vegetation. Table 4.7 presents current and potential 5-day average temperatures at monitored sites along the Scott River. The data indicate that some reaches of the Scott River mainstem would meet the non-core juvenile rearing temperature criteria presented in Table 2.8, given potential vegetation conditions. Although the criteria in Table 2.8 are based on 7-day averages, the values reported in Table 4.7 are comparable to these criteria since the five days modeled (July 28 –August 1, 2003) were the five days of 2003 in which water temperatures were the highest. In addition, these data and the stream temperature differences resulting from current and potential vegetation presented in Figure 4.16 clearly show that current stream conditions are not in compliance with the prohibition against temperature increases greater than 5 ^{o}F, stated in the Water Quality Objective for Temperature.

Surface Water Scenarios

Regional Water Board Staff evaluated the effects of surface water diversions on temperatures in the Scott River watershed. Simulations depicting stream temperatures that result from a range of stream diversion magnitudes were developed for the modeled reaches. The resulting longitudinal profiles of temperature modeling results, which quantify effects of changes in surface water diversions, are presented in Figure 4.17.

The results of the surface diversion analysis indicate that reduction of surface diversions from the Scott River would result in modest temperature decreases, relative to the groundwater and vegetation scenarios. However, it is important to consider the effects of surface water diversions when evaluating the cumulative impacts of human activities on stream temperatures.

Channel Geometry Scenarios

Regional Water Board Staff evaluated the effects that changes in stream channel width and sinuosity have on temperatures of the Scott River. Simulations depicting stream temperatures resulting from a range of channel widths were developed for the modeled reaches.

Figure 4.18 presents longitudinal profiles of temperature modeling results quantifying effects of changes in stream geometry. These results indicate that a reduction in channel widths alone would result in moderate reductions in the temperature of the Scott River. The analysis of the effects of channel straightening on temperatures of the Scott River indicates that the reductions in stream temperature associated with a more sinuous stream channel would not be significant. However, it is important to consider the effects of changes in channel geometry when evaluating the cumulative impacts of human activities on stream temperatures.

Combined Scenarios

Regional Water Board staff evaluated the combined effects of individual impacts of various factors affected by human activities on Scott River temperatures. The longitudinal profiles of temperature modeling results quantifying effects of combined scenarios are presented in Figure 4.19. The results of the combined impacts analysis indicate that much of the Scott River could provide summer habitat for juvenile salmonids in at least some years, and some reaches of the Scott River could provide summer habitat for juvenile salmonids even in drier years, if mature riparian vegetation were present. Additionally, the results clearly demonstrate that water quality standards are not being met.

The analysis clearly shows that mature riparian vegetation in and of itself does not prevent stream heating such that the water quality standard for temperature is met. Without improvements in other factors, such as water use and channel geometry, the beneficial uses of the Scott River will continue to be adversely affected by human activities, and thus the Scott River will not meet the water quality standard for temperature.

Discussion

Of the factors affected by human activities, two of the factors stand out as the most important:

- Shading by riparian vegetation, and
- Groundwater accretion.

These two factors affect stream temperatures differently.

Shade limits the amount of solar radiation reaching the water, and thus provides a direct control on the amount of thermal energy the water receives. The reduction in solar radiation results in a lower equilibrium temperature during the hottest parts of the day (which is why a container placed in direct sunlight will be a higher temperature then an identical container placed in shade).

Ground water accretion affects temperatures in a number of ways. Most importantly, groundwater accretion provides a stream with a cold source of water that dilutes the thermal energy in the stream. This dilution increases a stream's capacity to assimilate heat. Additionally, groundwater accretion increases the volume of water, which increases the thermal mass and velocity of the water. Thermal mass refers to the ability of a body to resist changes in temperature. Basically, more water heats or cools slower than less water. Increases in velocity reduce the time required to travel a given distance, and thus reduces the time heating and cooling processes can act on the water. These principles are true for any stream, however because the Scott River gains so much of its volume from groundwater accretion in most years (see discussion in section 4.3.1.7), the processes that groundwater accretion influences are particularly effective at limiting stream temperatures.

Although shade and groundwater accretion are the two factors that appear to be the most significant, the other factors (surface water diversions and channel geometry) are not trivial and should be considered when evaluating the cumulative impacts of human activities. Diversions of surface water affect stream-heating processes in much the same way that groundwater accretion does. Diversion of surface water reduces the velocities and thermal mass of a river, which ultimately causes it to heat faster.

Changes in channel geometry affect stream temperatures in multiple ways. Increases in channel widths result in a shallower stream for a given flow condition, which results in more of the water being accessible to solar radiation. Conversely, narrower channels have less of their surface exposed to solar radiation.

4.3.2 South Fork Scott River

4.3.2.1 Boundary Conditions

The boundary condition locations of the South Fork Scott River temperature model are listed in Table 4.2 and shown in Figure 4.6. The upstream boundary is just upstream of the road 40N21Y bridge (RM 5.1). The upstream boundary flows were based on the South Fork at Callahan preliminary gage record and a relationship between the gage record and measured flows (Figure 4.20 presents the relationship of flow at the South Fork Scott River gage to measured flows at the upper model boundary). Hourly temperature data collected at the site were used to define temperatures at the upstream boundary.

Boundary conditions were defined for two tributaries, as shown in Table 4.2 and shown in Figure 4.6. Tributary flows were estimated based on FLIR data (calibration period) and preliminary South Fork gage flow data (validation period). Daily flow values were adjusted based on the change in the South Fork gage record. Temperature data was not available for either of the tributaries. The tributaries were characterized using the temperature data from the upstream boundary.

4.3.2.2 Channel Geometry and Substrate Representation

The channel geometry and substrate of the South Fork Scott River was characterized based on channel type, channel mapping, and observations made by Regional Water Board staff.

The channel widths were developed based on the mapped wetted widths of the river on July 26, 2003, the date of the FLIR survey. The wetted widths were then sampled at 100-meter intervals and recorded in a database using the TTOOLs ArcView 3.2 extension. The decision to map wetted channel widths rather than widths of the near-stream disturbance zone, as described in the Heat Source documentation, was based on the assumption that the wetted widths would provide a better representation of the channel when modeled as a trapezoidal channel. The morphology of the South Fork Scott River is generally such that a low-flow channel exists within the larger bankfull channel during the summer months.

The width-to-depth ratio of the South Fork Scott River stream channel was assigned a value of 24, based on the Rosgen channel type (Rosgen, 1996; Boyd and Kasper, 2003). The entire South Fork Scott river channel was treated as a “C” type channel.

The substrate and embeddedness values assigned to the South Fork Scott River were assigned using best professional judgment. The substrate size was assigned a single value of 96 millimeters for the entire reach, based on observations made by Regional Water Board staff. The embeddedness was assigned a value of zero. Regional Water Board staff have found that the model results are not sensitive to either of these parameters.

Stream gradients were calculated for each node based on a 10-meter digital elevation model (DEM) using TTOOLs. A full description of the methodology employed by TTOOLs for the gradient calculation can be found in the Heat Source documentation (Boyd and Kasper, 2003). Stream gradients are presented in Figure 4.21.

The Manning's "n" channel roughness coefficients was assigned a single value of 0.04 for the entire reach. These values were based on the values reported in USGS Water Supply Paper 1849 (Barnes, 1967). Unlike the mainstem Scott River model application, the South Fork Scott River model required no adjustment of the channel roughness coefficient for calibration.

4.3.2.3 Flow Simulation

Regional Water Board staff developed estimates of tributary inputs and surface water diversions as part of the model development. The hydrologic depiction of the South Fork Scott River was developed using a mass balance approach. The methods used to define the flows at tributaries and upstream boundary is described in the boundary conditions section, above. Groundwater accretion into the South Fork Scott River was assumed to be negligible, based on the confined channel morphology. Two surface water diversions were estimated based on the water rights information. The flow routing was modeled using the Muskingum-Cunge method, with a storage factor of 0.2 (Boyd and Kasper, 2003).

4.3.2.4 Shade Simulation

Regional Water Board staff developed estimates of current and potential stream shade as part of the South Fork Scott River model development. The shade estimates were developed using the Shade-a-lator shade model, which is included with the Heat Source model package, and the TTOOLs pre-processor. The inputs to the Shade-a-lator model are the mapped land cover and associated height and density estimates, and the 10-meter DEM. The Shade-a-lator model calculates shade from both vegetation and topography. A full description of the Shade-a-lator methodology is provided in the Heat Source documentation (Boyd and Kasper, 2003).

Potential shade estimates were developed based on depictions of potential near-stream vegetation. The estimates of current shade are based on current near-stream vegetation. The estimated current and potential effective shade values are presented in Figure 4.22.

The potential near-stream vegetation depiction in the South Fork Scott River was developed based on the distribution and type of current vegetation. The potential vegetation was represented as the mature height of the current vegetation, with open areas represented as the mature condition of the vegetation surrounding them.

4.3.2.5 Meteorological Data

Meteorological conditions were characterized using air temperature data and relative humidity data from two sites, as shown in Table 4.2. Data from the Callahan weather station was used to characterize wind speed. Solar radiation intensity data from the Quartz Hill weather station was used to estimate cloud cover.

4.3.2.6 Model Calibration and Validation

The first application of the model was developed to represent the stream temperature conditions for the July 26 – July 31, 2003 time period. This time period was chosen because it was the time period with the most complete input data, and because it was the time period when the water was the warmest. The model performance for the July 26 – July 31, 2003 time period is detailed in Table 4.8.

Once the calibration of the July 26– July 31, 2003 model was complete, a second application of the model was developed for the August 28 – September 10, 2003 time period. The second time period was chosen because it is late enough in the season that flows and shade were substantially different from the first time period. Unfortunately, there was no tributary flow data corresponding to the second time period. The tributary flows were estimated based on the change in flow between the time periods at the South Fork Scott River gage. The estimated flows are less reliable than those estimated from FLIR data in the first time period. The mean absolute error for the validation period ranged was 1.0 ^{o}C (1.8 ^{o}F). Average bias of the daily average error for the validation period was –1.0 ^{o}C (-1.8 ^{o}F). The model performance for both time periods is presented in Table 4.8 and Appendix C. The measures of error are similar to results of other stream temperature modeling efforts conducted in the basin (Deas et al., 2003; PacifiCorp, 2003; ODEQ, 2002), including those that have been developed as part of adopted TMDLs.

4.3.2.7 Results and Discussion

Vegetation Scenarios

The results of the riparian vegetation analysis, presented in Figure 4.23, show that small (<0.5 ^{o}C) differences in temperature would result from the achievement of potential riparian vegetation conditions in the modeled reach of the South Fork Scott River. These results suggest that riparian vegetation in the modeled reach of the South Fork Scott River is already near the

potential condition, as modeled. Other factors that may explain the similarities are the moderating influence of Boulder Creek and a relatively short travel time.
Surface Water Scenarios

The results of the surface diversion analysis, presented in Figure 4.23, indicate that diversions from the South Fork Scott River result in minimal temperature increases. The minor difference in model temperatures reflect the fact that the amount of water diverted from the South Fork is small relative to the total flow.

Discussion

The results of the analysis indicate that the modeled reach of the South Fork Scott River is near potential conditions, and the impact of surface diversions on stream temperatures is minor when conditions are as they were in the summer of 2003. It is possible that surface diversions could have more of an effect on stream temperatures in dry years when flows are lower. The impact of surface diversions on stream temperatures would increase as flows in the South Fork Scott River decreased.

4.3.3 East Fork Scott River

4.3.3.1 Boundary Conditions

The boundary condition locations of the East Fork Scott River temperature model are listed in Table 4.2 and shown in Figure 4.6. The upstream boundary is just downstream of Houston Creek (RM 14.0). The flow values were based on the East Fork at Callahan preliminary gage record and a relationship between the gage record and measured flows at the upstream model boundary (Figure 4.24). Hourly temperature data collected at the site were used to define temperatures at the upstream boundary.

Boundary conditions were defined for five tributaries, as shown in Table 4.2 and Figure 4.6. Flows were estimated based on FLIR data and preliminary East Fork gage flow data. Daily flow values were adjusted based on the change in the East Fork gage record. Temperature data was not available for any of the tributaries. The tributaries were characterized using the temperature data from a site on Rail Creek. The Rail Creek data was adjusted based on the difference between the FLIR measurement of the tributary and the Rail Creek record. Regional Water Board staff assumed that the difference between the FLIR-derived tributary measurements and the temperature of Rail Creek at the time of the measurement (4:00 pm) represented a reasonable approximation of the daily maximum temperatures difference at the sites. The differences ranged from 1.4 to 4.0 ^{o}C. Synthetic temperature records were then constructed for the five tributaries such that the absolute difference in maximum and minimum stream temperatures was equal to the difference between the FLIR-derived temperature and the temperature of Rail Creek.

4.3.3.2 Channel Geometry and Substrate Representation

The channel geometry and substrate of the East Fork Scott River was characterized based on channel type, channel mapping, and observations made by Regional Water Board staff.

The channel widths were developed based on the mapped wetted widths of the river on July 25, 2003, the date of the FLIR survey. The wetted widths were then sampled at 100-meter intervals and recorded in a database using the TTOOLs ArcView 3.2 extension. The decision to map wetted channel widths rather than widths of the near-stream disturbance zone, as described in the Heat Source documentation, was based on the assumption that the wetted widths would provide a better representation of the channel when modeled as a trapezoidal channel. The morphology of the East Fork Scott River is generally such that a low-flow channel exists within the larger bankfull channel during the summer months.

The width-to-depth ratio of the East Fork Scott River stream channel was assigned a value of 40, based on the professional judgment and observations of Regional Water Board staff, who noted that the East Fork Scott River was very wide and shallow in comparison to other streams.

The substrate and embeddedness values assigned to the East Fork Scott River were assigned using best professional judgment. The substrate size was assigned a single value of 64 millimeters for the entire reach, based on observations made by Regional Water Board staff. The embeddedness was assigned a value of 0. Regional Water Board staff have found that the model results are not sensitive to either of these parameters.

Stream gradients were calculated for each node based on a 10-meter digital elevation model (DEM) using TTOOLs. A full description of the methodology employed by TTOOLs for the gradient calculation can be found in the Heat Source documentation (Boyd and Kasper, 2003). Stream gradients are presented in Figure 4.25.

The Manning’s “n” channel roughness coefficients were assigned a single value of 0.06 for the entire reach. These values were based on the values reported in USGS Water Supply Paper 1849 (Barnes, 1967). Unlike the mainstem Scott River model application, the East Fork Scott River model required no adjustment of the channel roughness coefficient for calibration.

4.3.3.3 Flow Simulation

Regional Water Board staff developed estimates of tributary inputs and surface water diversions as part of the model development. The hydrologic depiction of the East Fork Scott River was

developed using a mass balance approach. The methods used to define the flows at tributaries and upstream boundary are described in the boundary conditions section, above.
Stream flows in the East Fork Scott River are complex. Thermal infrared imagery of the East Fork shows at least thirteen springs scattered along the length of the East Fork of the Scott River, eight of which were represented in the model application (the five remaining springs were identifiable, but deemed negligible). The spring flow rates were estimated using the FLIR data and mass balance techniques described in Section 2.3. The estimated flows ranged from 0.2 – 1.1 cfs. The temperatures of the springs were assigned the accretion temperature calculated by the model. The modeled stream flows of the East Fork Scott River are presented in Figure 4.26.

The East Fork Scott River hydrology reflects the intense irrigation practiced in the basin, in addition to the natural hydrologic complexity. Ten irrigation diversions were accounted for in the model application. Additionally, a number of sites were identified where tailwater (irrigation runoff) was re-entering the river. Water rights information was not helpful for defining diversion amounts because the water rights exceeded the estimated flow of the river. Instead, Regional Water Board staff estimated the rate of diversion by comparing the wetted dimensions of the channel upstream and downstream of the diversion, by estimating the efficiency of gravel dams, and by best professional judgment. Tailwater return flows were not accounted for in the model due to lack of data.

Groundwater accretion was used as a calibration parameter in this analysis. Accretion values were adjusted to ensure the simulated stream did not become dewatered, and to match the trends seen in the infrared data. The modeled groundwater accretion values are shown in Figure 4.27.

The flow routing was modeled using the Muskingum-Cunge method, with a storage factor of 0.2 (Boyd and Kasper, 2003).

4.3.3.4 Shade Simulation

Regional Water Board staff developed estimates of current and potential stream shade as part of the East Fork Scott River model development. The shade estimates were developed using the Shade-a-lator shade model, which is included with the Heat Source model package, and the TTOOLs pre-processor. The inputs to the Shade-a-lator model are the mapped land cover and associated height and density estimates, and the 10-meter DEM. The Shade-a-lator model calculates shade from both vegetation and topography. A full description of the Shade-a-lator methodology is provided in the Heat Source documentation (Boyd and Kasper, 2003).

Potential shade estimates were developed based on depictions of potential near-stream vegetation. The estimates of current shade are based on current near-stream vegetation. The estimated current and potential effective shade values are presented in Figure 4.28. In areas where the natural vegetation type is intact the potential vegetation was represented as the mature height of the current vegetation, with open areas represented as the mature condition of the vegetation surrounding them. In areas that have been converted to pasture, such as the areas upstream of Masterson road, the potential vegetation was simulated as mature Black Cottonwood, based on vestigial stands in the area.

4.3.3.5 Meteorological Data

Meteorological conditions were characterized using air temperature data and relative humidity data from two sites, as shown in Table 4.2. Data from the Callahan weather station was used to characterize wind speed. Solar radiation intensity data from the Quartz Hill weather station was used to estimate cloud cover.

4.3.3.6 Model Calibration and Validation

The East Fork model application was developed to represent the stream temperature conditions for the July 25 – July 31, 2003 time period. This time period was chosen because it was the time period that coincides with the infrared data, and because it was the warmest time period. The infrared data and associated imagery were relied on extensively during the model development and calibration process, due to a lack of on-the-ground data. Because of the complex hydrology of the East Fork Scott River and the paucity of data, a model application was not developed for another time period. The model performance for the July 25– July 31, 2003 time period is detailed in Table 4.9.

The results of the model calibration indicate that the model simulates the trends seen in the infrared and instream data. The error statistics presented in Table 4.9 indicate the model underestimates temperatures at both sites, with site two being underestimated considerably more than site one. The shade estimates that the Shade-a-lator model calculated for the reach between Masterson Road and Highway 3 are relatively high. Regional Water Board were denied access to this reach of the river, and the available oblique aerial photos only cover a small portion of the reach. Given that, the vegetation classification has greater uncertainty. Given the uncertainty associated with the vegetation mapping and the estimated flows and temperatures of the lower tributaries (Mule, Grouse, and Big Mill Creeks) and their great influences on downstream temperatures, it is not surprising that the model has less accuracy at Callahan site two.

4.3.3.7 Results and Discussion

Vegetation Scenarios

The longitudinal profiles of temperature modeling results quantifying effects of vegetation are presented in Figure 4.29. The results of the vegetation analysis indicate that the East Fork Scott River has great potential for reduced temperatures. These results indicate that the restoration of potential vegetation conditions could result in a decrease of daily maximum temperatures in the range of 2-6 ^{o}C, and suggest that current stream conditions may not be in compliance with the 5 ^{o}F limit on increased stream temperatures stated in the Water Quality Objective for Temperature. If temperatures were to decrease by 2-6 ^{o}C, much of the East Fork Scott River would improve substantially, and possibly achieve temperature conditions suitable for salmonid migration. The presence of springs also suggests that there is potential for thermal refugia with temperatures suitable for rearing.

Surface Water Scenarios

The longitudinal profiles of temperature modeling results quantifying effects of stream diversions are presented in Figure 4.29. The results indicate that diversions from the East Fork Scott River result in minimal temperature increases. The minor difference in modeled temperatures may reflect that the East Fork Scott River reaches equilibrium quickly regardless of whether the flows are unimpaired.

Discussion

The East Fork Scott River analysis indicates that temperature conditions could improve substantially if riparian areas were restored to their potential conditions. Although the modeling analysis of the East Fork Scott River presents a macro-scale depiction of temperature conditions, the analysis is not able to adequately evaluate the increase in cold water refugia that would accompany the increase in riparian vegetation near the thirteen springs identified in the TIR data. It is likely that an increase in shade would increase the volume of cold water habitat currently created by the springs.

This analysis does not quantify the effects of changes in tributary temperatures on temperatures of the East Fork Scott River. However, it is clear that tributaries such as Crater, Houston, Grouse, and Big Mill Creeks significantly influence the temperature of the East Fork Scott River. Restoration of potential vegetation conditions in these tributaries may provide additional temperature reductions in the East Fork Scott River.

The East Fork Scott River analysis was developed with much less instream data than the other analyses presented. A lack of data describing the flow rates of diversions, tailwater returns, tributaries and springs has resulted in more uncertainty in the model results. However, although there is more uncertainty associated with the East Fork Scott River model applications, the results are consistent with the findings of the other modeling exercises presented in this report.

4.3.4 Houston/Cabin Meadows Creeks

Regional Water Board staff developed an application of the Heat Source model that encompasses the reach of Houston Creek from its mouth at the East Fork Scott River to Cabin Meadows Creek (1.6 miles), then up Cabin Meadows Creek to the 41N03 road crossing, 2.2 miles upstream of Houston Creek. The approach used to develop the Houston/Cabin Meadows model application differed from the approach used to develop the other model applications due to the resolution of the available imagery.

4.3.4.1 Boundary Conditions

The boundary condition locations of the Houston/Cabin Meadows model application are listed in Table 4.2 and shown in Figure 4.6. The upstream boundary is just downstream of the 41N04 road crossing. The flow values were based on measurements made by Regional Water Board staff. Hourly temperature data collected at the site were used to define temperatures at the upstream boundary.

Boundary conditions were defined for two tributaries (upper Houston and Little Houston Creeks), as shown in Table 4.2 and Figure 4.6. Flows were estimated using the mass balance equations described in Section 2.3.6, based on estimates of upstream flows and temperature data from upstream, downstream, and within the tributaries.

4.3.4.2 Channel Geometry and Substrate Representation

The channel geometry and substrate of the modeled reaches of Houston and Cabin Meadows Creeks were characterized based on channel type, and measurements and observations made by Regional Water Board staff.

The upper half kilometer (RM 4.4 - 4.7) of Cabin Meadows Creek stream channel was represented as a B-type channel, with a width-to-depth ratio of 17. From RM 4.4 to RM 2.1, the channel was represented as an A-type channel, with a width-to-depth ratio of 8. Downstream of RM 2.1 the Cabin Meadows and Houston Creek channels were represented as a B-type channel, with a width-to-depth ratio of 17. These representations of the stream channels were based on gradient and field estimates of the wetted widths and depths.

The Manning's "n" channel roughness coefficients were assigned a value of 0.04 in the B-type channel reaches from RM 4.4 to RM 4.7, 0.2 in the A-type reaches (RM 4.4 to RM 2.1), 0.06 from R 2.1 to RM 1.1 and 0.04 downstream of RM 1.1. The values were assigned based on model performance, gradient, and observations of morphological characteristics.

The wetted channel widths were developed based on the relationship of bankfull width to drainage area described in Section 4.2.9. The approximation of channel widths assumed that wetted channel widths were half the bankfull width, based of field measurements.

The substrate and embeddedness values assigned to the modeled reaches of Houston and Cabin Meadows Creeks were assigned using best professional judgment. The substrate size was assigned a single value of 64 millimeters for the all reaches, based on observations made by Regional Water Board staff. The embeddedness was assigned a value of 0. Regional Water Board staff have found that the model results are not sensitive to either of these parameters.

Stream gradients were calculated for each node based on a 10-meter digital elevation model (DEM) using TTOOLs. A full description of the methodology employed by TTOOLs for the gradient calculation can be found in the Heat Source documentation (Boyd and Kasper, 2003). Stream gradients are presented in Figure 4.30.

4.3.4.3 Flow Simulation

Regional Water Board staff developed estimates of tributary inputs using a mass balance approach. The methods used to define the flows at tributaries and upstream boundary is described in the boundary conditions section, above. Groundwater accretion was approximated for only the upper 0.5 km (0.3 mi) of stream channel, the only reach in an alluvial setting.

4.3.4.4 Shade Simulation

Regional Water Board staff developed estimates of current and potential stream shade for the modeled reaches of Houston and Cabin Meadows Creeks. The shade estimates were developed using the Shade-a-lator shade model, which is included with the Heat Source model package, and the TTOOLs pre-processor. The inputs to the Shade-a-lator model are the mapped land cover and associated height and density estimates, and the 10-meter DEM.

High-resolution imagery was unavailable for the modeled reaches of Houston and Cabin Meadows Creek. Instead, the landcover mapping of the modeled reaches was developed based on digital orthophotos. Because the mapping is based on lower-resolution imagery, the uncertainty of the mapped landcover attributes is greater than in the other model applications.

The density of coniferous trees (primarily Pine and Cedar) in the modeled reaches of Houston and Cabin Meadows Creeks is less than the tree density of coniferous reaches (primarily Douglas Fir) in the other model applications, such as the canyon area of the mainstem Scott River and South Fork Scott River. The difference in tree density is reflective of the drier conditions found in the eastern areas of the watershed. The vegetation density was reduced from 60% to 25% in the higher density coniferous areas and from 30% to 10% in the lower density coniferous areas. These values were determined by comparison of modeled shade results with measured shade values.

4.3.4.5 Meteorological Data

Meteorological conditions were characterized using air temperature data and relative humidity data from five sites, as shown in Table 4.2. Wind speed data collected at the bottom end of the modeled reach was used to characterize wind speed for the entire modeled reach. Solar radiation intensity data from the Quartz Hill weather station was used to estimate cloud cover.

4.3.4.6 Model Calibration and Validation

The Houston/Cabin Meadows model application was developed to represent the stream temperature conditions for the August 2 – August 3, 2004 time period. This time period was chosen because of data availability. These are the only two days of data available for this reach.

The model performance is summarized in Table 4.10 and Appendix C. The results demonstrate that the model accurately predicts temperatures on both an hourly and daily basis. The measures of error are similar or better than results of other stream temperature modeling efforts conducted in the basin (Deas et al., 2003; PacifiCorp, 2003; ODEQ, 2002), including those that have been developed as part of adopted TMDLs. However, the model has not been validated with data from an independent time period.

4.3.4.7 Results and Discussion

Vegetation Scenarios

Regional Water Board staff did not develop a depiction of potential vegetation conditions for the Houston / Cabin Meadows model application. Staff did not prepare such an analysis because the resolution of the available imagery is not sufficient to depict a meaningful representation of current and potential vegetation. Regional Water Board staff traversed a significant portion of the modeled reaches (~ 25-35% of the total length). While traversing these reaches, staff observed large tree stumps near the banks of the creek in many of the reaches, and other reaches that appeared undisturbed. Many of the tree stumps were in locations where standing trees would have provided significant shade. Unfortunately, due to the resolution of the imagery, the distinction between the more and less disturbed areas was difficult or impossible to discern in the 1993 orthophotos.

Surface Water Scenarios

Regional Water Board staff evaluated the effects of stream diversions in the Houston / Cabin Meadows Creek stream system. There are currently no stream diversions in Houston or Cabin Meadows Creek. However, stream diversions were evaluated because other similar streams do have diversions, which can be inferred to have similar temperature impacts as those evaluated in this exercise. Regional Water Board staff simulated the effects of stream diversions by parameterizing the flow at the upstream boundary, in 25% increments. Longitudinal profiles of temperature modeling results quantifying effects of surface water flow are presented in Figure 4.31. The results of the surface diversion analysis indicate that diversions of water from small streams can lead to significant temperature increases. . The results presented in Figure 4.31 indicate that, given a 75% reduction in flow, an increase in temperature of 3 ^{o}C (5.4 ^{o}F) would occur 4.8 kilometers downstream of the simulated diversion. An increase of 3 ^{o}C clearly violates the water quality objective for temperature. A stream with less ambient stream shade would be expected to have more extreme temperature increases. Also, without the cool flows of Houston Creek, the reduction in surface flows would result in greater temperature increases downstream.

Evaluation of Forest Practice Rules Effects on Temperatures

Regional Water Board staff developed hypothetical scenarios in order to evaluate the effectiveness of the California Forest Practice Rules' (FPRs) measures for protecting stream temperatures. The analysis evaluated the effects of changes in both shade and microclimate conditions.

Because the pattern of vegetation in the Houston Creek watershed is relatively sparse, potential vegetation conditions are likely to result in less canopy cover than the minimum canopy retention specified in the FPRs. Also, the more sparse vegetation pattern may not result in a significant microclimate. Because of these considerations, Regional Water Board staff developed hypothetical depictions of mature forest conditions that would be expected in a high-density Douglas Fir-dominated environment, which typically has near-stream microclimates. This approach is meant to evaluate the adequacy of the FPRs in a worst-case scenario. Microclimate changes and/or reductions of riparian shade from timber harvest activities are not an issue in all harvest plans.

Regional Water Board staff developed hypothetical depictions of alterations to near-stream microclimate that could occur as a result of near-stream vegetation removal. The depictions were developed based on the magnitude of microclimate changes as reported in the literature (Bartholow, 2000; Brosofske, 1997; Chen et al., 1993; Chen et al., 1999; Dong et al., 1998;

Ledwith, 1996). Because of the variability reported in the literature, a range of microclimate alterations was evaluated.

Four depictions of meteorological conditions were developed as part of the analysis of microclimate effects on temperature. The depictions were developed by multiplying the measured wind speed and relative humidity data by a constant, and increasing air temperature by adding a constant. The constants used to develop the microclimate analysis are presented in Table 4.11. The depictions and the measured meteorological data,

The Houston Creek watershed naturally has a low vegetation density, which has been further reduced by timber harvesting. The meteorological data collected at the five sites monitored in 2004 (listed in Table 4.2) do not provide a good representation of the meteorological conditions associated with forest-stream microclimates in a more dense forest setting (e.g. Douglas Fir). Accordingly, a depiction of riparian microclimate was developed using the measured meteorological data.

The four depictions are meant to provide a range of possible microclimate alteration. The approach used to parameterize changes in microclimate assumes a constant shift. In reality, increases of air temperatures and wind speeds, and decreases of relative humidity resulting from reductions of riparian vegetation are greater in the mid-day than in the morning and evening. Given the approximate nature of the simulation of microclimate alteration, the results of the microclimate analysis should be interpreted accordingly.

Regional Water Board staff evaluated the temperature effects of riparian buffer requirements for both the standard rules, as well as the "Threatened and Impaired" (T&I) rules. The T&I rules apply to watercourses in planning watersheds where threatened species are present. Watercourses in the Scott River could fall under either of the rule sets, depending on whether the watercourse is in a planning watershed upstream of a barrier to salmonid migration.

The FPR stream canopy requirements for T&I waterbodies differ for class I and class II streams. For class I streams, defined as streams with fish always or seasonally present or streams that provide water for domestic use, foresters are required to retain at least 85 percent stream canopy within 75 feet of the stream, with 65 percent retained in the next 75 feet. Additionally, 25 percent of the existing overstory must be composed of conifer species and the 10 largest diameter conifers along any 330-foot stretch of stream must be retained. For class II streams, defined as streams providing aquatic habitat for nonfish aquatic species, foresters are required to retain 50 percent of the total canopy, with retention of 25 percent of the existing overstory conifer (Ch. 14 CA Code of Regulations, Section 916, available online at: http://www.fire.ca.gov/ResourceManagement/pdf/2005FPRulebook.pdf#page2).

The standard FPR stream canopy requirements allow for riparian canopies to be reduced to 50% for class I and class II streams, with the residual overstory canopy consisting of at least 25% of existing overstory conifers. The width of the canopy is required to be 75 feet to 150 feet for class I streams, and 50 feet to 100 feet for class II streams, depending on the slope of the ground.

The results of the analysis of the T&I rules indicate that a reduction from 95% to 85% canopy would not significantly affect stream temperatures of Houston / Cabin Meadows Creek. However, the results indicate temperature increases of approximately 0.5 ^{o}C may occur when combined with microclimate effects. Diurnal temperature modeling results quantifying effects of CA Forest Practice Rules' threatened and impaired riparian buffer requirements and potential microclimate effects are presented in Figure 4.32.

The results of the analysis of the standard FPR riparian canopy requirements indicate that a reduction from 95% to 50% canopy would significantly affect stream temperatures of Houston / Cabin Meadows Creek. The modeling results indicate temperatures would increase from 0.5 ^{o}C to 1.5 ^{o}C. When microclimate effects are taken into account temperatures may increase an additional 0.5 ^{o}C. Diurnal temperature modeling results quantifying effects of CA Forest Practice Rules' standard riparian buffer requirements and potential microclimate effects are presented in Figure 4.33.

The California Forest Practice Rules allow for reduction of stream canopy, as much as 50 percent in some cases. Although stream canopy and effective shade are different measures of riparian characteristics, effective shade is dependent on stream canopy, thus large reductions of stream canopy result in large reductions in effective shade in many cases. The Basin Plan's water quality objective for temperature states that temperatures of intrastate waters shall not be altered unless it can be shown that such an alteration does not impact beneficial uses. Our analysis of factors affecting stream temperatures has determined that reductions of stream shade cause increases in stream temperature. Therefore, the California Forest Practice Rules do not ensure that water quality objectives set in the Basin Plan will be met.

4.3.5 Conclusions of Model Applications

The analysis of factors affecting the temperature of the Scott River and its tributaries indicate that human activities have resulted in significant increases in temperature in many areas of the watershed, small to modest increases in other areas of the watershed, and that removal of vegetation could cause temperature increases in the future. The primary factor affecting stream temperatures is increased solar radiation resulting from reductions of shade provided by riparian vegetation. Groundwater accretion is also a primary factor affecting stream temperatures in Scott Valley. Diversions of surface water lead to relatively small temperature impacts in the Scott River, but add to the cumulative impacts of human activities and have the potential to significantly affect temperatures in smaller tributaries, where the volume diverted is large relative to the total flow.

The analysis of the effects that alteration of near-stream microclimates have on stream temperatures, while crude, indicates that microclimate alterations have potential to increase stream temperatures. The analysis results indicate that the magnitude of such increases is moderate. However, microclimate impacts may be more significant in some situations, and add to cumulative impacts of human activities.

4.4 TEMPERATURE TMDL AND ALLOCATIONS

This section presents the temperature TMDL and load allocations. The starting point for the analysis is the equation that describes the Total Maximum Daily Load or loading capacity:

$$\text{TMDL} = \Sigma\text{WLAs} + \Sigma\text{LAs} + \text{Natural Background}$$

where Σ = the sum, WLAs = waste load allocations, and LAs = load allocations. Waste load allocations are contributions of a pollutant from point sources while load allocations are contributions from management-related non-point sources.

Figure 4.34 shows the adjusted potential shade and current shade aggregated into cumulative frequency curves for the entire set of stream reaches included in the shade analysis. These curves are analogous to curves such as grain size distribution curves that show the percent of the grain size sample that is finer than a given grain diameter. In this case, the curves show the percent of the stream length in the watershed that is shadier than a given shade value. For instance, currently 50% of the stream length in the watershed has an effective shade index greater than 3.6, whereas the 50% of the stream length in the watershed is estimated to have an adjusted potential effective shade index greater than 6.3. Figure 4.35 presents the same information in a different format. Table 4.12 presents in tabular form the same information as Figures 4.34 and 4.35. The estimated adjusted potential shade conditions expressed in Table 4.12 constitute the temperature TMDL for the Scott River watershed.

4.4.1 Development of Pollutant Load Capacity and Surrogate Measures

Under the TMDL framework, and in this document, identification of the ‘loading capacity’ is a required step. The loading capacity represents the total loading of a pollutant that a water body can assimilate and still meet water quality objectives so as to protect beneficial uses. The water quality objective of concern is the temperature objective, which states that natural receiving water temperatures must be met. The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring a water body into compliance with standards.

This temperature TMDL is focused on the heat loads that arise from changes in streamside vegetation. Other controllable factors possibly influenced by human activities have been identified (i.e, changes in stream flow, microclimates, and channel geometry), but are not included in the TMDL at this time, due to a lack of information. However, these issues are addressed in the implementation actions described in Chapter 5. Regional Water Board staff expect that channel geometry issues will be resolved through reductions in sediment loads that result from implementation of the sediment TMDL. Temperature impacts that result from changes in microclimates will be addressed in the forthcoming Wetland and Riparian Protection Policy, currently under development. The lack of information related to groundwater and surface water interaction and water use is addressed in the implementation plan. Therefore, this temperature TMDL is based on heat loads that arise from changes in streamside vegetation. The temperature TMDL may require revision as hydrologic information becomes available.

To use the loading capacity that focuses on heat loads that arise from changes streamside vegetation, and to be able to compare it to current conditions, a surrogate measure of loading capacity is proposed. It is possible to relate heat load to effective shade (that shade resulting from topography and vegetation that reduces the heat load reaching a stream) and to relate effective shade to temperature conditions. Effective shade can be readily measured in the field and also can be calculated using mathematical equations. EPA regulations (40 CFR §130.2(i)) allow for the use of other appropriate measures (surrogate measures) to allocate loads for conditions "when the impairment is tied to a pollutant for which a numeric criterion is not possible…" (USEPA, 1998c).

For this temperature TMDL, the loading capacity is expressed as effective shade on the summer solstice. Effective shade is an inverse surrogate for solar radiant energy load. The percentage of effective shade represents a percentage reduction of the possible radiant energy load reaching the streams of the watershed during critical temperature periods. Effective shade is evaluated at summer solstice because it is the date at when the sun is highest in the sky and solar radiation loading is the greatest. The annual maximum stream temperature conditions generally occur about four to five weeks after the solstice.

In this analysis, natural effective shade is estimated as potential effective shade (based on fully mature trees growing along the bankfull channel of the streams) reduced by 10 percent to account for natural disturbances such as fire, windthrow, and earth movements that would reduce the actual riparian area vegetation below the site potential. This modified condition is referred to in this document as adjusted potential effective shade, and is the desired condition that meets the water quality objective for temperature and the TMDL.

There are no point sources of temperature within the Scott River watershed, thus the WLA is zero. Therefore, the TMDL loading capacity is equal to adjusted potential effective shade conditions and the associated solar loading. The TMDL equation becomes:

TMDL = Loading Capacity = Adjusted Potential Effective Shade

The loading capacity estimate uses a GIS model developed as part of the Scott River Temperature TMDL analysis (and described in Kennedy et al., 2005; attached) to approximate shade provided by potential vegetation conditions throughout the watershed. The GIS model also was used to estimate current effective shade conditions. These results were used to calculate adjusted potential effective shade. The difference between current and adjusted potential effective shade is the amount of effective shade increase and reduced solar loading that is required to restore beneficial uses.

4.4.2 Load Allocations

In accordance with EPA regulations, the TMDL (i.e., loading capacity) for a water body is to be allocated among the various sources of the targeted pollutant, with a margin of safety. The sum of the load allocations for individual locations in the watershed is equivalent to the loading capacity for the watershed as a whole. Allocations for point sources are known as wasteload allocations. Those for non-point sources are known as load allocations. There are no known point sources of heat into the Scott River and its tributaries.

The TMDL for temperature for the Scott River and its tributaries is distributed among the non-point sources of heat in the watershed, with a margin of safety. In this case, with the non-point sources being sunlight at the various streamside locations in the watershed, and with effective shade being used as a surrogate for solar energy, the establishment of load allocations equates to the identification of the effective shade requirement for any specific streamside location.

Site-specific potential shade is set as the legally required load allocation for the Scott River Temperature TMDL. The load allocations for this TMDL are the shade provided by topography and potential vegetation conditions at a site with an allowance for natural disturbances such as floods, wind throw, disease, landslides, and fire, and is approximated as adjusted potential shade conditions as described in Section 4.4.1. The results of the shade modeling exercises provide an approximation of potential effective shade conditions at the watershed scale. The adjusted potential effective shade conditions for the East Fork Scott River, South Fork Scott River, and mainstem Scott River were calculated from Shade-a-lator model results. Adjusted potential effective shade conditions for the rest of the stream reaches were calculated from the RipTopo model results. The results should not be used to define load allocations at the site-specific level.

The extent of streams in the Scott River watershed that have the potential to support the COLD beneficial use during the critical time periods was developed based on the perennial designation in the "srfish" stream database, and best professional judgment. The adjusted potential shade estimates are presented as an index, with values ranging from 0 (no shade) to 10 (complete shade). The distribution of adjusted potential shade index values, presented in Figure 4.36, is the TMDL load allocation.

4.5 SYNTHESIS

Based on the insights gained from this analysis, Regional Water Board staff have developed the following opinions and judgments related to stream temperatures of the Scott River and its tributaries.

4.5.1 Mainstem Scott River

The mainstem Scott River has been drastically altered over the past 170 years. During that time the following changes have occurred:

- The beaver population has been dramatically reduced,
- the river has been straightened and levied,
- flows have been diverted,
- the extent and quality of riparian forests has been drastically reduced,
- a number of periods of increased sediment loads have occurred.

All of the historic changes mentioned above have affected the temperature regime. Despite these changes, the mainstem Scott River is an important cold water resource that has great potential to contribute to the recovery of salmonid species.

Efforts to actively restore cold water habitats and reduce stream temperatures should proceed in a manner that takes into account the current hydrological setting. Efforts to re-establish riparian vegetation should begin in areas of high groundwater accretion, where the water table is within reach of the trees' roots. Areas of high groundwater accretion are:

- Downstream of the dredger tailings to approximately Etna Creek.
- From the valley/canyon transition upstream to approximately one-half mile upstream of the Quartz Valley Road bridge.
- Downstream of Kidder Creek an unknown distance (the TIR data indicates groundwater accretion, but accretion was not confirmed with flow measurements).

Efforts to re-establish riparian vegetation outside these areas may be limited by the rate at which the water table elevation drops during the growing season. These areas may not recover until changes in water use and management have occurred.

Efforts to restore floodplain processes in the dredger tailing reach downstream of Callahan should also take into account the great ability for this reach to exchange heat with the alluvial substrate. Thermal infrared data clearly demonstrate the pronounced cooling that occurs in this reach via hyporheic processes. A restoration design that includes side channels and other avenues for hyporheic exchange could create significant thermal refugia. In the intervening period, significant increases in cold water habitat volume could be created by enhancement of the west side channel.

The temperature of the Scott River is affected by groundwater in two ways. First, groundwater accretion directly affects stream temperature by direct addition of cold water, changes in volume, and transit time, as described in section 4.3.1.7. Second, the elevation of groundwater affects the ability of riparian tree species to thrive and reproduce, which indirectly affects stream temperatures by increasing exposure to solar radiation.

The degree to which water use affects the elevation of groundwater is unknown. Although groundwater pumping must affect water table elevations, percolation of irrigated water and leaky conveyance ditches must also partially offset pumping effects. A better understanding of groundwater dynamics is needed for future management of Scott Valley water resources. It may be that the aquifers of Scott Valley represent an opportunity to store more water for all uses. The interaction of groundwater elevation, riparian vegetation, and stream temperatures is clearly an area deserving more study.

4.5.2 Scott River Tributaries

Riparian shade is the most important factor affecting the temperatures of tributaries to the Scott River. The current riparian conditions of Scott River tributaries vary widely, due to differences in past and current management practices. In some areas the vegetation is at or near potential conditions, while in other tributaries riparian vegetation has been nearly eliminated.

Management of riparian areas in timber production zones has greatly improved in recent decades, although room for improvement still exists. The current Forest Practice Rules are not protective of stream temperatures in many situations. In addition, the assessment of the effects of timber activities on stream temperatures during the timber harvest planning process could be improved so that a project’s potential for altering stream temperatures could be more reliably evaluated.

Efforts to actively restore cold water habitats and reduce stream temperatures in Scott River tributaries should make use of the results of the shade modeling developed as part of this analysis. The shade modeling results can be used to identify areas that are well below potential conditions. When considered together with other pertinent factors, the RipTopo results could be used to develop a prioritized list of riparian restoration sites.

Debris flows related to road fills, stream crossings, and other management features are another factor affecting stream temperatures that is related to forest management activities. Debris flows often drastically reduce riparian shade for great distances downstream of the initial failure. Management-related debris flows that occurred during the flood of 1997 resulted in tremendous changes to riparian areas throughout the Klamath National Forest, including areas of the Scott River watershed (de la Fuente and Elder, 1998). In the Scott River watershed debris flows devastated riparian areas in Tompkins, Kelsey, and Houston Creeks. Efforts to abate the discharge of sediment will positively affect stream temperatures by reducing the risk of future debris flows.

Cattle grazing practices are an ongoing factor related to increased stream temperatures in some Scott River tributaries, particularly but not only in the eastern half of the watershed. In these areas, unrestricted grazing of riparian areas has resulted in a reduction of the density, succession, and vigor of riparian vegetation. Although past and current management in these areas has had a negative effect on riparian vegetation, management approaches have been developed that use grazing as a tool for managing riparian areas in a way that benefits the riparian vegetation, while increasing the available forage. These management approaches take into account the environmental requirements of the particular riparian species, as well as the behavior of cattle and sheep. Outreach efforts that promote these types of management approaches should be supported and encouraged.

4.6 RECOMMENDATIONS FOR ADDITIONAL STUDY AND FUTURE ACTION

- Reduce uncertainty of vegetation mapping in the East Fork Scott River between Masterson Road and Highway 3.
- Reduce uncertainty of vegetation mapping in the Houston / Cabin Meadows Creek model application.
- Complete the mainstem Scott River model development all the way to the East and South Forks.
- Work with stakeholders to develop and implement a Scott Valley groundwater study.
- Work with stakeholders to develop a list of high priority sites for riparian restoration, based on the Rip Topo results.
- Participate in the development and negotiation of Habitat Conservation Plans to ensure long-term planning efforts conform with water quality standards.
- Develop a strategy for addressing issues related to grazing in riparian areas.

- Support riparian grazing workshops where local range managers and other experts can exchange information on the latest techniques for managing riparian areas in rangelands.
- Work with agencies involved in flood response to identify areas of overlapping regulatory authority and develop coordination protocols.

4.7 MARGINS OF SAFETY AND SEASONAL VARIATION

The Clean Water Act Section 303(d) and the associated regulations at 40 CFR §130.7 require that TMDLs include a margin of safety that takes into account any lack of knowledge concerning the relationship between the pollutant loads and the desired receiving water quality. The margin of safety is often implicitly incorporated into conservative assumptions used in calculating loading capacities, waste load allocations, and load allocations (USEPA, 1991). The margin of safety may also be incorporated explicitly as a separate component in the TMDL equation. For this TMDL analysis, conservative assumptions were made that account for uncertainties in the analysis.

- This report analyzes temperature and sediment separately. Some improvements in stream temperature that may result from reduced sedimentation are not calculated explicitly. Reduced sediment loads could be expected to lead to increased frequency and depth of pools and to reduced wetted channel width/depth ratios. These changes tend to result in lower stream temperatures overall and in more lower temperature pool habitat. These changes are not accounted for in the analysis and provide a margin of safety.

- While the potential shade conditions used to calculate the loading capacity assume that the occurrence of potential vegetation at a site extends to the bankfull channel width, the effective shade curves can be applied to either current channel widths or to projected bankfull widths. Application of the curves to current channel conditions does not account for channel narrowing that may occur as a result of reduced sediment loads. These effects constitute a margin of safety.

- Changes in streamside vegetation toward larger, mature trees will increase the potential for contributions of large woody debris to the streams. Increases in large woody debris benefit stream temperatures and associated cool water habitat by increasing channel complexity, including the number and depth of pools. These changes were not accounted for in the analysis and provide a margin of safety.

With respect to seasonal variations in stream temperatures, the analysis takes the most extreme heating conditions as measured by the 7-day running average of temperatures as constituting a limiting condition for salmonid survival with respect to temperature. Additionally, the analysis evaluated thermal processes during the time of year when the streams are the hottest.