NAVARRO WATERSHED RESTORATION PLAN

A JOINT PROJECT OF

THE MENDOCINO COUNTY WATER AGENCY
THE COASTAL CONSERVANCY
THE ANDERSON VALLEY LAND TRUST

Prepared by:

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ACRONYMS AND ABBREVIATIONS USED IN THE TEXT

A.V. (or AV)	Anderson Valley
ACE	Army Corps of Engineers
AG	Advisory Group (Navarro Watershed Advisory Group)
AVCSD	Anderson Valley Community Services District
AVLT	Anderson Valley Land Trust
AVUSD	Anderson Valley Unified School District
CalTrans	California Department of Transportation
CDF	California Department of Forestry and Fire Protection
CDFG	California Department of Fish and Game
CSCC	California State Coastal Conservancy
CTM	Critical Thermal Maximum
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
L.P.	Louisiana Pacific Corporation
LWD	Large Woody Debris
MCWA	Mendocino County Water Agency
NCRWQCB	North Coast Regional Water Quality Control Board
NMFS	National Marine Fisheries Service
NRCS	Natural Resources Conservation Service (formerly the Soil Conservation Service of the US Department of Agriculture)
RCD	Resource Conservation District
RWQCB	Regional Water Quality Control Board
SWRCB	State Water Resources Control Board
UCCE	University of California Cooperative Extension
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
YOY	Young of the Year

[1] Compiled by Dan Sicular

TECHNICAL TERMS USED IN THE TEXT

Aggradation: A geologic process which raises the level of a stream bed by the deposition of sediment. Occurs when the stream's ability to transport sediments is exceeded by the sediment load.

Alluvial: Sediment deposited by flowing water, as in a valley.

Anadromous: Fish that migrate upstream to spawn.

Basin: Same as a watershed.

Bioengineering: A method of watershed restoration using partly or exclusively live or dead plant material and structural engineering methods to strengthen or protect slopes and streambanks, and at the same time to improve habitat conditions and the appearance of the site.

Biotechnical: See bioengineering.

Canopy: The overhead branches and leaves of stream-side vegetation.

Canopy cover: The vegetation that projects over the stream.

Coarse sediment: rock fragments of gravel size or greater.

Coho: One of six species of pacific salmon (*Oncorhynchus kisutch*). Also called silver salmon. Spawning males are sometimes called "hookbills".

Cover: May refer to *canopy cover*, or to logs and other large woody debris and boulders in streams that provide shade, shelter, and protection from predators for fish.

Critical Thermal Maximum (CTM): The temperature at which a fish loses equilibrium and dies.

Diurnal: Daily cycle.

Embedded: When larger rock particles (gravel, cobbles, or boulders) are surrounded or covered by fine sediment. Usually measured in classes according to the percentage of coverage of larger particles by fine sediments.

Endangered: In danger of becoming extinct.

Ephemeral stream: A stream that does not run year round, or that runs only during and soon after rain.

Fill: Localized deposition of material on the stream bed by flowing water. Opposite of *Scour*.

Fine sediment: Small particles of rock and organic debris. Includes clay, silt, and sand size particles.

Floodplain: Usually a flat or nearly flat area adjoining a river channel constructed by the river in the present climate and overflowed at times of high discharge.

Franciscan Assemblage: A geologic formation typical of the Northern California coast ranges.

Geomorphology: The study of the processes that shape the surface of the earth, including geologic processes, erosion, mass wasting, and stream flow.

Gradient: The general steepness of a slope or streambed.

Hydrology: The study of flowing water.

Incised: A stream that has cut downward, lowering the elevation of its bed.

Inner gorge: A deep, steep-sided canyon. Examples of inner gorges in the Navarro Watershed include the mainstem Navarro downstream of Floodgate; Mill Creek; lower Rancheria Creek; and the North Fork of Indian Creek.

Shallow landslides: less than 5 feet deep.

Deep-seated landslides: 10 feet deep or greater.

Large woody debris: A large piece of relatively stable woody material having a diameter greater than 12 inches and a length greater than 6 feet that intrudes into the stream channel. A log or root wad.

Limiting factor: A particular environmental feature that limits the ability of an organism to survive or thrive. Limiting factors for salmon and steelhead may include stream temperature, frequency and quality of pool habitat, streambed sedimentation, and, especially when populations are abnormally low, degree of predation.

Melange: A terrain characterized by serpentine or other ultramafic rock and highly erodible soils.

Natal stream: The stream in which an *anadromous* fish begins life, and returns to spawn.

Order: See *Stream order* or *Order of magnitude.*

Order of Magnitude: A factor of 10 (10X). An order of magnitude sediment budget provides data that are accurate within a factor of 10 of the actual number.

Reach: A relatively homogeneous section of a stream having a repetitious sequence of physical characteristics and habitat types; or a specified length of stream (for example, 5 times the average stream width).

Redd: A salmon or steelhead nest built by the spawning female in a gravelly streambed.

Refuge: For fish, a part of a stream where they can seek protection from life-threatening events, such as very high stream flows.

Refugia: A part of a stream that exhibits an extraordinary characteristic necessary for fish to survive, for example, a deep pool where water is colder than the rest of the stream.

Riffle: A part of a stream characterized by rapidly flowing, turbulent water.

Riparian: Anything connected with or immediately adjacent to the banks of a stream.

Riparian vegetation: Vegetation growing on or near the banks of a stream.

Salmonid: Salmon and trout.

Scour: The localized removal of material from the stream bed by flowing water. Opposite of *fill.*

Sediment: Fragments of rock and organic debris. Coarse sediment is gravel size or larger; fine sediment includes particles the size of clay, silt, and sand.

Sediment budget: An accounting of the sources and disposition of sediment at it travels from its point of origin to its eventual exit from a watershed.

Sediment production: The rate at which sediment enters stream channels from various sources.

Side channel: A stream channel connected to the main channel that is only wetted during high flows.

Steelhead trout: One of 6 species of pacific salmon (*Oncorhynchus mykiss*). Genetically identical to rainbow trout.

Stream order: The designations (1,2,3, etc.) of the relative position of stream segments in a drainage basin network: the smallest, unbranched, perennial tributaries are designated order 1; the junction of two first-order streams produces a stream segment of order 2; the junction of two second-order streams produces a stream segment of order 3, etc.

Subbasin: A watershed within a larger watershed. Also called tributary basin.

Substrate: The mineral and organic material that forms the bed of a stream.

Threatened: In danger of becoming *endangered.*

Watershed: The land area that drains to a common waterway. May also be called *drainage basin* or *basin.*

Young-of-the-year (YOY): Juvenile fish in their first year of life.

In the four year life of this project, well over a hundred people have contributed substantial time and resources to its completion. It is impossible to fully thank the many contributors to the Navarro Watershed Restoration Plan. However, we would like to specially acknowledge the following people and organizations without whom this plan could not have been produced:

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THE NAVARRO WATERSHED ADVISORY GROUP

The members of this group, including local residents, other stakeholders and agency personnel, were instrumental in the oversight of this complex project. Their dedication and public-spirited cooperation helped this planning effort more fully reflect the needs and concerns of the Navarro community. While the composition of the Advisory Group changed over the years of this project, every member made an invaluable contribution and all are listed in Table 1-1.

LANDOWNERS GRANTING ACCESS

The fieldwork that occurred in the many sub-basins around the Navarro was possible through the hospitality of the landowners listed below. Their participation helped ground the project in both science and common sense.

Anderson Vineyards
Peryl Aston
Tim and Karen Bates
Robert and Eileen Beaumont
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Richard and Maureen Bishop
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STAFF AND CONSULTANTS

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Connie Best
Boonville, June 1998

PROJECT GOALS, OBJECTIVES, AND SCOPE

At the outset of the planning process in the spring of 1995, the Navarro Watershed Restoration Plan Community Advisory Group (AG) established the following goals for this plan:

1. Restore the water quality, salmon fishery, and former abundance of other renewable resources within the Navarro watershed.

2. Sustain a diverse, viable local economy that is in balance with a natural environment rich in diversity of native species and habitats.

3. Enhance the efforts of those who live and work in the Navarro Watershed in taking personal responsibility for managing their land and activities in order to minimize negative impacts on the health of the watershed, respecting both the rights and responsibilities of private property.

4. Facilitate cooperation between government agencies and landowners so that government regulations help, and do not hinder, efforts to restore and maintain the health of the watershed.

To achieve these goals, the watershed project conducted a study of limiting factors to salmon production and land use-related impacts to water quality, and a strategic analysis of the sub-basins and stream reaches where restoration and enhancement actions can have the greatest benefit. Background studies for the Plan include hydrology, geomorphology, sediment production, salmonid habitat condition and distribution, stream flow, stream temperature, water quality, land use patterns, and impacts of the major historical and current land uses. Based on these studies, the Plan makes recommendations for voluntary restoration and conservation actions to benefit water quality in general and the salmon fishery in particular

The Plan provides an initial structure for the Anderson Valley community and interested groups and government agencies to implement a comprehensive watershed restoration and enhancement effort. The Plan is intended to engage the range of stakeholders in the Navarro Basin in seeking scientifically-based, voluntary solutions to long-standing water quality and fishery problems in this watershed.

FINDINGS

FISHERIES

The fisheries study reviews existing literature on the Navarro watershed, and reports on field work conducted in the summer of 1996 (see Section 4.0). The field work included surveys of 11 representative streams covering over 16 miles of channels. The surveys collected data on the distribution and relative abundance of fish, and on the quality of fish habitat. Data was collected on habitat type, length, and width; pool depth and forming features; spawning habitat quality; potential for aquatic insect production; high flow refuge habitat quality; canopy closure; and in-stream cover for fish in pool habitats. In addition, the fisheries study incorporates the results of other recent studies conducted in the Navarro River watershed by California Department of Fish and Game (CDFG), and National Marine Fisheries Service. A separate study of the Navarro River estuary in 1996-1997 was independently conducted by AVLT and Humboldt State University Foundation under grants from the Northwest Emergency Assistance Program administered by Humboldt County Resource Conservation District (Appendix F). The fisheries study provides a comprehensive picture of the current state of the Navarro's coho salmon and steelhead fishery. The major findings of the fisheries study are as follows:

1. Coho salmon occurred in only 3 of 11 streams surveyed by the project consultants and 9 of the 34 streams surveyed by CDFG in 1994, 1995 and 1996. Streams containing coho salmon are principally located in the western part of the drainage, either in small tributaries to the mainstem Navarro River or in North Fork Navarro basin.

2. Steelhead occurred in all 11 streams surveyed by the project consultants and 32 of 34 streams surveyed by CDFG in 1994, 1995, and 1996. Steelhead are widely distributed throughout the watershed.

3. Pool habitat is generally less frequent than expected for forested streams. Large woody debris is lacking in most stream channels and only a small percentage of pools were formed by large woody debris. Riffle, run and glide habitat frequency are high. The poor quality and limited availability of pool habitat are detrimental to production of coho salmon in the watershed. Recruitment of large woody into stream channels is low, a result primarily of past and current logging practices.

4. Summer water temperatures are unsuitable throughout much of the watershed for coho salmon and are suitable to marginal for steelhead. Suitable summer water temperatures for coho salmon occur in much of the North Fork Navarro system and in some of the second order tributaries to the lower Navarro River. A few other tributaries, somewhat distant from the North Fork Navarro, such as Mill Creek, lower Indian Creek, and tributaries to lower Rancheria Creek, have suitable temperatures for coho where sufficient summer stream flows occur in channels that are well-shaded. Most of the Navarro River basin has adequate

summer temperature regimes to support steelhead. Anderson Creek in the Anderson Valley is generally too warm during summer to support steelhead. Unsuitable temperatures result from wide, exposed stream channels, and very low summer stream flows.

5. Many of the streams surveyed had abundant sand or fine sediments, which can cause gravels to become embedded or cemented, making spawning difficult and reducing the survival of embryos while incubating in the gravel. Fine sediment can also fill the spaces between gravel, reducing the intragravel flow of water and limiting aquatic insect production.

The limited distribution and generally low abundance of coho salmon in the watershed calls for a restoration strategy that focuses first on the conservation of the coho salmon population by protecting existing habitat.

WATER QUALITY

Temperature

In 1995, 1996, and 1997, the Mendocino County Water Agency deployed a number of continuous temperature recording devices in streams throughout the Navarro watershed (see Appendix E). The results of the temperature monitoring indicate that maximum water temperatures are unsuitable for salmonids in much of the watershed, and in many streams diurnal fluctuations are stressful for salmonids. Temperatures suitable for coho are found principally in the western portion of the watershed. Temperatures are generally suitable or marginal for steelhead throughout the watershed.

Where streams are located in close proximity to the coast (e.g., North Fork Navarro), stream temperatures are moderated by the local marine influence. At inland locales (e.g., Anderson Valley, the upper Indian Creek basin, and the upper Rancheria Creek basin), stream temperature increases are much greater because maximum air temperatures are higher than in the coastal areas. Present-day stream temperatures in most locations along the large, inland streams with open canopies, such as Indian Creek, Rancheria Creek, and Anderson Creek, are unsuitable for coho salmon. Recent aerial photography and other evidence such as cross-section surveys, indicate that most of the main channels, except Anderson Creek in Anderson Valley, have been recovering from the widening which was evident in the 1950s.

The primary cause of high stream temperatures (determined by air photo analysis and other evidence such as cross-section surveys) is the discontinuous canopy closure. In the early 1950s, many tributary streams that flowed through narrow valleys had complete canopy closure. Today many of these streams have only discontinuous canopy closure. This causes stream temperatures to be much more responsive to changes in air temperature and exposes them to direct solar heating. Canopy openings are due to historic widening of channels, caused by sediment accumulation; and to loss of riparian vegetation through logging and other land use practices. Diversion of water, particularly on the lower reaches of Anderson and Rancheria Creeks, also contributes to high water temperatures on these streams.

Stream Flow

Stream flow monitoring by the Mendocino County Water Agency and the State Water Resources Control Board in 1995, 1996, and 1997, and by volunteer monitors in 1995 and 1996, provide detail for the understanding of low flows during the dry summer months (Appendix E). These studies indicate that summer flows in the lower reaches of Anderson, Rancheria, and Indian Creek are at times significantly reduced by agricultural pumping. In aggraded stream reaches, summer flow may be entirely subsurface. Several monitored streams dried up completely, or had only isolated pools during the late summer months, while others persisted through the dry season.

No coho, and few steelhead, were observed in the lower reaches of the main trunk streams that are most affected by agricultural pumping. This is likely due to the high water temperatures in these streams. The long-term restoration of these large streams must therefore include efforts to reduce summer stream temperatures, to improve summer flows, and to improve pool habitat.

Sediment

The sediment budget identifies sediment sources and sediment-related impacts to channels and fish habitat in the Navarro watershed (see Section 3.0 and Appendix A). Because the primary goals of the Plan are to restore and enhance the Navarro's anadromous fishery and to improve water quality, the focus of this study was on those landscape features and geomorphic processes which deliver sediment to stream channels. The sediment budget is used to identify the major erosion processes that contribute sediment to stream channels, in order to focus planning efforts for erosion prevention and control; and to discern the long-term trends in sedimentation and stream channel responses to it. The major findings of the sediment budget are as follows:

1. The Navarro Watershed includes highly erodible soils derived from rocks associated with the melange unit of the Franciscan Assemblage, found in much of the Anderson Creek basin, middle and upper Rancheria Creek basin, and a portion of the Indian Creek basin. Soils associated with the Coastal Belt of the Franciscan Assemblage, found in much of the rest of the watershed, are more stable and resistant to erosion. Alluvial fill, found in the Anderson Valley and in low-lying reaches of the major tributaries, is also highly erodible.

2. Sediment production rates in the 1980's and 1990's are lower than they were during the recent historical period from the 1950's to the 1970's. This change is likely due to improved timber harvest practices and regulations, as well as to generally improved road construction and maintenance practices for active logging roads. However, present-day rates of sediment production remain undesirably high in comparison with the pre-settlement era, and continue to have deleterious effects on salmonid habitat.

3. Most tributaries and extensive reaches of the main trunk streams, including Indian Creek, mainstem Navarro, lower Rancheria, and the North Fork Navarro, are recovering from channel aggradation and widening that was initiated in the 1950's or 1960's during the period of unregulated tractor logging. There were also several major storm events during this period which had profound effects on stream channel morphology and fish habitat. Time sequential air photos indicate that the current trend in most streams is toward recovery, as most channels are narrowing and scouring their beds, returning to about pre-aggradation levels.

4. Streambed aggradation and widening persist in a few of the major trunk streams where the gradient is gentle and the valley bottom is wide, especially Anderson Creek in the Anderson Valley, and in upper and middle Rancheria Creek. These streams still exhibit poorly developed riparian vegetation, shallow pools, and a large amount of frequently mobilized sediment.

5. The most pervasive sediment problem affecting stream channels today is an excess of fine sediment. Fine sediment deposition is typically most extreme on the larger streams where the gradient is relatively low and the valley bottom is wide. However, fine sediment deposition is widespread throughout the watershed. This problem manifests as accumulation of fine sediment in pools and in riffles.

6. Roads are one of two major contributors to elevated levels of sediment entering stream channels. The amount of sediment eroded from roads and entering stream channels is related to road density, road type and level of use, geology, and topographic location. Those subbasins with the highest rates and overall volume of road-related production of sediment to stream channels are the North Fork Navarro and mainstem Navarro basins. Road-related sediment is estimated to be about 26 percent of total sediment production to streams.

7. Bank erosion and shallow landslides in larger channels, especially those that flow through alluvial valleys and those flowing through the melange terrain, are the other major contributors of sediment, accounting for about 37% of total sediment production to streams.

8. Bank erosion and shallow landslides to smaller channels (15 percent) and gullies (16 percent) constitute the next tier of sources of sediment production to stream channels.

9. Infrequent but large deep-seated landslides account for about 6% of total sediment production to streams. Deep seated landslides occur in the Rancheria Creek Basin and the mainstem Navarro River basin.

10. The highest rates of sediment production, calculated on the basis of tons per square mile of drainage area, are found in the Anderson Creek basin, followed by the Rancheria Creek, mainstem Navarro, North Fork, and Indian Creek basins. The significantly higher rates and total amount of sediment from the Anderson

Creek basin are attributable primarily to the highly erodible soils and Franciscan melange geology.

11. Most of the sediment that enters smaller (first and second order) stream channels is transported relatively quickly to lower gradient, higher order streams. This is attributable to the smaller channel's confinement within narrow valleys, and their lack of large woody debris.

Large Woody Debris

Another widespread impact to streams throughout the Navarro Watershed is the lack of large, stable woody debris in channels. Prior to the 1950's and 1960's, large, old-growth redwood trunks were common in many channels. These large woody debris trunks created several important fish habitat elements, including diverse channel morphology, habitat complexity, and excellent cover; deep and frequent pools; sediment storage sites that buffered streams from the impacts of high sediment production; and sites for deposition and retention of spawning gravels. Much of the large woody debris was removed in the 1950's and 1960's as part of salvage logging operations or because fisheries managers believed that the debris created barriers to upstream fish migration. Degradation of riparian forests, and continued logging in riparian areas have interrupted the recruitment of large woody debris and recovery of this crucial element of fish habitat.

RECOMMENDATIONS

OBJECTIVES AND PRIORITY ACTIONS

Section 5.0 establishes three broad objectives that must be met in order to achieve the Plan's goals of conserving and restoring the salmon and steelhead habitat and improving water quality. These are:

1. increase the frequency and depth of pool habitat;

2. decrease summer stream temperatures; and

3. reduce accelerated sediment production.

The eight priority actions for achieving these three objectives are listed below. Since each of the five drainage basins of the Navarro watershed encompasses a large geographic region with diverse geologic, vegetative, land-use, and aquatic habitat conditions, the most important priority actions will vary in each basin. Section 5.0 discusses existing conditions and identifies the priority actions which are most important in each basin.

1. Increase large woody debris recruitment to streams;

2. Install in-stream habitat structures;

3. Increase riparian shading;

4. Increase summer baseflows;
5. Remediate and repair gullies;
6. Reduce road-related erosion;
7. Stabilize streambanks;
8. Modify land management practices to reduce impacts on streams, including timber harvest, agriculture (including livestock), and residential and commercial development. Section 6.0 of the plan includes detailed recommendations for land management practices to achieve the three objectives stated above. These are meant to be used by interested landowners who wish to take voluntary actions to reduce the impacts of their land management on stream resources. Many of the recommended land management practices include details for implementation of the other priority actions.

Recovery of coho salmon stocks must begin with maintaining existing population levels and increasing abundance in the short term through conservation of remaining good habitat. As abundance increases, the distribution of coho salmon into wider areas of the watershed is more likely to occur. The primary basin still supporting coho salmon is the North Fork Navarro. Simply maintaining existing populations in the North Fork may be insufficient to increase the distribution of coho salmon in the watershed. Abundance in this basin should be not only maintained, but improved. Habitat improvements should also be implemented in the other designated priority areas (see below). Additional consideration, in consultation with Department of Fish and Game and National Marine Fisheries Service, should be given to planting coho salmon into these priority locations.

PRIORITY STREAMS FOR FISHERIES RESTORATION AND CONSERVATION

Streams throughout the Navarro Watershed were evaluated for their suitability for restoration and conservation (see Section 5.0). High priority status was given to streams with the following attributes: a) restoration actions are feasible; b) restoration efforts are likely to be effective and to have a low risk of failure; c) restoration treatments implemented in the field would improve habitat conditions in the near-term (about 5 years); and d) restoration treatments would likely benefit coho salmon, as well as steelhead and water quality in general.

The best opportunities to improve habitat conditions over a relatively short planning horizon are in those locations where stream temperatures are still suitable for coho, where there have been recent historical observations of coho presence, where channel conditions are amenable to in-channel restoration treatments, and where reduction of excess sediment supply is feasible. Overall, these tend to be locations in the forested Coastal Belt geologic terrain, and within the western portion of the watershed. The high priority streams for restoration and conservation are:

<u>North Fork Navarro Basin:</u>

Mainstem North Fork Navarro River subbasin
Little North Fork Navarro and its tributary subbasins
Flynn Creek, Dutch Henry Creek, John Smith Creek subbasins
South Branch North Fork Navarro River and its tributary subbasins below the confluence with Low Gap Creek

Mainstem Navarro Basin:
Marsh Gulch subbasin
Mill Creek subbasin

Indian Creek Basin:
Lower Mainstem Indian Creek (Parkinson Gulch to Navarro River)

Rancheria Creek Basin:
Adams Creek and Yale Creek subbasins (for steelhead management only)
Dago Creek, Cold Springs Creek, Minnie Creek, Horse Creek, Camp Creek, and lower mainstem of Rancheria Creek subbasins

Anderson Creek Basin:
Con Creek and Soda Creek subbasins (for steelhead management only)

In addition to short-term restoration actions, long-term modifications to land management practices will be necessary to ensure the survival and recovery of salmon and steelhead, and the improvement of water quality throughout the watershed. Historically, land management practices have profoundly altered streams and impaired their ability to support healthy populations of coho and steelhead. Widespread, voluntary adoption of improved land management practices to reduce erosion and sedimentation, protect and enhance riparian forests, and improve stream habitat is critical to the recovery of coho and steelhead, and to the improvement of water quality.

PUBLIC INFORMATION AND EDUCATION

Implementation of the Plan will require participation of the whole Anderson Valley community. Section 8.0 identifies the following means for dissemination of the goals, objectives, findings, and recommendations of the Plan:

- Implement the demonstration projects planned in Section 7.0, and encourage tours of the sites by school groups, landowners, and others. Planned demonstration projects include road upgrading, streambank stabilization and revegetation, and gully remediation.

- The Anderson Valley Unified School District will continue to play a central role in teaching watershed and restoration concepts and skills to Anderson Valley's youth.

- The Anderson Valley Lending Library will serve as the repository for project documents, including maps and air photos.

- Several organizations, including U.C. Cooperative Extension, the RCD/NRCS, the Coastal Conservancy, and the AVLT plan to sponsor workshops and short courses on watershed processes and watershed management.

- The Plan will be available to all interested residents.

- There is interest in creating a community-based Geographic Information System (GIS) for watershed planning, monitoring, and education.

PLAN IMPLEMENTATION

Three major strategies for implementation of the Plan are discussed in Section 9.0. These are:

- Implementation of the recommended land management practices identified in Section 6.0;
- Restoration of priority basins and tributary streams;
- Restoration of major trunk streams, focusing on reestablishing streambank stability and riparian forests.

Two watershed groups exist in the Anderson Valley, and it is anticipated that both of these, as well as possible future watershed groups, will take part in conservation, restoration, and recovery of the Navarro watershed. In addition, a number of private organizations and public agencies are expected to be involved in restoration and conservation activities.

The Plan identifies possible funding sources for implementation of restoration and conservation actions. It is expected that government agencies, including the California State Coastal Conservancy, the State Water Resources Control Board, California Department of Fish and Game, and the Resource Conservation District/Natural Resources Conservation Service and other agencies will fund restoration actions through grants, cost-shares with interested landowners, technical assistance, and outright funding of restoration projects.

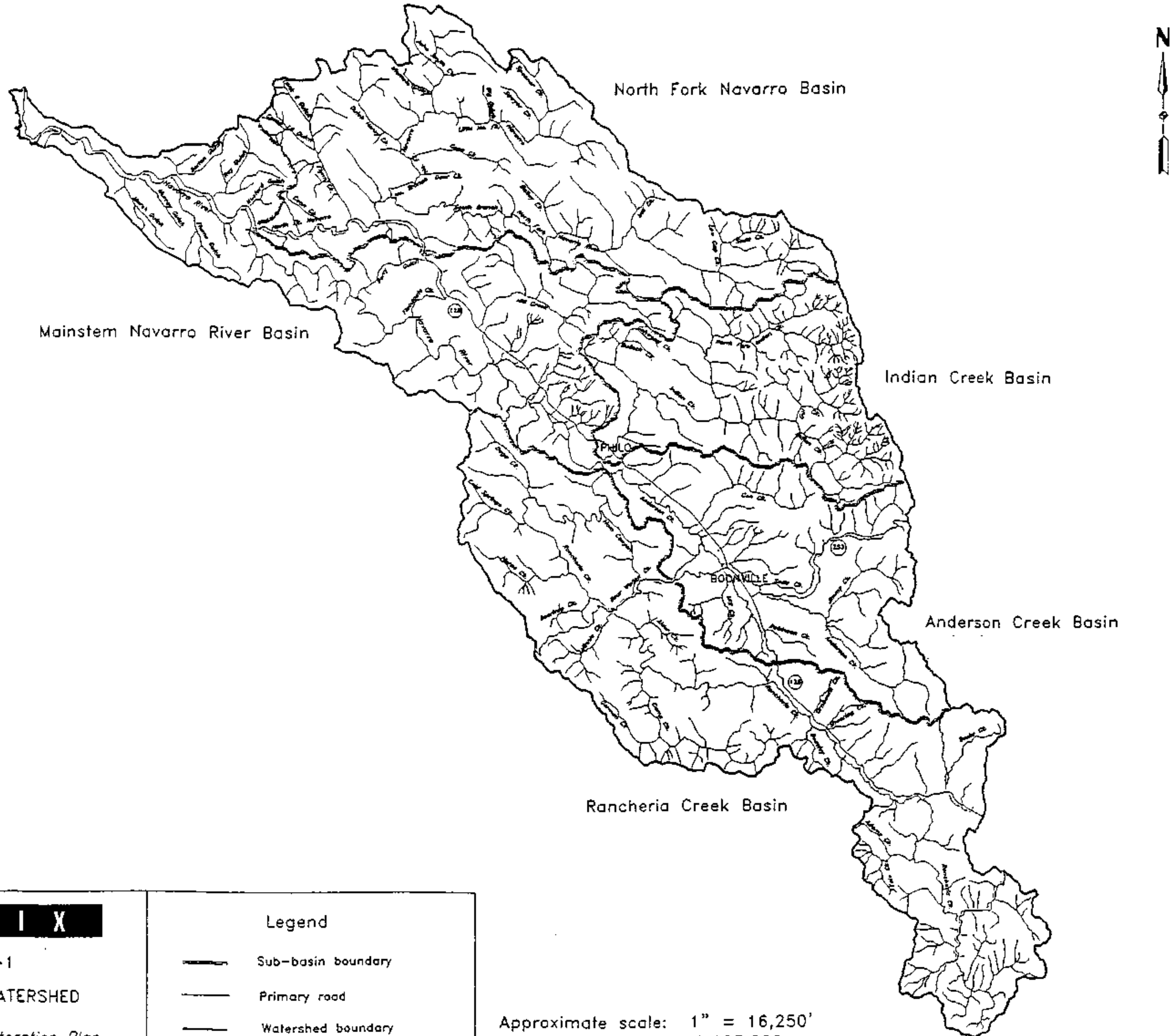
Some restoration projects will require project proponents to obtain permits before work commences. Permit requirements are discussed in the introduction to Section 6.0, and are summarized in Table 9-2 in Section 9.0.

1.0
INTRODUCTION

1.1 BASIS OF NEED FOR RESTORATION PLAN

The Navarro River watershed (Figure 1-1) is located in southern Mendocino County, approximately 120 miles north of San Francisco and 30 miles west of Ukiah. Encompassing 315 square miles, it is the largest coastal basin in Mendocino County. The watershed can be subdivided into 5 major drainage basins: mainstem Navarro River, North Fork Navarro River, Indian Creek, Anderson Creek, and Rancheria Creek. The population of the watershed is about 3,500 people, with most living in and around the towns of Boonville and Philo. Land-use in the watershed includes forestland (70%), rangeland (25%), and agriculture (5%) with a small percentage devoted to rural residential development. Since the mid-1800's the Navarro River watershed has been exploited for timber production, livestock grazing, and agriculture. Increasing pressure on natural resources continue as new permanent and part-time residents from the "greater Bay Area" engage in many of these land-use and development activities. Today, commercial timber harvesting, viticulture, orchards, grazing, and tourism are the principal economic enterprises.

Although the above land-uses are the basis of the local economy and community, over time they have had a significant adverse impact on water quality and the fishery. Historically, the Navarro River watershed was considered to have high quality and extensive anadromous fish habitat supporting a productive coho salmon and steelhead trout fishery comparable to any basin in Mendocino County. However, commercial fishing has been in serious decline, with an estimated 3,000 fishing related jobs lost in the coastal Mendocino County region. Sport fishing for coho salmon in local streams has ceased. The geographic distribution of coho salmon has been shrinking, and the species is likely near extirpation from the watershed. Recognizing the wide-spread loss of coho salmon populations along the north central California coast, the National Marine Fisheries Service (under the federal Endangered Species Act), listed coho salmon as a threatened species in 1997. National Marine Fisheries Service (NMFS) ruled in March 1998 that steelhead populations along the northern California coast would not be listed as a federally endangered or threatened species. NMFS has indicated that ongoing conservation and restoration plans being developed by the state in northern California make it unnecessary to list steelhead at this time. However, steelhead will remain a candidate species, so that NMFS could list them as threatened or endangered sometime in the future, if necessary. In addition to the listing by NMFS, the State Water Resources Control Board (SWRCB) lists the Navarro River, under Section 303(d) of the federal Clean Water Act, as an impaired water body whose beneficial uses are threatened due to sedimentation and high stream temperatures.



ENTRIX

Figure 1-1

NAVARRO RIVER WATERSHED

Navarro Watershed Restoration Plan

Legend

- Sub-basin boundary
- Primary road
- Watershed boundary

Approximate scale: 1" = 16,250'
1:195,000

Despite the significant impacts which land-use development and resource extraction activities have had on water quality and the fishery, there has never been a comprehensive, watershed-wide investigation on which to base either restoration decisions or land management practices. Prior investigations have been limited in the scope of their technical studies, or have focused on specific geographic locations within the watershed. Without the baseline scientific information needed to understand how land-use activities are limiting the fishery and impairing water quality, restoration and enhancement plans will not be well founded.

1.2 PURPOSE OF THE RESTORATION PLAN

The Plan provides an assessment of watershed conditions and identifies opportunities for enhancement of water quality and recovery of the fishery. The process of developing, and in the future implementing elements of the Plan, provides a forum for discussion and expansion of the public's knowledge of watershed processes and how they are influenced by human activities. A primary purpose of the plan is to engage and educate the community by building a greater understanding of water quality and fishery problems, and cooperatively resolving the threats to natural resource productivity which affect the social and economic well-being of the region. As state and federal resource agencies give closer scrutiny to north coastal California streams, particularly with the listing of coho salmon and the impending establishment of Total Maximum Daily Load (TMDL) limits for stream pollutants, the need for cooperative, community based solutions to problems in the watershed becomes critically important. Resource agencies may intervene with more stringent and widespread regulatory requirements intended to recover coho and steelhead habitat, and to improve water quality, in the absence of scientifically supported and voluntarily enacted, community-based plans.

1.2.1 GEOGRAPHIC AND TECHNICAL SCOPE

The Plan identifies the nature, sources, and extent of threats to water quality and to the fishery. The technical chapters include reviews of previous studies and present new data and analysis. The project undertook studies of sediment production, channel conditions, fish distribution, aquatic habitat conditions, stream flows, and water temperature. The geographic scope of studies conducted for this Plan encompassed all of the watershed area drained by freshwater streams upstream of the Navarro estuary[1]. These studies were conducted by the project's consultants, the Mendocino County Water Agency, the California Department of Fish and Game, and numerous volunteers from the Anderson Valley community. The Plan focuses on the riverine or pre-smolt life history phases of salmon and steelhead. The study examines habitat conditions that existed during the mid 1990s (especially during the summer of 1996, when the majority of the fieldwork was

1. The AVLT and Humboldt State University Foundation received a separate grant fund for study of the estuary. The Navarro Estuary and Lagoon Study (Appendix F) was administered by the Humboldt County Resource Conservation District.

conducted), and places these in the context of historical changes in physical habitat in the watershed.

The results of these studies form the basis for a range of recommendations for land management practices, a prioritized list of restoration activities and priority locations in the watershed, and specific examples of remedial actions (demonstration projects) that are needed to protect and to restore water quality and fish habitat. Landowners are provided with technical guidance and basic assistance needed to implement effective water quality and fish habitat restoration activities that will have a high likelihood of success. Since the vast majority of the watershed is in private land-ownership, widespread support and implementation of the land management practices and remedial actions described here are crucial to achieving the project's overall purpose. A more detailed list of the specific goals and objectives are provided in Section 2.0, *Project Goal and Objectives.*

Entrix, the prime consultant for this project, was given the task of examining the physical condition of the entire Navarro River watershed. This included an assessment of aquatic habitat conditions in the streams supporting coho salmon and steelhead, an assessment of stream channel conditions, and an assessment of erosion processes ongoing in the watershed. The study utilized historic and recent data on fish distribution, an aerial photographic record, and other information in conjunction with a field sampling program as an approach to understanding changes to watershed conditions, stream channel adjustments, and the status of aquatic habitat. The objective of the study was to determine the condition of coho salmon and steelhead habitat, understand how habitat conditions have changed and why, and to recommend actions to aid in restoring good quality habitat and water quality in the Navarro River Watershed.

For the aquatic habitat and fish distribution study, Entrix's scope of work focused on the pre-smolt (juvenile freshwater life history phase) of coho salmon and steelhead, and on physical habitat parameters. Other factors may affect salmonid populations but were not within the scope of this study. For example, Entrix did not examine any aspect of the Navarro estuary (though an estuary study was conducted independently; see Appendix F). Neither was there an assessment of the influence of ocean sport or commercial harvest of ocean conditions on coho salmon or steelhead. Ocean conditions can change from year to year and can have an influence on the abundance of adults and hence the abundance of juveniles. Harvest of salmon from the ocean can also directly affect the availability of salmon for spawning. Commercial harvest is closed for coho salmon in California and steelhead are not a commercially fished species. This project did not examine a multitude of other factors that may affect coho salmon and steelhead populations, such as inland sport fishing, poaching, or predation by harbor seals, river otters, great blue herons, kingfishers, or other mammalian and avian predators. Similarly, the potential for predation or competition with other native fish species such as roach, suckers, and scullions found within the Navarro River basin was not included in Entrix's scope of work.

In summary, the aquatic habitat and fish distribution study was not meant to be an all-inclusive biological documentary. It was focused primarily on the limiting physical habitat parameters for coho salmon and steelhead. The objective of the study was to identify why aquatic habitat is less than optimum and to make recommendations to improve conditions in the near and long term.

Future studies may wish to examine the influence of ocean conditions and predation on salmonid populations. However, anyone considering undertaking such a study should weigh the effort that would be necessary with the expected value resulting from the study.

1.3 PROJECT ORGANIZATION

Creation of the Plan involved numerous individuals, organizations, and agencies. Management of the project has been the responsibility of the three sponsoring agencies: the Anderson Valley Land Trust (AVLT), the Mendocino County Water Agency (MCWA), and the California State Coastal Conservancy (CSCC). These three organizations each appointed a representative (as shown below) to oversee the project, and the three organizations jointly contracted with a project coordinator.

PROJECT MANAGEMENT TEAM

- Connie Best, Anderson Valley Land Trust
- Julia McIver, California State Coastal Conservancy
- Dennis Slota, Mendocino County Water Agency
- Dan Sicular, Project Coordinator

Development of the Plan was directed and overseen by the project's Community Advisory Group (AG). This group is made up of community representatives of a range of interests and organizations in the Navarro Watershed, as well as representatives of interested government agencies. Up to the publication of the draft Plan, the AG met a total of 20 times. All meetings were noticed through local media outlets and were open to the public. Meeting agendas and meeting minutes are available in the Project's document repository at the Anderson Valley Lending Library.

The role of the AG was to guide development of the Plan. Because of the broad range of interests represented by AG members, the Plan addresses many of the concerns and interests of the Anderson Valley community regarding the present condition of the watershed and directions for restoring it. AG members with technical expertise and experience in different fields also provided information for the Plan. The AG, along with interested members of the public, also reviewed and commented on each section of the document as it was drafted.

The major actions of the AG, through March, 1998 were:

Date	Action
4/22/95	Discussed and approved ground-rules for functioning of AG meetings.
5/10/95	Approval of Project goals, objectives, work plan, and the role of the AG (these went through three revisions, with AG members commenting on each).
7/12/95	Discussion and approval of use of data collected by volunteer monitors.
7/12/95	Selection of a consultant to prepare the Plan.
Dec. 95 and Jan 96	Discussion of Sediment Budget methodology
2/29/96	Approval of revised Sediment Budget methodology
4/25/96	Discussion of draft Field Study Plan
6/27/96	Approval of revised Field Study Plan
9/26/96	Formation of Water Conservation Subcommittee
11/7/96	Discussion of AG's role and meeting process. Discussion of expansion of role of AG beyond project oversight.
3/27/97	Review and discussion of fisheries study results
4/24/97	Approval of policy to support development of winter diversion ponds as a summer water conservation measure
5/23/97	Review and discussion of Sediment Budget results
6/26/97	Review of draft recommendations for restoration priorities. Direction to expand the draft recommendations to be more comprehensive.
8/28/97	Decision to proceed with drafting of recommended land management practices and demonstration projects. Approval of recommendations for restoration priorities.
8/97-9/97	Landowner survey and interviews to gage concerns regarding watershed health and interest in watershed restoration (Appendix H).
Oct. 1997-March 1998	Discussion and revision of draft recommended land management practices.

Table 1-1 indicates the membership of the AG over three years. During this time, several AG members dropped off of the group, some to be replaced by others who represented the same interest or organization; others withdrew from the process without appointing a replacement. Although invited, California Department of Forestry and Fire Protection (CDF) never participated in the Project.

The contract to prepare the Plan was originally awarded to Trihey & Associates, Inc. Mid-way through the project, Trihey & Associates, Inc. merged with ENTRIX, Inc., a consulting firm in Walnut Creek, California and took over the contract, though with little change in personnel working on the project. Subcontractors to ENTRIX, Inc. who worked on the project include Pacific Watershed Associates of Arcata, California, Circuit Rider Productions of Windsor, California, both of whom worked on portions of Sections 6.0 and 7.0; and Prof. Andre Lehre, Thomas Dunklin, and Rocco Fiori of Humboldt State University, who worked on the technical appendix to Section 3.0. Diane Sutherland of Humboldt State University prepared the maps for Section 3.0. Circuit Rider Productions prepared the over-sized watershed maps. The Navarro Estuary Study was conducted by Steve Cannata, under the direction of Prof. Terry Roelofs of Humboldt State University. The crew for the Estuary Study included Robert Baxter, Gisele Reaney, Michael Maahs, and Ernie Quintana. A complete list of the consultants who contributed to the preparation of this plan is provided below.

CONSULTANTS

Mitchell Katzel	Project Manager	ENTRIX, Inc.
Tom Taylor	Senior Fisheries Biologist	ENTRIX, Inc.
Michael Napolitano	Senior Geomorphologist	ENTRIX, Inc.
Lanette Davis	Fisheries Biologist	ENTRIX, Inc.
Joyce Ambrosius	Fisheries Biologist	ENTRIX, Inc.
Andrew Wilcox	Geomorphologist	ENTRIX, Inc.
Tom Dunklin	Geomorphologist	ENTRIX, Inc.
Rocco Fiori	Geomorphologist	ENTRIX, Inc.
Andre Lehre	Sr. Consulting Geomorphologist	Humboldt State University
Diane Sutherland	GIS Mapping	Humboldt State University
William Weaver	Geomorphologist	Pacific Watershed Assoc.
Danny Hagans	Geomorphologist	Pacific Watershed Assoc.
Karen Gaffney	Riparian Ecologist	Circuit Rider Productions
Katherine Gledhill	Autocadd Mapping	Circuit Rider Productions

1.4 ORGANIZATION OF THE RESTORATION PLAN

The Restoration Plan is organized into 11 sections, with accompanying appendices. The project goals and objectives are discussed in Section 2.0. A description of the technical studies which were performed and presentation of the results are provided in Section 3.0, *Sediment Production and Channel Conditions*, and Section 4.0, *Fish Distribution and*

Table 1-1. Advisory Group Members and Period of Service.

Name	Representing	Joined AG	Left AG	Notes
Hillary Adams	Navarro Estuary Project	4/95	1/97	Rixanne Wehren attended several meetings as an alternate
Josh Bartone	A.V. Unified School District	10/97	--	Replaced Rob Goodel
Sophia Bates	A.V. Youth	10/97	--	Replaced Chaya Mandelbaum
Morgan Baynham	A.V. Grange	4/95	--	
Marty Bradford	Livestock Growers	4/95	--	
Jeff Burroughs	Sports fishing	4/96	--	
Charles Crayne	Mendocino Co. R.C.D.	4/95	--	
Bruce Fodge	SWRCB	4/95	--	
Greg Frantz	SWRCB Water Quality Planning Program	4/95	--	
Gregory Giusti	Farm Advisor/Wildlands Ecology	4/95	--	
Rob Goodel	A.V. Unified School District	9/96	10/97	Replaced by Josh Bartone
Don Gowan	Farm Bureau	4/95	--	
Henry Gundling	Non-industrial Timberland Owner	4/95	3/96	
Bruce Gwynne	Regional Water Quality Control Board	12/95	--	Replaced Cecile Morris
Steve Hall	A.V. Community Services District	4/95	8/97	
Eva Johnson	Woolgrowers Association	4/95	--	
Weldon Jones	California Department of Fish and Game	4/95	7/97	Retired from CDFG
Richard Jordan	Supervisor Charles Peterson	4/95	--	
Helen Libeu	Sierra Club Redwood Chapter	4/95	--	
Louisiana Pacific Corp: Scott Butler, Tom Daugherty	Industrial Timberland Owners	4/95	11/97	Put up land in Watershed for sale

Table 1-1. Advisory Group Members and Period of Service (concluded).

Name	Representing	Joined AG	Left AG	Notes
Rick Macedo	California Department of Fish and Game	4/95	6/97	Transferred to another position
Chaya Mandelbaum	A.V. Youth	5/95	9/97	Left for college
Michael Maahs	Salmon Trawlers Assoc.	4/95	--	
Larry Mailliard	Non-Industrial Timberland Owners	1/98	--	
Sharon Moreland	Army Corps of Engineers	7/95	6/97	No replacement appointed by ACE
Cecile Morris	North Coast Regional Water Quality Control Board	4/95	12/95	Replaced by Bruce Gwynne
Daniel Myers	Friends of the Navarro	6/96	--	Replaced Diane Paget
Diane Paget	Friends of the Navarro	4/95	6/96	Replaced by Dan Myers
Renee Pasquinelli	California Dept of Parks and Rec.	4/95	--	
Tom Schott	Natural Resources Conservation Service	4/95	--	
Karen Taussig	A.V. Unified School District	4/95	8/96	Replaced by Rob Goodel
Chris Tebbut	Redwood Coast Watersheds	4/95	8/97	Linda Perkins attended several meetings as an alternate
Martin Ukofsky	CalTrans	1/97	--	
Steve Williams	Wine growers	4/95	--	

Aquatic Habitat Conditions. In Section 5.0, *Restoration/Conservation Objectives and Priorities*, the technical study results presented in Sections 3.0 and 4.0 are integrated to provide a characterization of the conditions, limiting factors, and restoration potential within each of the major drainage basins. Section 5.0 concludes by establishing objectives and priority actions for each basin. In Section 6.0*, Recommended Land Management Practices*, the types of impacts associated with each of the major land-uses are discussed. A wide range of recommended land management practices are described to address the water quality problems, and to protect and restore the anadromous fishery. Section 7.0, *Demonstration Project Designs*, presents several restoration projects, including site-specific measures and plans for riparian revegetation, gully erosion control, and re-design of roads to prevent erosion and reduce sediment delivery to streams. In Section 8.0*, Public Information and Education,* the location and content of reports, maps, and other documents relevant to restoration planning in the watershed is described. In addition, the role of public schools in watershed restoration is discussed. Section 9.0, *Implementation Plan*, considers overall implementation strategies, funding opportunities, permit requirements, monitoring programs, and describes the roles of private organizations and governmental agencies in implementation of an overall restoration strategy. Section 10.0, *Bibliography*, provides an extensive listing and description of reports, maps, and other information sources that were reviewed for the fisheries, sediment production, and channel condition studies.

Appendices A through H provide the technical data and analyses related to the various scientific studies which were performed for this project. As part of the Navarro Restoration Plan, a detailed watershed database was prepared using the geographic information system ARC-INFO. The database consists of a series of over-sized maps produced at 1:24,000 scale (7.5 minute series U.S. Geological Survey quadrangles) which cover the Navarro watershed. Geology, fisheries, and vegetation cover type data are provided on the maps. Due to the large size of each map, they are not included in this report, but are archived at the Mendocino County Water Agency, the AVLT, and the Anderson Valley Lending Library in Boonville. Smaller scale maps (1:195,000) are replicated for the geology and vegetation cover data in Appendix G. A summary version of the fisheries map data (1:195,000 scale) is reproduced in Section 4.0

PROJECT GOALS AND OBJECTIVES

At the outset of the process to prepare the Navarro Watershed Restoration Plan, the project's Community Advisory Group (AG) established the following goals:

- Restore water quality, salmon fishery, and former abundance of other renewable resources within the Navarro watershed.
- Sustain a diverse, viable local economy that is in balance with a natural environment rich in diversity of native species and habitats.
- Enhance the efforts of those who live and work in the Navarro watershed in taking personal responsibility for managing their land in order to minimize negative impacts on the health of the watershed, respecting both the rights and responsibilities of private property.
- Facilitate cooperation between government agencies and landowners so that government regulations help, and do not hinder, efforts to restore and maintain the health of the watershed.

To achieve these goals, the AG set the following objectives for the planning process:

- Perform the technical studies necessary to identify the factors which are adversely affecting water quality and fish habitat, including studies related to sedimentation, fish distribution, review of temperature and streamflow data, and consideration of other aquatic and riparian habitat conditions which may be important to the recovery of salmon populations and improving water quality
- Develop land management strategies and restoration designs to improve water quality.
- Develop land management strategies and restoration designs to improve salmon habitat.
- Identify and rank sub-basins and stream reaches based on their suitability and value for fish habitat and water quality restoration or conservation activities.
- Recommend land management strategies and restoration activities to decrease sediment delivery to streams from forest lands, range lands, agricultural lands, and residential areas in the watershed.
- Recommend restoration activities that include a range of scales and costs, and a range of technologies.

- Formulate restoration strategies that ensure involvement and endorsement of the local community, resource and regulatory agencies.

- Disseminate the findings of the project and other relevant information to residents and landowners in the Navarro watershed to facilitate future voluntary implementation of restoration plans and land management strategies.

The following chapters represent the realization of the AG's directives.

The federal government has listed the Navarro as an "impaired water body" because of sedimentation,[2] and the decline in the salmon and steelhead fishery is attributable in part to sedimentation. Fine sediments -- silt and sand -- can choke spawning beds, and coarser sediments -- gravel, cobbles, and boulders -- fill deep pools and change the shape of stream channels. Some of the consequences of excess sedimentation in stream channels include destabilized stream banks; broader, shallower channels in which water is more likely to heat up; and streambed aggradation, or raising the level of the channel bed.

The Project undertook a study to identify sediment sources and sediment-related impacts to channels and fish habitat in the Navarro watershed. Because the primary goals of the Navarro Watershed Restoration Plan are to restore and enhance the Navarro's anadromous fishery and to improve water quality, the focus of this study is on those landscape features and geomorphic processes which deliver sediment to stream channels. The study includes an analysis of *sediment production*, defined as the rate at which sediment enters stream channels from various sources; an investigation of the recent changes in the amount of sediment stored in stream channels and the effects of accelerated sediment production on stream channels over the past several decades; and an evaluation of the capacity of the Navarro River to carry bedload sediment through its main channel near its mouth.

The Navarro River sediment budget, fisheries, and channel condition studies provide a quantitative, scientific basis for restoration planning. The sediment production and channel conditions studies are used for two purposes:

- to identify the major erosion processes that contribute sediment to stream channels, in order to focus planning efforts for erosion prevention and control;

- to discern the long-term trends in sedimentation and stream channel responses to it. This provides insight into the Watershed's ability to recover from past disturbances, and the likelihood of success of in-stream restoration efforts.

This chapter summarizes the finding of the sediment production and channel conditions studies prepared for the Plan. The full text of these studies is presented in Technical Appendix A.

[2]The Navarro has also recently been listed as an impaired water body due to high temperatures.

3.1 SCOPE AND PURPOSE

Sources and quantities of sediment in the Navarro Watershed were determined by constructing an order-of-magnitude sediment budget, using Reid and Dunne's "Rapid evaluation of sediment budgets" method. A sediment budget is an accounting of the sources and disposition of sediment as it travels from its point of origin to its eventual exit from a drainage basin (Reid 1995). The level-of-precision, specific types of information required, and the methods used to gather the information for a sediment budget are dependent upon the specific questions and resource problems that are to be addressed by land managers. The sediment budget for the Navarro Watershed identifies the origin of sediment entering stream channels, estimates the amount of sediment delivered to stream channels, and determines what happens to sediment once it enters the stream system.

The sediment budget was constructed from field data, aerial photographic interpretation, and a review of the available scientific literature. The results of the sediment budget, in conjunction with other studies to characterize fish habitat and channel conditions, provide a context for prioritizing watershed restoration efforts: the sediment budget is used to determine the relative importance of different sediment sources in order to assign priorities for erosion control.

The channel conditions study prepared for the plan describes sediment and non-sediment related impacts to salmonid habitat and discusses the disposition of sediments that are delivered to stream channels. This study includes the following elements:

- *Channel Sediment Routing,* characterizes how sediment input to the channels is accommodated;
- *Bedload Yield*, estimates the bedload transport capacity of the mainstem Navarro River near the mouth.
- *Channel Sediment Storage* describes the volume, distribution, and recent historical patterns of sediments stored in the channel of the major tributaries and mainstem Navarro River, and recent historical changes in channel width.
- *Channel Conditions*, discusses channel morphology, pool and bank forming factors, and changes in channel width.

The findings of these studies are summarized below. The full text of the studies are presented in Technical Appendix A.

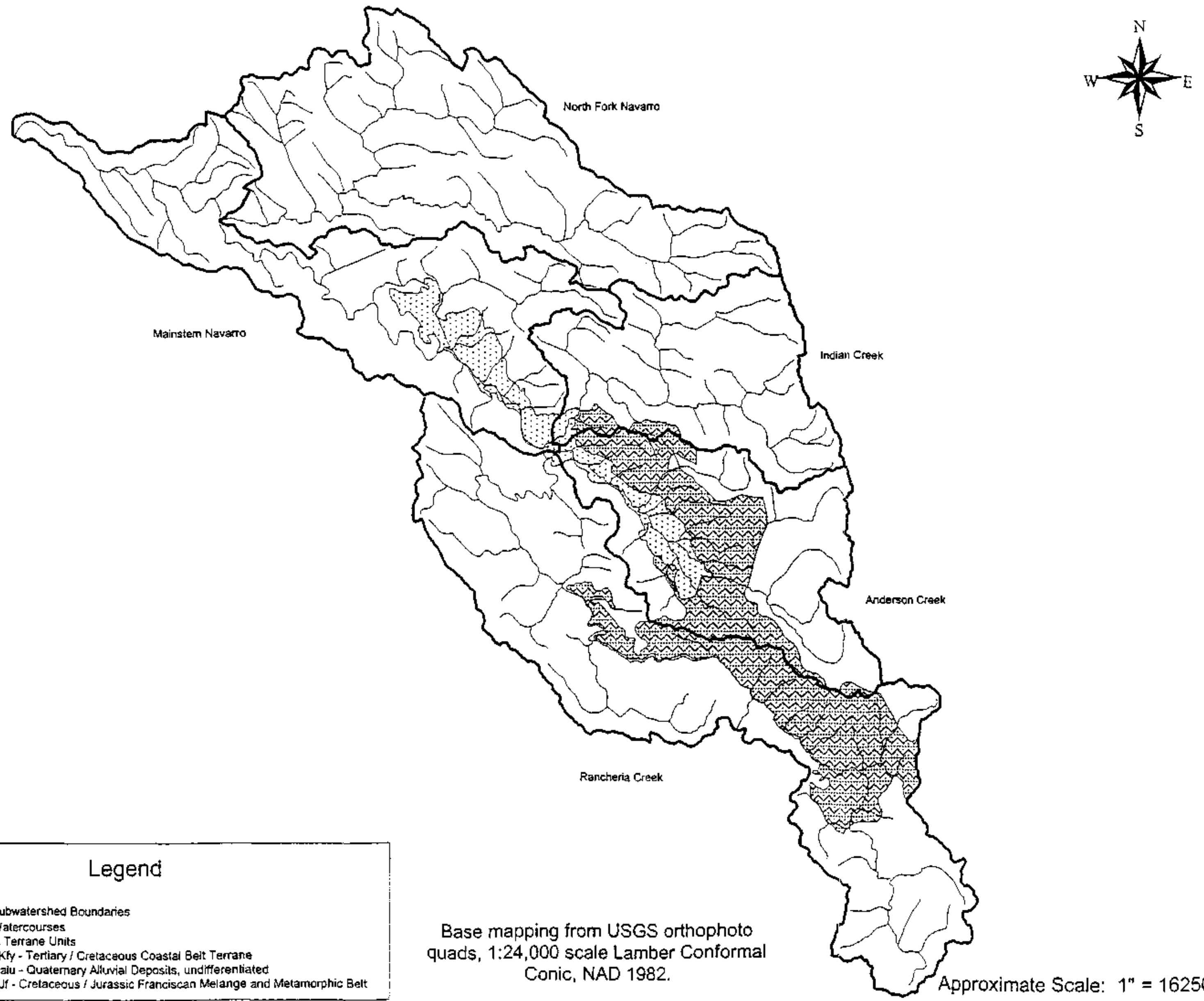


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Figure 3-1

Erosion Terrane Units in the Navarro River Basin

Navarro Watershed Restoration Plan

Legend

- Subwatershed Boundaries
- Watercourses

Erosion Terrane Units

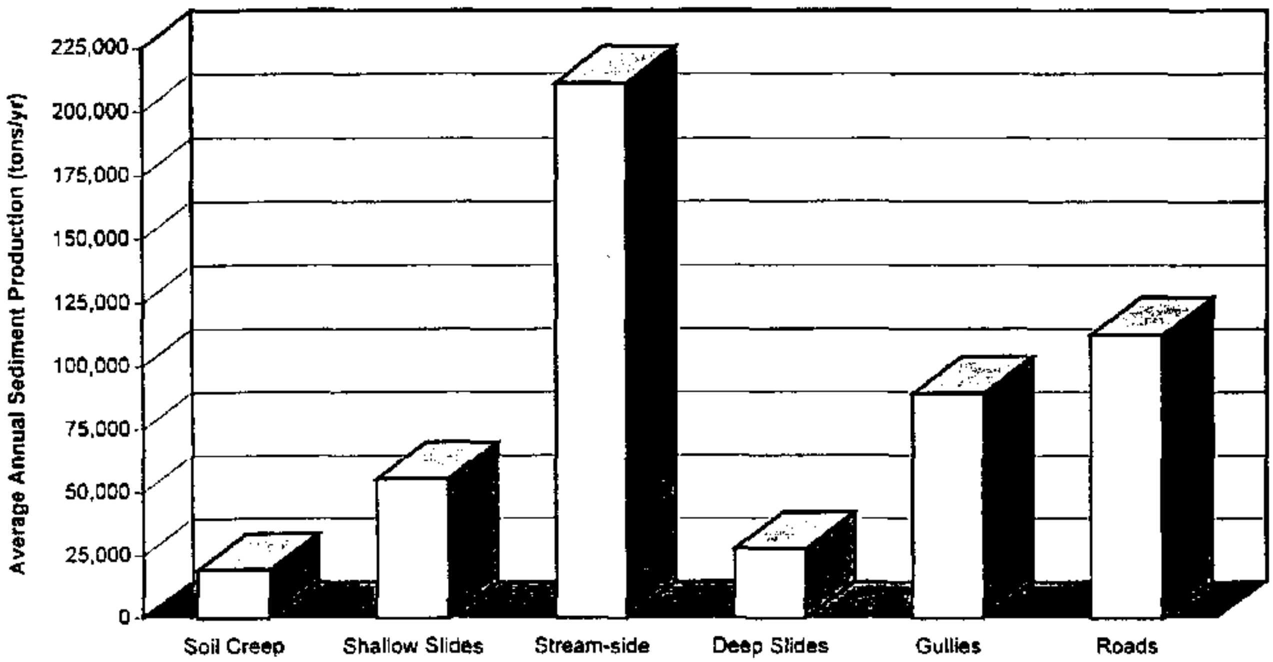
- TKfy - Tertiary / Cretaceous Coastal Belt Terrane
- Qalu - Quaternary Alluvial Deposits, undifferentiated
- KJf - Cretaceous / Jurassic Franciscan Melange and Metamorphic Belt

Base mapping from USGS orthophoto quads, 1:24,000 scale Lamber Conformal Conic, NAD 1982.

Approximate Scale: 1" = 16250'

Table 3-1. Navarro Watershed Sediment Production by Source and Basin.

	Bank Erosion & Shallow Slides 1st & 2nd Order Channels		Bank Erosion & Shallow Slides 3rd & Larger Order Channels		Gullies		Deep-seated Landslides		Roads		Total Sediment Production	
	(tons/yr.)	(%)	tons/yr.)	(%)	(ton/yr.)	(%)	(tons/yr.)	(%)	(tons/yr.)	(%)	(tons/yr.)	(ton/mi^2/yr.)
Anderson Creek	12,100	11%	53,500	49%	25,300	23%	0	0%	18,100	17%	109,000	2,400
Indian Creek	10,500	25%	15,600	38%	10,700	26%	0	0%	4,700	11%	41,500	1,100
Mainstem Navarro	12,100	13%	31,500	34%	3,900	4%	15,700	17%	30,200	32%	93,400	1,500
North Fork Navarro	15,000	17%	20,700	23%	1,900	2%	0	0%	53,300	59%	90,900	1,200
Rancheria Creek	24,900	16%	62,100	40%	36,000	23%	12,000	8%	20,700	13%	155,700	1,700
Navarro Watershed	74,600	15%	183,400	37%	77,800	16%	27,700	6%	127,000	26%	490,500	1,600



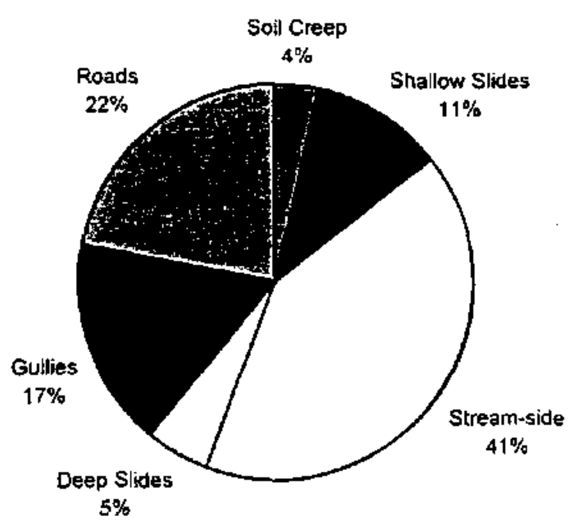
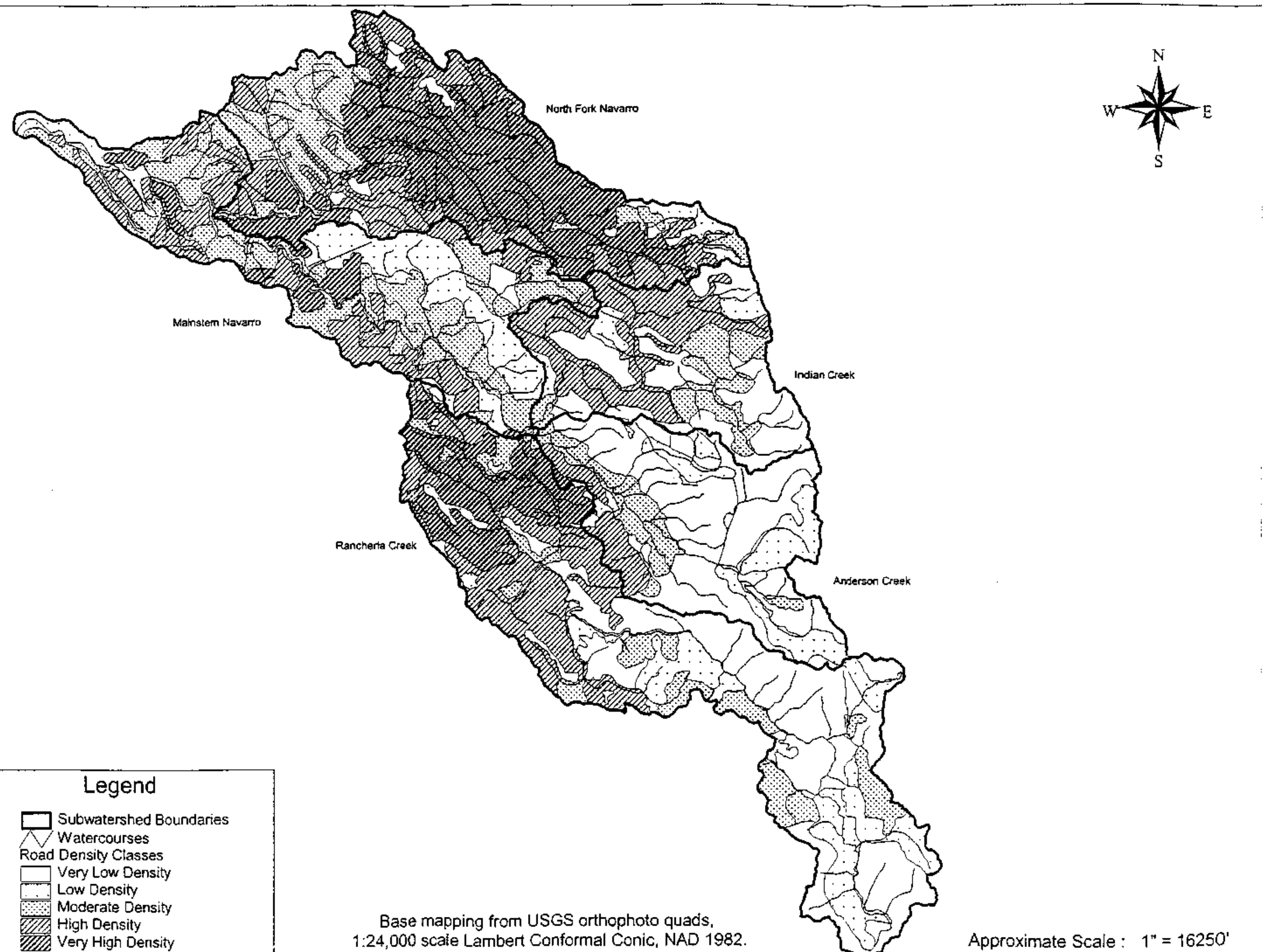


Figure 3-2. Sediment Production by Source.



ENTRIX

Figure 3-3

Road Density Classes in the Navarro River Basin

Navarro Watershed Restoration Plan

Legend

Subwatershed Boundaries
Watercourses
Road Density Classes
Very Low Density
Low Density
Moderate Density
High Density
Very High Density

Base mapping from USGS orthophoto quads, 1:24,000 scale Lambert Conformal Conic, NAD 1982.

Approximate Scale : 1" = 16250'

3.2 FINDINGS

The major findings of the sediment budget and the channel conditions studies are as follows[3]:

1. Erosion rates and rates of sediment production to stream channels are closely related to soil type and to the underlying geology. The Navarro watershed includes highly erodible soils derived from rocks associated with the melange unit of the Franciscan Assemblage, found in much of the Anderson Creek basin, middle and upper Rancheria Creek basin, and a portion of the Indian Creek basin. Soils associated with the Coastal Belt of the Franciscan Assemblage, found in much of the rest of the watershed, are more stable and resistant to erosion. Alluvial fill, found in the Anderson Valley and in low-lying reaches of the major tributaries, is also highly erodible. The location of Melange, Coastal Belt, and Alluvial Fill terrane types are shown in Figure 3-1. The overall estimated rate of sediment production to stream channels in the Navarro watershed is 490,500 tons per year. The contribution of sediment from each of the major sources to streams throughout the watershed is shown in Table 3-1 and in Figure 3-2.

2. Sediment production rates today (1980's to 1990's) are lower than they were during the recent historical period (1950's to 1970's). This change is likely due to improved timber harvest practices and regulations, as well as to generally improved road construction and maintenance practices for active logging roads. However, present-day rates of sediment production remain undesirably high in comparison with the pre-settlement era, and hence some impacts to salmon habitat continue to persist today.

3. Most tributaries and extensive reaches of the main trunk streams -- for example, Indian Creek, mainstem Navarro, lower Rancheria, North Fork Navarro -- are recovering from channel aggradation and widening that was initiated in the 1950's or 1960's. The current trend in these streams appears to be toward recovery, as most channels are narrowing and scouring their beds, returning to about pre-aggradation levels.

4. Streambed aggradation and channel widening persists in only a few of the major trunk streams where the gradient is gentle and the valley width is large; for example Anderson Creek in the Anderson Valley, and in upper and middle Rancheria Creek. More detailed follow-up studies are needed to determine the future trends in channel sedimentation at these locations.

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[3]Please note that the annual tonnage figures stated in this section are estimates that are accurate within an order of magnitude (a factor of 10), which is the intended level of accuracy for this study. Also, annual rates are averaged over a period of years.

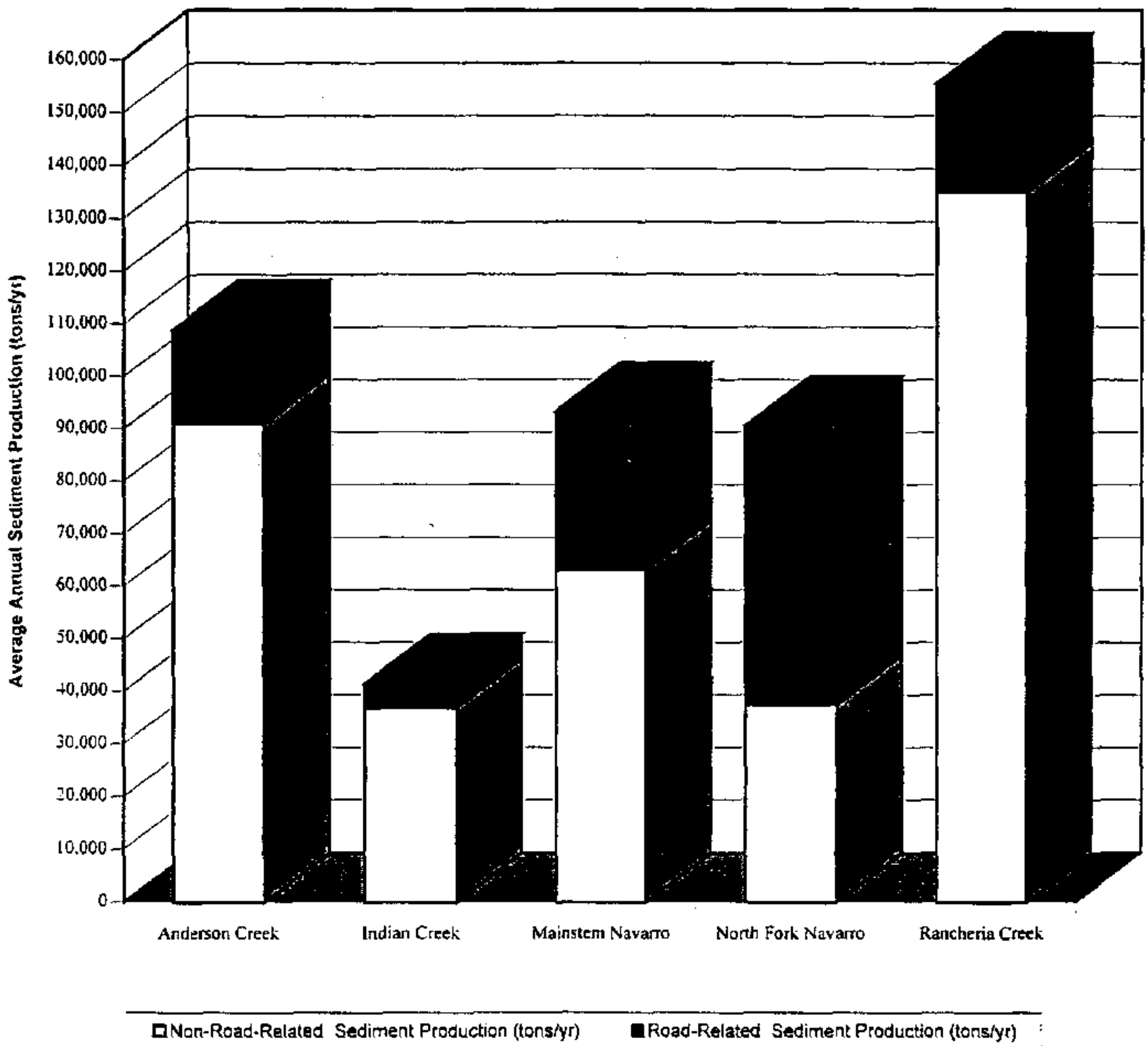


Figure 3-4. Road and Non-road Related Sediment Production by Basin.

Table 3-2. Sediment Production By Geology-Vegetation Units (sources other than roads).

Geology-Vegetation (General Locations)	Drainage Area (mi^2)	Stream Order	Source	Sediment Production (tons/yr)	Sediment Production ($tons/mi^2/yr$)	% of Total
Melange-Grassland	37.5	1 and 2	Shallow slides 1st-2nd order	15,600	420	10.5%
(Anderson Ck basin,		3 thru 6	Shallow slides 3rd-8th order	78,000	2,080	52.8%
Upper Rancheria Ck)		na	Gullies	54,000	440	36.6
			subtotal	147,600	3,900	100.0%
Coastal-Belt, forested	211.5	1 and 2	Shallow slides 1st-2nd order	41,200	190	32.6%
(North Fk. Navarro,		3 thru 8	Shallow slides 3rd-8th order	58,000	270	45.7%
Lower Rancheria Ck,			Deep-seated Landslides	27,600	130	21.8%
Mainstem Navarro)						
			subtotal	126,800	600	100.0%
Coastal-Belt, grass-scrub	53	1 and 2	Shallow slides 1st-2nd order	17,800	330	30.4%
(North Fk. Navarro,		3 thru 8	Shallow slides 3rd-8th order	17,100	320	29.2%
Rancheria Ck, Indian Ck		na	Gullies	23,700	450	40.4%
Mainstem Navarro)						
			subtotal	58,600	1,100	100.0%
Valley Fill	13.2	1 thru 4	Shallow slides 1st-2nd order	15,455	1,200	51.4%
		5 thru 7	Shallow slides 3rd-8th order	14,600	1,100	48.6%
(Anderson Valley)						
Navarro River)			subtotal	30.055	2,300	100%

5. The most pervasive sediment problem affecting stream channels today is an excess of fine sediment. Fine sediment deposition is typically most extreme on the larger streams where the gradient is relatively low and the valley bottom is wide. However, observations made in a wide variety of stream reach types and sizes indicates that fine sediment deposition is widespread throughout the watershed.

6. Roads are one of two major contributors to elevated levels of sediment entering stream channels. The Navarro watershed is heavily, but not uniformly roaded (Figure 3-3). The amount of sediment eroded from roads and entering stream channels is related to road density, road type and level of use, geology, and topographic location. Those subbasins with the highest rates and overall levels of road-related production of sediment to stream channels are the North Fork Navarro and Main Stem Navarro basins (see Table 3-1 and Figure 3-4). Total road-related sediment production is estimated at 127,000 tons per year, about 26 percent of total sediment production.

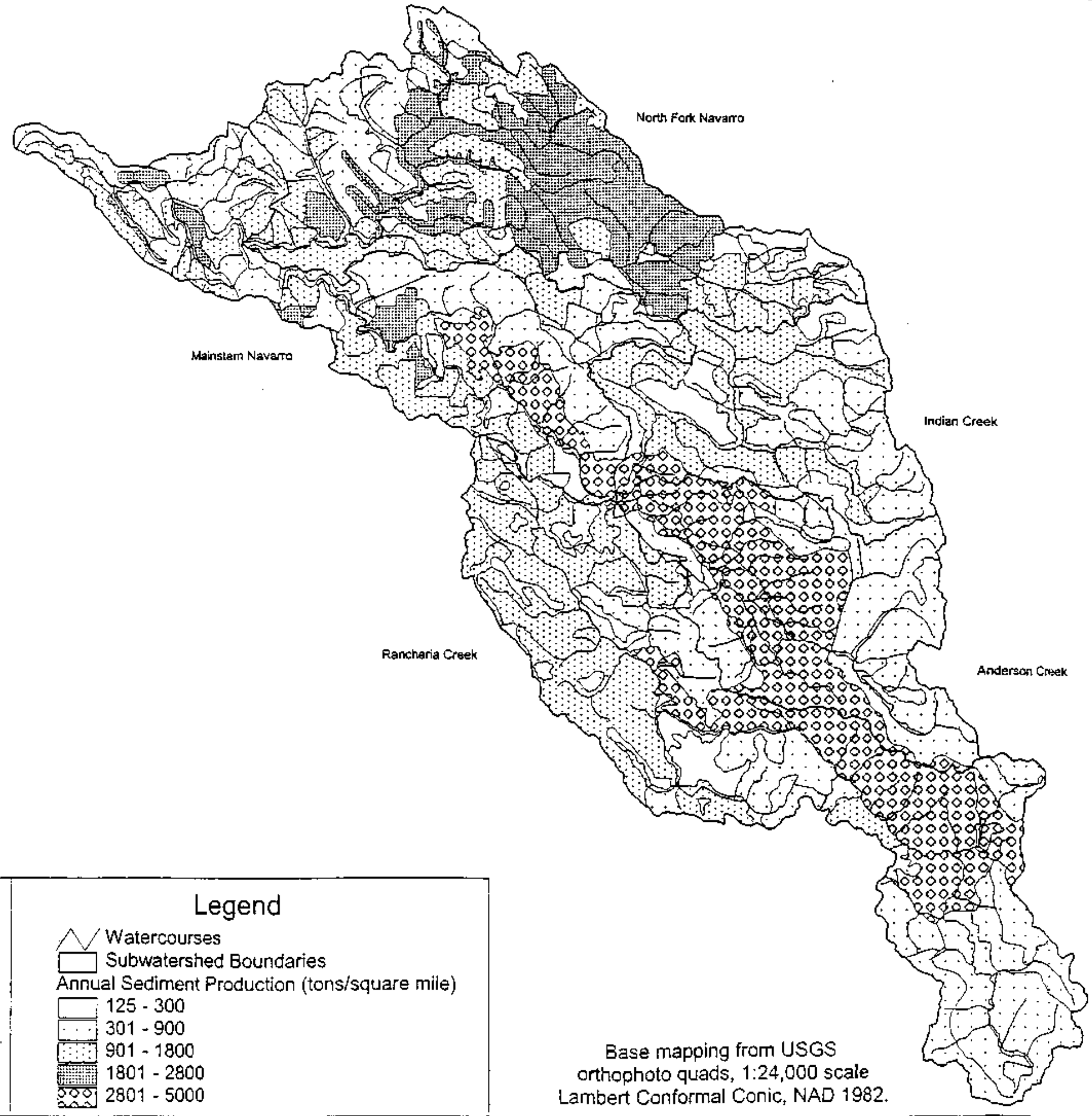
7. Bank erosion and shallow landslides to third order and larger channels, primarily flowing through alluvial valleys and in streams flowing through the melange terrain, is the other major contributor of sediment. Total sediment production to channels from bank erosion and shallow landslides in larger streams is estimated at 183,400 tons per year, about 37% of total sediment production (see Table 3-1).

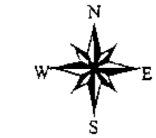
8. Bank erosion and shallow landslides to first and second order channels, and gullies, constitute the next tier of sources of sediment production to stream channels. Shallow-seated landslides occurring in hillslope hollows produce large quantities of sediment to lower order (smaller) channels in forested and grassland coastal belt terrain (Table 3-2). Bank erosion and shallow-seated landslides to smaller channels contribute an estimated 74,600 tons per year, about 15% of total sediment production (see Table 3-1). Gullies are most problematic in the melange terrain and in Coastal Belt grasslands and oak woodlands, where they produce significant quantities of sediment, primarily to higher order stream channels (Table 3-2). Total sediment production to stream channels from gullies is estimated at 77,800 tons per year, about 16% of total sediment production (see Table 3-1).

9. Deep-seated landslides account for an estimated 27,700 tons of sediment per year, about 6% of total sediment production (see Table 3-1). Deep-seated landslides are not significant sediment production sources in Anderson Creek, Indian Creek, or North Fork Navarro basins. A relatively small percentage (8%) of sediment delivered to stream channels is derived from deep-seated landslides in the Rancheria Creek basin. Only in the mainstem Navarro River basin are deep-seated landslides a relatively important sediment production source, accounting for approximately 17% of all sediment delivered to stream channels.

Table 3-3. Sediment Production Rates by Basin.

	Drainage Area (mi²)	Non-Road-Related Sediment Production		Road-Related Sediment Production		Total Sediment Production	
		(tons/yr.)	(tons/mi²/yr.)	(tons/yr.)	(tons/mi²/yr.)	(tons/yr.)	(tons/mi²/yr.)
Anderson Creek	46	91,600	2,000	18,100	390	109,000	2,400
Indian Creek	39	36,900	900	4,700	120	41,600	1,100
Mainstem Navarro	63	63,900	1,000	30,200	480	93,400	1,500
North Fork Navarro	74	37,500	500	53,300	720	90,800	1,200
Rancheria Creek	94	135,400	1,400	20,700	220	155,700	1,700
Navarro Watershed	315	365,300	1,200	127,000	400	490,500	1,600





ENTRIX

Figure 3-5

Regional Sediment Production

Navarro River Basin

Navarro Watershed Restoration Plan

Legend

- Watercourses
- Subwatershed Boundaries

Annual Sediment Production (tons/square mile)

- 125 - 300
- 301 - 900
- 901 - 1800
- 1801 - 2800
- 2801 - 5000

Base mapping from USGS
orthophoto quads, 1:24,000 scale
Lambert Conformal Conic, NAD 1982.

Approximate Scale: 1" = 16250'

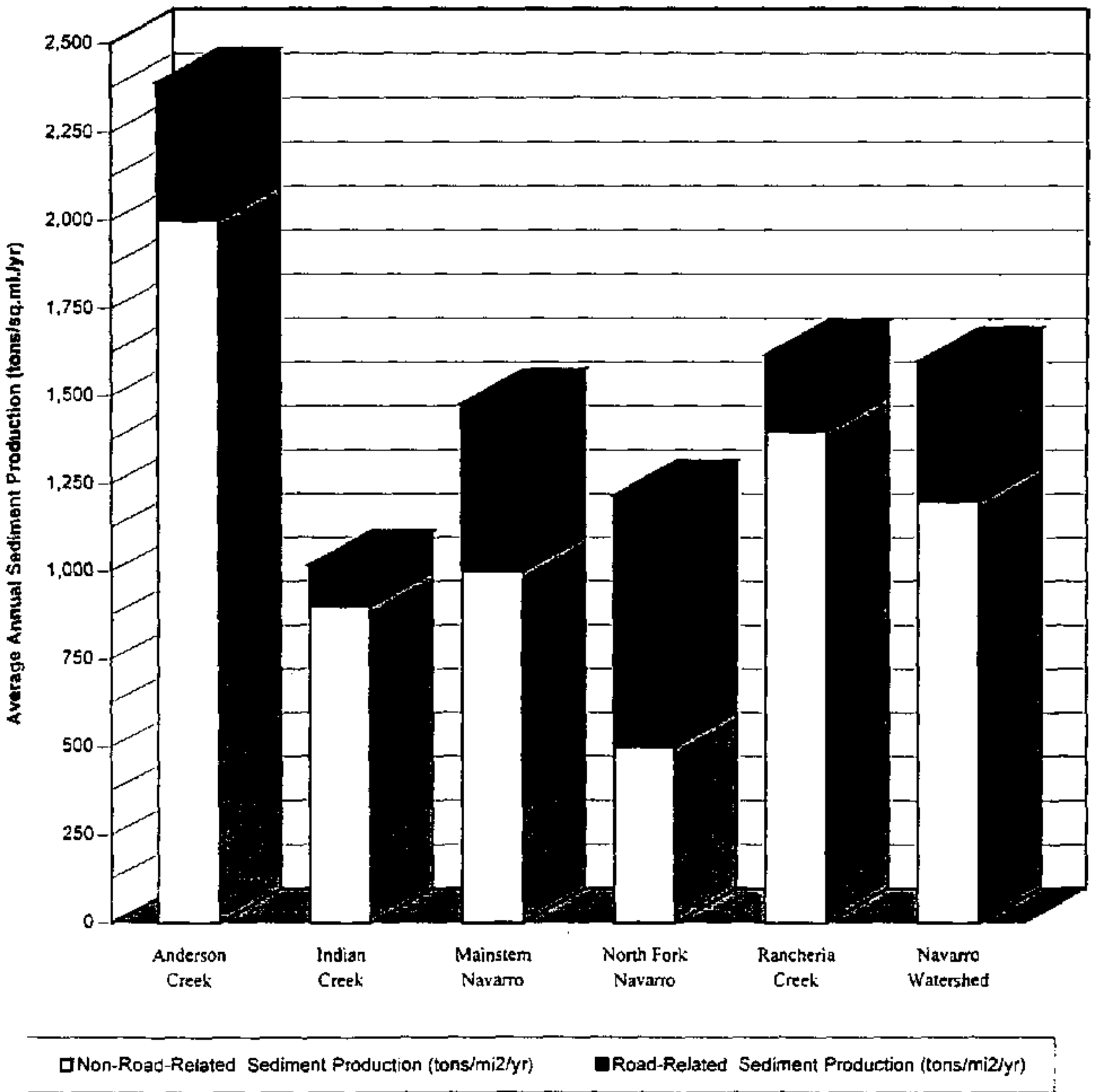


Figure 3-6. Sediment Production Per Square Mile.

Table 3-4. Summary of Channel Condition Surveys, 1996.

Stream	Channel Aggradation	Fine Sediment	Coarse Sediment	Bank Erosion	Loss of LWD[1]	Steelhead	Coho
Bear Wallow Creek	No	Yes	No	High	Yes	Yes	No
Con Creek	No	Yes	Yes	High	Yes	Yes	No
John Smith Creek	No	Yes	No	Moderate	Yes	Yes	Yes
Little North Fk Navarro	No	No	No	Low	Yes	Yes	Yes
Mill Creek (Meyer Gulch reach)	No	Yes	No	Low	Yes	Yes	No
Mill Creek (Red Hill Gulch reach)	No	Yes	No	High	Yes	Yes	No
Marsh Gulch	No	No	No	Low	No	Yes	Yes
North Branch North Fk Navarro	Yes	Yes	Yes	Moderate	Yes	Yes	Yes
North Fork Indian Creek	Yes	No	Yes	Moderate	Yes	Yes	No
Ray's Gulch	No	Yes	No	Low	Yes[2]	No	No
So. Branch No. Fk. Navarro (Bailey Gulch-downstr.)	No	Yes	No	Low	Yes	No	No
So. Branch No. Fk. Navarro (McGarvey Ck to Shingle Mill Ck)	No	No	No	Low	Yes	Yes	No

[1] Loss of stable, large caliber tree trunks and root-wads

[2] Ray's Gulch has an accumulation of small unstable woody debris

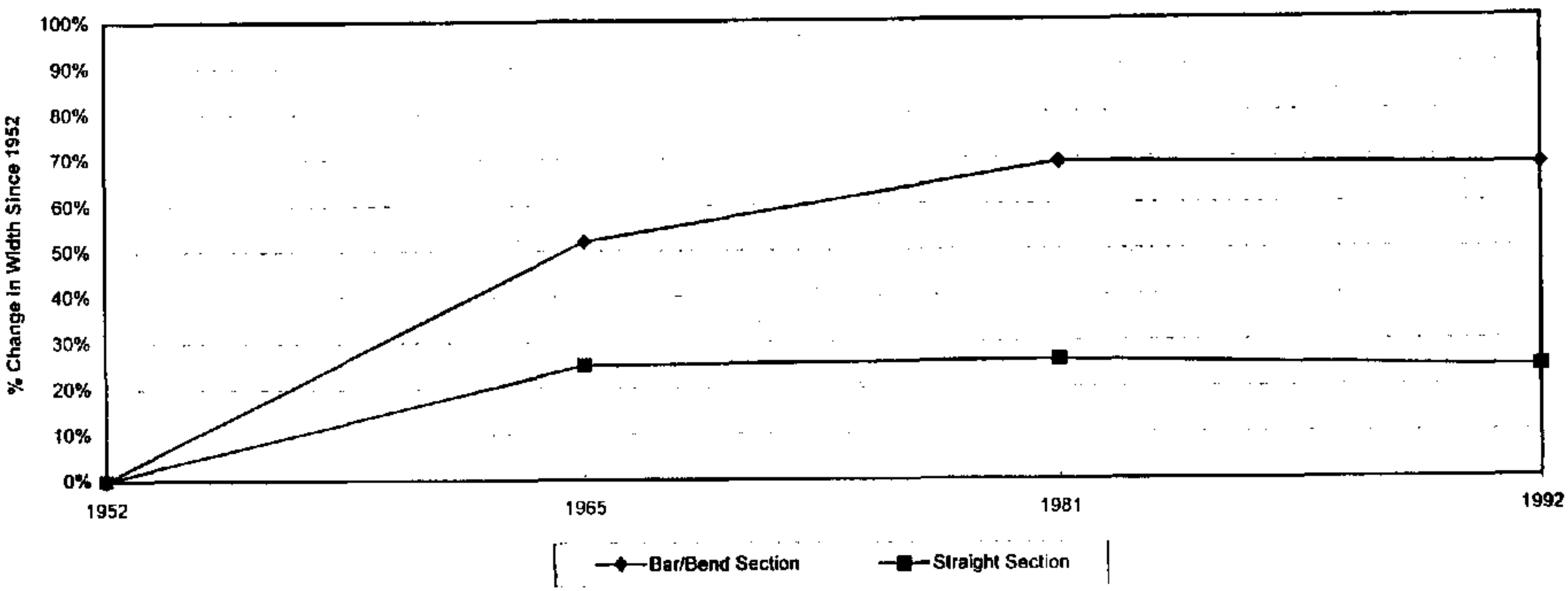
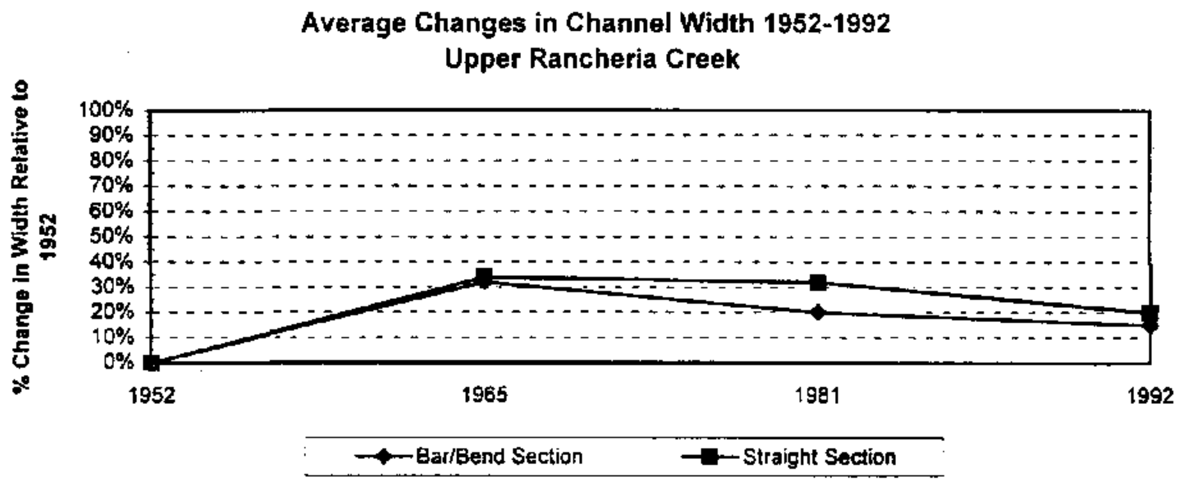
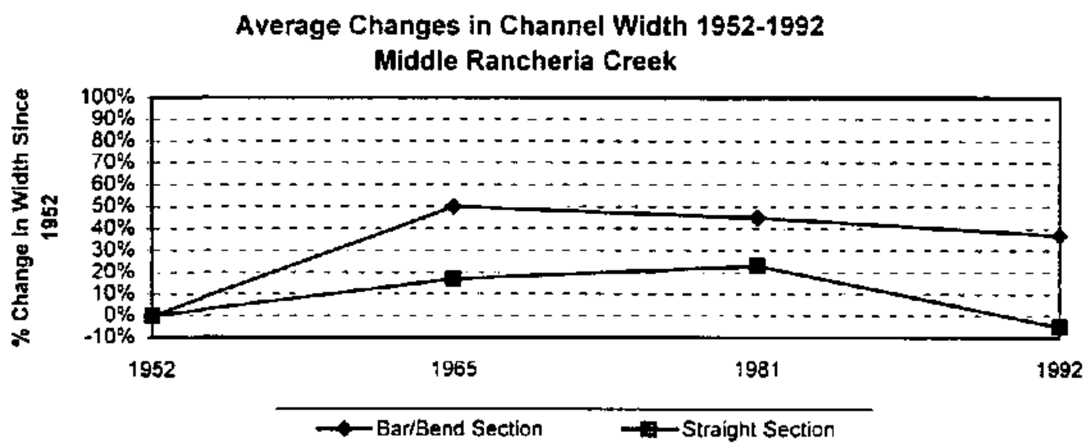


Figure 3-7. Average Changes in Channel Width 1952-1992 Anderson Creek in Anderson Valley.





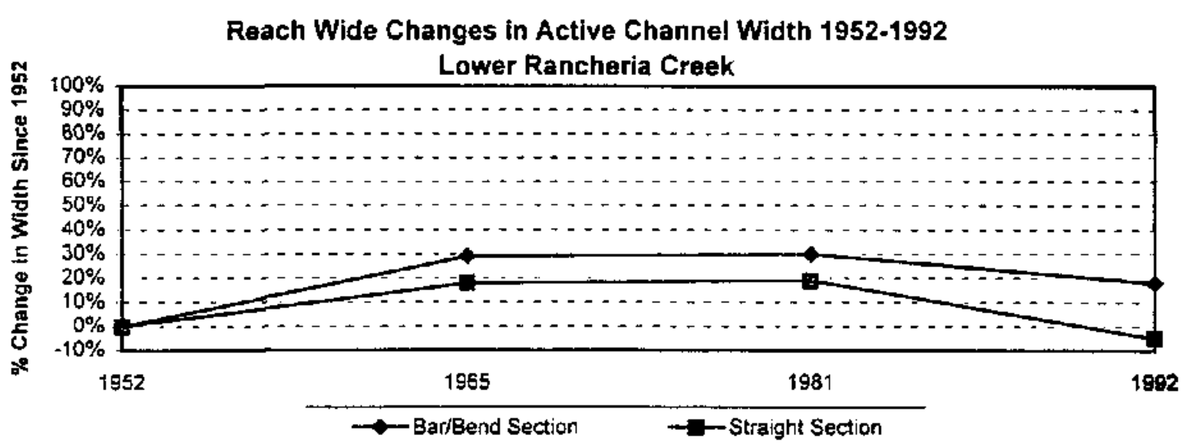


Figure 3-8. Average Changes in Channel Width 1952-1992 - Rancheria Creek.

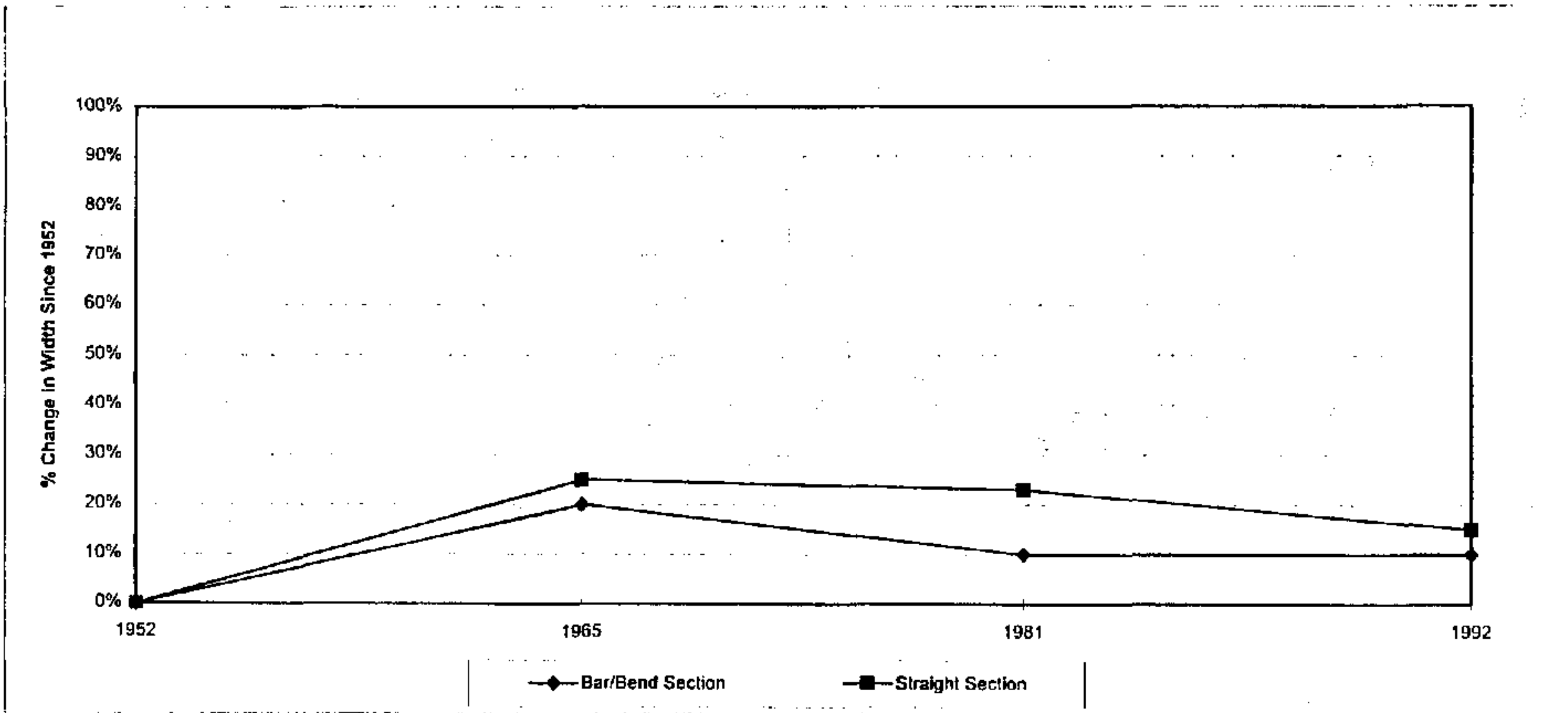


Figure 3-9. Average Changes in Channel Width 1952-1992 - Navarro River.

10. The major basins that contribute the most sediment to their respective streams are Rancheria Creek and Anderson Creek basins. These are followed by the Mainstem Navarro basin, North Fork basin, and the Indian Creek basin (see Table 3-1 and Figure 3-5).

11. The highest rates of sediment production to stream channels, calculated on the basis of tons per square mile of drainage area, are found in the Anderson Creek basin, followed by the Rancheria Creek, Main Stem Navarro River, North Fork Navarro River, and Indian Creek basins (see Table 3-3, and Figures 3-4 and 3-6). The significantly higher rates and total amount of sediment from the Anderson Creek subbasin are attributable primarily to the highly erodible soils and Franciscan melange geology.

12. Most of the sediment that enters first and second order stream channels is transported relatively quickly to lower gradient, higher order streams. This is attributable to their steepness, their confinement within narrow valleys, and their lack of large woody debris (Table 3-4).

13. The lower gradient reaches of the higher order streams where they flow through wide valleys, such as Anderson Creek in the Anderson Valley, and reaches of Rancheria Creek along Highway 128 and upstream, have accumulated large quantities of sediment in recent decades. This is evident in aerial photographs, which show a widening of stream channels and the development of large unvegetated gravel bars between 1952 and 1992, in repeated surveys of channel cross sections at bridges, which indicate channel aggradation in some streams, and in anecdotal reports of long-time residents of the filling of deep pools and of changes in stream channels. Much of the sediment accumulation appears to be related to the timber boom of the late 1930's through the early 1950's, and to the large floods of 1955, 1964, and 1974. There is evidence that in recent years, these channels (with the exception of Anderson Creek and portions of Rancheria Creek) have scoured back down to near their 1952 levels, and there has been some narrowing in channel width (Figures 3-7 through 3-9). These streams, however, still exhibit poorly developed riparian vegetation, shallow pools, and a large amount of frequently mobilized sediment.

14. As of 1952, many tributary streams that flow through narrow valleys had complete canopy closure for several miles. Today many of these streams have discontinuous canopy closure. This causes stream temperatures to be much more responsive to changes in air temperature and exposes them to direct solar heating. Where streams are located in close proximity to the coast (e.g., South Branch North Fork Navarro River), the increase in stream temperature as a result of stream canopy opening is moderated. At inland locales (e.g., Anderson valley and further upstream, the upper Indian Creek basin, and the upper Rancheria Creek basin), stream temperature increases as a result of canopy opening are greater because maximum air temperatures are higher than in the coastal areas.

Present-day stream temperatures in most locations along the large, inland streams (with open canopies) are not suitable for coho salmon.

15. Sixteen miles of stream channels within a wide variety of sub-basin settings (e.g., geology, vegetation, land uses) were surveyed to characterize present-day channel conditions in relation to salmonid habitat quality, sediment storage, and channel stability (see Table 3-4). Channel aggradation and widening were only apparent in three of the reaches surveyed. Based upon these surveys and the channel storage assessment (technical Appendix A), channel aggradation and widening are not as widespread today as they were two or three decades ago. The most widespread sediment related problem today is chronic deposition of fine sediment. This problem manifests as accumulation of fine sediment in pools and in riffles.

16. Another widespread, non-sediment related impact to channels in the Navarro River basin is the loss of large, stable woody debris in channels (see Table 3-4). Prior to the 1950's and 1960's, large, old-growth, redwood trunks were common in many channels. These large woody debris trunks created: a) diverse channel morphology, habitat complexity, and excellent cover for fish; b) deep and frequent pools; c) sediment storage sites that buffered streams from the impacts of high sediment production occurring as a result of natural or land use related disturbances, and d) sites for deposition and retention of spawning gravels. Much of the large woody debris was removed in the 1950's and 1960's as part of salvage logging operations or because fisheries managers believed that the debris created barriers to upstream migration by steelhead and coho salmon.

3.3 CONCLUSIONS

Sediment production to streams throughout the Navarro watershed is generally less today than it has been in the recent past (1950's-1970's). However, fine sediment deposition in channels is widespread. This is due to excess sediment production caused by roads, timber harvest, agriculture, grazing, grading, and other land disturbances. The effects of these high levels of sediment input to streams are most keenly felt in the lower gradient reaches of the major tributaries. These lower-gradient main tributaries, primarily Anderson Creek in the Anderson Valley, and mid-to-upper Rancheria Creek, have also been subject to channel aggradation and widening due to coarse sediment accumulation. These channel changes, in turn, result in increased bank erosion and input of additional sediment.

Other significant impacts to channels and fish habitat that limit steelhead and coho distribution and abundance in the Navarro watershed are: (1) loss of large woody debris and (2) elevated stream temperatures. The loss of large woody debris is directly related to a reduction in habitat complexity, lack of high-quality cover, and a reduction in the frequency of pools. High stream temperatures and large diurnal fluctuations in temperature are related to opening of the stream canopy, as well as to shallowing and widening of the channel due to sediment accumulation.

3.4 IMPLICATIONS FOR RESTORATION PLANNING

The findings and conclusions of the sediment budget and channel conditions studies help shape restoration planning priorities and strategies. The following points constitute a distillation of the these studies and their application to restoration planning.

- Roads are responsible for approximately 26% of the sediment production delivered to stream channels over the Navarro watershed.

- Road-related erosion accounts for a significant portion of the total (tons/yr.) and unit (tons\mi^2\yr) sediment production (see Table 3-4, Figures 3-4 and 3-6) in the North Fork and Mainstem Navarro basins. Therefore, restoration actions taken to reduce erosion from roads in the North Fork Navarro and Mainstem Navarro basins are likely to substantially reduce total sediment delivery to streams in those basins.

- The forested Coastal-Belt terrain generally has the highest density of roaded area and road-related erosion is a significant contributor to total sediment production in this terrain. A comprehensive road erosion control and prevention program in forested Coastal-Belt sub-basins should be considered as a primary element of the watershed-wide restoration planning effort.

- The results of the road-related sediment production assessment indicate that there has been a relatively small increase in sediment production due to the development of roads in the Anderson Creek, Indian Creek, and portions of the Rancheria Creek basins, compared with sediment production from other erosion processes in these basins (see Table 3-2 and Figure 3-4). Actions taken to reduce erosion from roads in the Anderson Creek, Indian Creek, and upper Rancheria Creek basins, although they may be valuable locally, cannot be expected to substantially reduce total sediment delivery to their respective stream systems, since sources such as stream bank erosion deliver much greater quantities of sediment.

- Sediment production in the melange terrain is extremely sensitive to land-use activities. Currently, relatively few roads exist in the melange terrain of the Anderson, Indian, and upper Rancheria Creek basins, where ranching is the predominant land-use activity. Actions should be considered to support continuation of this land-use and to assist ranchers in reducing erosion from grazing activities. New road developments or other land-uses such as housing, orchards, and vineyards, should be discouraged to prevent future accelerated sediment production in the Melange terrain.

- The lower Rancheria Creek sub-basin should be distinguished from the mid-to-upper basin due to its comparatively high density of industrial timberland road development. Acceleration of sediment production due to roads in this portion of the basin is likely to be much greater than in the drainage as a whole. Within the high-density roaded areas of the lower basin, it is likely that road improvements would substantially reduce total sediment delivery to stream channels in this sub-basin.

- Anderson Creek in the Anderson Valley is actively aggrading with coarse sediments and widening. Due to the active aggradation and widening, bank stabilization and in-channel treatments to restore fish habitat conditions would prove to be ineffective at this time and are not recommended. Rather, upland erosion control treatments should be considered a priority to reduce sediment delivery, and thereby minimize the resulting aggradation and channel widening which is occurring in this section of Anderson Creek.

- Smaller low-order streams draining Valley Fills, such as Robinson Creek, are a significant source of sediment production. Bank stabilization treatments in these streams are likely to be an effective means of reducing sediment delivery to channels. Considering the typical bank heights (15 to 20 feet or more), bank steepness, and their unconsolidated to poorly consolidated slopes, efforts to stabilize streambanks by re-establishing mature woody vegetation may also require biotechnical treatments to stabilize the foot-slopes of these streambanks. Further study is warranted in order to evaluate site-specific technical and economic feasibility of such treatments.

- In-channel restoration treatments are not advised on the low-gradient, larger tributaries to the Navarro River that are developed in wide alluvial valleys. Streams with these characteristics tend to store large amounts of sediment in the channel. Other than Anderson Creek, Rancheria Creek along and upstream of Highway 128, is the most notable example of a low-gradient, wide valley-bottom stream that would not be suitable for in-channel restoration treatments.

- Stream bank erosion and shallow landsliding from hillslope hollows are frequent and widespread, often occurring in direct proximity to sensitive channel and hillslope features. This close proximity to sensitive features and their widespread nature, renders watershed-scale erosion control treatments for stream-side sources costly and difficult to implement. Perhaps the best way to reduce land-use related increases in stream bank erosion and shallow landsliding in hollows would be to encourage landowners to reduce or eliminate logging within riparian corridors, along steep-walled inner gorge areas, and near sensitive hillslope features. Promoting voluntary land-use practices, such as protecting riparian corridors by establishing buffer strips, is a cost-effective means for reducing stream-side sediment production over the long term. Such land-use practices would allow, over the long-term, opportunities for conifers to establish in streamside areas, eventually providing greater stream canopy closure in many of the small and medium size tributaries, and a source of large woody debris recruitment to channels.

- Considering the quantitative importance of sediment production from grassland gullies in the melange and Coastal-Belt terranes, restoration treatments to reduce gully erosion is likely to be an effective means to substantially reduce sediment delivery to channels.

- Historical and recent failures of deep-seated, rotational and/or translational landslides on steep inner gorge slopes located adjacent to stream channels, although infrequent spatially and temporally in the Navarro River basin, result in substantial point sources of sediment production to channels when they do occur. In a some cases, major haul roads on deep-seated slides may have contributed to their failure. Therefore, existing haul roads located on recently active or ancient deep-seated slides within the inner gorge should be closed, deconstructed, and relocated.

4.1 SUMMARY

This section provides a description of the methods and results of the 1996 fish distribution and aquatic habitat field surveys performed in the Navarro River watershed. The surveys were conducted on 11 representative streams covering over 16 selected miles of channel to assess aquatic habitat conditions and fish distribution and to determine potential fish production limiting factors. Several other studies were also conducted in the Navarro River watershed during the summer of 1996 and later in 1997. These studies included California Department of Fish & Game (CDFG) habitat typing surveys and outmigrant trapping studies, presence/absence studies by the National Marine Fisheries Service (NMFS), the Navarro River Estuary Study and a reconnaissance level fish distribution study by Humboldt State University in Yale Creek. For this report we reviewed the recent fish distribution data collected by the CDFG habitat typing crews and by NMFS.

We also reviewed fish habitat data and available historical information or studies which identify the distribution of salmonids in the watershed over time. The fish distribution data is summarized in Figures 4-1 and 4-2[4]. The results of the available historical and recent fish distribution surveys are divided into two time periods; pre-1989 and post-1989. The earliest surveys date back to 1952, and are relatively few in number compared with more recent studies which are grouped into the post-1989 survey period. The post-1989 surveys include the recent results of the presence/absence studies performed in 1996 by NMFS, and by CDFG between 1989-1996, as well as studies conducted by Louisiana Pacific. A list of streams recently surveyed by CDFG (1994-1996) is provided in Table 4-1. The change in watershed-wide fish distribution over time is discussed in Section 5.0.

Other information relevant to fish habitat conditions or to fish distribution were also reviewed. Stream temperature, streamflow, and water quality data collected by the Mendocino County Water Agency (MCWA) (Appendix E) were examined to further assess how species occurrence or abundance are influenced. Results from these studies are integrated with results from the channel condition and sediment budget investigations to develop priorities for restoration in the Navarro River watershed. (see Section 5.0, Section 5.4.2, Limiting Factors).

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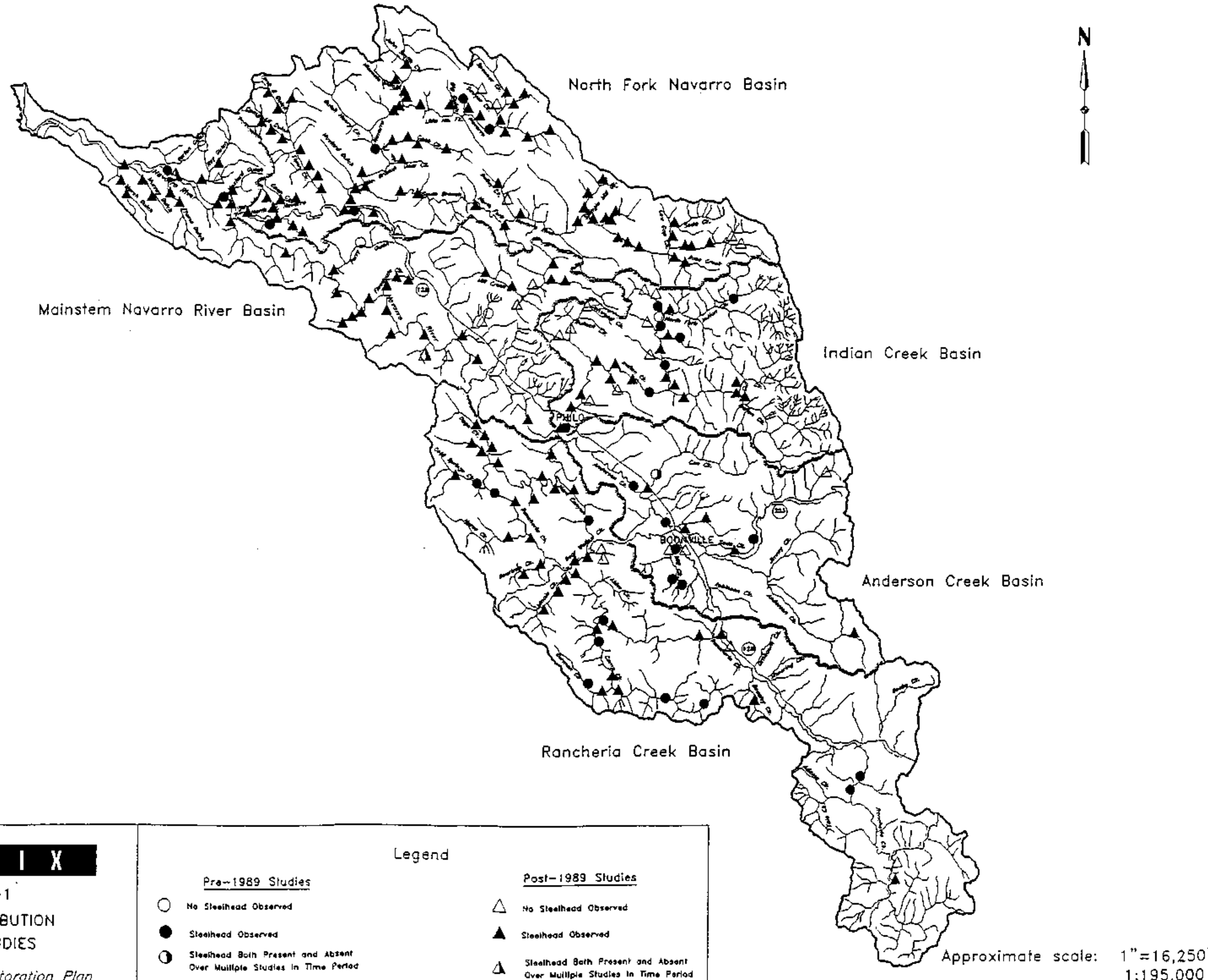
[4] The fish distribution data in Figures 4-1 and 4-2 are also provided on the over-sized maps available at the MCWA or AVLT libraries. The over-sized maps include more detailed information on the stream reach locations which were surveyed, the agency or organization which conducted the survey, and the type of survey method used.



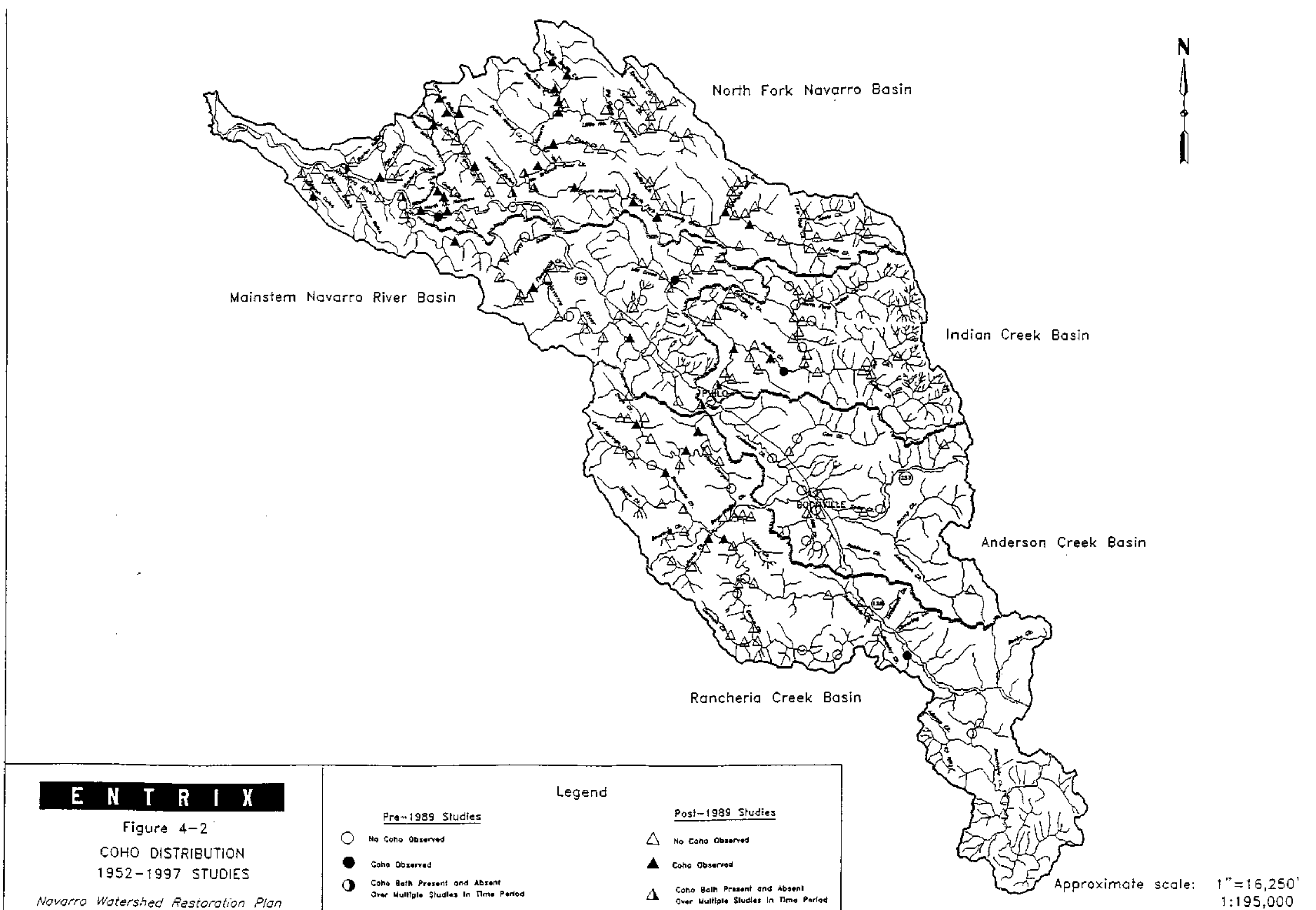
ENTRIX

Figure 4-1
STEELHEAD DISTRIBUTION
1952-1997 STUDIES

Navarro Watershed Restoration Plan

Legend

Pre-1989 Studies	Post-1989 Studies
○ No Steelhead Observed	△ No Steelhead Observed
● Steelhead Observed	▲ Steelhead Observed
◑ Steelhead Both Present and Absent Over Multiple Studies in Time Period	◭ Steelhead Both Present and Absent Over Multiple Studies in Time Period



ENTRIX

Figure 4-2
COHO DISTRIBUTION
1952-1997 STUDIES

Navarro Watershed Restoration Plan

Table 4-1. Streams Recently Surveyed by CDFG (1994-1996).

		Fish Present	
Sub-basin	**Stream**	**Coho**	**Steelhead/ Rainbow Trout**
Navarro River	Berry Creek	N	N
Navarro River	Floodgate Creek	N	Y
Navarro River	Marsh Gulch	Y	Y
Navarro River	Murray Gulch	N	Y
Navarro River	Mustard Gulch	N	N
Navarro River	Shingle Mill Creek	N	Y
North Fork Navarro	Bottom Creek	N	Y
North Fork Navarro	Camp 16 Gulch	Y	Y
North Fork Navarro	Cook Creek	Y	Y
North Fork Navarro	Coon Creek	N	Y
North Fork Navarro	Dead Horse Gulch	Y	Y
North Fork Navarro	Deer Creek	N	Y
North Fork Navarro	Flume Gulch	N	Y
North Fork Navarro	Flynn Creek	Y	Y
North Fork Navarro	John Smith Creek	Y	Y
North Fork Navarro	Little North Fork Navarro	Y	Y
North Fork Navarro	Low Gap Creek	N	Y
North Fork Navarro	McCarvey Creek	N	Y
North Fork Navarro	North Branch North Fork Navarro	Y	Y
North Fork Navarro	Redwood Creek	N	Y
North Fork Navarro	Rose Creek	N	Y
North Fork Navarro	Soda Creek	N	Y
North Fork Navarro	South Branch North Fork Navarro	N	Y
North Fork Navarro	Spooner Creek	N	Y
North Fork Navarro	Sawyer Creek	N	Y
North Fork Navarro	Tank 4 Gulch	Y	Y
North Fork Navarro	Township Gulch	N	Y
Rancheria Creek	Bailey Creek	N	Y
Rancheria Creek	Bear Trap Creek	N	Y
Rancheria Creek	Cold Springs Creek	N	Y
Rancheria Creek	Dago Creek	N	Y
Rancheria Creek	Ham Canyon Creek	N	Y
Rancheria Creek	Horse Creek	N	Y
Rancheria Creek	Rancheria Creek	N	Y
Rancheria Creek	S. Fork Dago Creek	N	Y

During the summer of 1996, the field crew collected data on the distribution and relative abundance of fish and habitat data including: a) habitat type, length and width; b) pool depth and forming features; c) spawning habitat rating; d) aquatic insect production rating; e) high flow refuge habitat rating; f) canopy closure; g) in-stream cover for fish in pool habitats; and h) stream temperature. Summary information about habitat conditions in the streams surveyed is provided in Tables 4-2 and 4-3. A sample field data sheet is provided in Appendix B.

The distribution of salmonids in the surveyed stream reaches varied greatly. Coho were only observed in three of the streams surveyed (North Branch of the North Fork Navarro, Little North Fork Navarro, and John Smith Creek) (Table 4-4). Similarly, coho were only observed in five of the 19 streams surveyed by CDFG in 1996, and one of those streams, Marsh Gulch, was contained in both data sets (see Table 4-4). The fish in Marsh Gulch were found only in the downstream most 1000 feet of stream, and not in the upstream reach where the stream gradient is steep (see Table 4-3).

Habitat information was collected to determine possible habitat limiting factors affecting salmonid distribution and abundance[5]. A summary of the habitat typing indicates that pool habitats are not as abundant as reported in some previous field surveys in which pools comprised as much as 70 to 80 percent of the habitat in some streams within the Navarro River watershed (Rich 1991) (see Table 4-4 and Appendix C). Pools ranged from 10 to 43 percent of the habitat types and were generally less than expected for forested streams (Montgomery *et al.* 1995). Runs and glides (flatwater habitats) and riffles and cascades (fastwater habitats) ranged from 4 to 90 and zero to 68 percent of the habitat types, respectively.

Many of the pools found were freely formed by the interaction of flow and sediment transport. Some pools were created by local obstructions (“forced”) such as bedrock, boulders, bank projections, and large woody debris (LWD) consisting of downed logs, root wads, or debris jams, which cause flow velocity changes that scour the channel bed (Montgomery *et al.* 1995) (Table 4-5). A small percentage of the forced pools were caused by LWD. However, in John Smith Creek, where there was a large amount of LWD compared to the other surveyed streams, over half of the LWD pools were associated with structures constructed or LWD placed by California Conservation Corps crews. The LWD in John Smith Creek was placed at many pre-existing pool sites to increase available cover, and at a few sites, the LWD was positioned to aid in pool formation.

Habitat complexity and associated cover for fish is often attributed to LWD. Pools with complexity from LWD provide feeding sites, low flow escape cover, and high flow

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[5] It should also be noted that Ray Gulch essentially contained no habitat deemed suitable for anadromous fish. The channel bed over the entire reach was comprised of fine sediments and only pool habitat or a marsh-like habitat with abundant cattails was observed (Appendix D, Photos 13a & b). Habitat conditions in Ray Gulch will not be discussed further in this report.

Table 4-2. Representative Inventory Streams for the Salmonid Resource Assessment.

Stream	Tributary To	Reach(s) Length (mi.)	Drainage Area (mi^2)	Slope (ft/ft)	Channel Confinement*
Mainstream Navarro	Ocean	2.0	297.0	<1%	m
Marsh Gulch	Mainstem Navarro	1.0	1.4	6-14%	m-c
S. Branch N. Fork Navarro	N. Fork Navarro	4.0	29.8	0.7-1.4%	m-c
N. Branch N. Fork Navarro	N. Fork Navarro	1.0	25.0	<1%	m-c
Little N. Fork Navarro	N. Fork Navarro	1.0	11.2	1.4%	c
John Smith	Little N. Fork Navarro	1.0	4.5	0.7-1.8%	m
Mill	Mainstem Navarro	1.8	9.3	1.3-2.5%	m-c
N. Fork Indian	Indian	1.5	13.5	1.6%	m
Con	Anderson	0.8	2.5	6.0%	m-c
Bear Wallow	Rancheria	1.0	est. 1.5	5.5%	c
Beasley	Rancheria	1.5	1.2	3-4%	m

*Confinement describes the relationship of the river to its valley and landform features. Confinement is qualitatively defined as the vertical containment of a river and the degree to which is incised in the valley floor. Confinement was determined in the field using the following key: m = moderately confined, c = confined.

Table 4-3. Summary of Observed Salmonid Habitat Condition.

	General Habitat Condition of Surveyed Reach(s)					
Stream	Adult Passage	Adult Holding	Spawning	Juvenile Summer Rearing	Juvenile Winter Rearing	Food Production
Mainstem Navarro	adequate	fair to good	poor	fair	fair to good	poor
Marsh Gulch	limiting*	fair	poor to fair	fair to good	fair	fair to good
S. Branch N. Fork Navarro	adequate	fair	poor to fair	fair	poor to fair	poor to fair
N. Branch N. Fork Navarro	adequate	fair	good	fair	fair	fair
Little N.F. Navarro	adequate	fair	fair	fair	fair	fair
John Smith	adequate	fair to good	fair	fair to good	poor to fair	poor
Mill	adequate	fair to good	good	fair	poor to fair	poor to fair
N. Fork Indian	adequate	fair	good	fair	fair	good
Con	adequate	fair	fair	poor to fair	fair	fair to good
Bear Wallow	limiting*	poor	poor to fair	fair	poor to fair	poor to fair
Beasley	limiting*	fair	poor to fair	fair	poor to fair	poor to fair

*Primarily limiting because of gradient and not habitat degradation.

Table 4-4. Habitat Composition by Stream.

Stream	% Habitat Type*			Max Water Temp (°C)♦	Salmonids†
	Pool	Flatwater	Fastwater		
Mainstem Navarro	27	60	13	23	yoy & 1+ SH
Marsh Gulch	31	7	62	13	yoy SH
S. Branch N. Fork Navarro	30	35	35	20	yoy & 1+ SH
N. Branch N. Fork Navarro	25	43	32	20	CS, yoy & 1+ SH
Little N.F. Navarro	21	36	43	20.5	CS, yoy & 1+ SH
John Smith	43	28	29	19.5	CS, yoy & 1+ SH
Mill	25	34	41	19.5	yoy SH
N. Fork Indian	19	21	60	21	yoy & 1+ SH
Con	28	4	68	24	yoy & 1+ SH
Bear Wallow	15	80	5	19	yoy & 1+ SH
Beasley	36	15	49	17	yoy & 1+ SH

*Flatwater = runs and glides, Fastwater = riffles and cascades.
†CS = coho salmon, SH = steelhead, yoy = young-of-the-year, 1+ = yearling plus.
♦Instantaneous temperature measurements made during field survey.

Table 4-5. Pool Characteristics by Stream.

Stream	% Freely Formed	Total % Forced	% Forced By				Avg. Max Depth (ft.)	% Surface Area Cover
			LWD	Bank[1/]	Boulders	Bedrock		
Mainstem Navarro	56	44	20	80	--	--	4.0	23
Marsh Gulch**	22	78	17	--	83	--	1.4	35
S. Branch N. Fork Navarro	78	22	19	8	12	61	3.0	24
N. Branch N. Fork Navarro*	55	45	14	25	25	36	2.4	17
Little NF Navarro*	53	47	20	29	22	29	2.0	13
John Smith[2/]*	42	58	79	13	8	--	2.1	15
Mill	46	54	14	36	28	22	2.0	19
Con	22	78	39	6	55	--	1.5	24
N. Fork Indian	69	31	16	50	16	18	2.3	27
Bear Wallow	14	86	21	13	59	7	1.5	15
Beasley	50	50	11	--	80	9	1.5	26

[1]Bank = bank projections and includes root wads of standing trees.
[2]54% of the LWD pools were created by objects placed by CCC crews.
*Coho observed by ENTRIX survey.
**Coho observed by CDFG survey.

refuge for salmonids (Baltz and Moyle 1984a). Woody debris is also important for retaining and storing sediment, which assists in maintaining spawning and aquatic insect production (Lisle 1986, Montgomery *et al.* 1995). When woody debris is removed from streams, salmonid populations are typically reduced (Tschaplinski and Hartman 1983, Dolloff 1986). Assessment of LWD loading in Navarro streams indicates considerable wood loss (see Section 3.0 and Appendix A).

In some streams quality of spawning and food production habitat may be limiting. Many streams had riffle habitats with substrates comprised of cobbles (greater than approximately 6 cm) or large gravels (approximately 5 to 6 cm) which were often embedded with fine sediments. This substrate is likely too large to provide good coho and steelhead spawning habitat, primarily because the fish have difficulty moving the larger substrate to create redds. Studies have reported that gravel between 0.8 and 4.5 cm (Bratovich and Kelley 1988) or 2.0 and 6.4 cm (Bovee 1982, Hampton 1988) are optimum for both coho and steelhead spawning. Likewise, small substrate, consisting mostly of sand or small pebbles, is inappropriate for spawning, primarily because it does not allow egg oxygenation and it is prone to scour, which results in redd loss, at relatively low flows. Gravels or cobbles embedded (partially buried) with sand were also rated as very poor spawning habitat because of the difficulty fish have breaking up the substrate to create redds.

High quality spawning substrate was only observed in the North Branch of the North Fork Navarro (Table 4-6). A few other streams provided some good spawning habitat, but the majority of spawning habitat in the surveyed streams was rated as poor or fair. In several streams, lack of spawning habitat may be limiting salmonid presence and/or abundance.

Sandy substrate or highly embedded gravels or cobbles were also rated as poor for aquatic insect production, because they do not provide cracks and crevices for insect attachment. No streams were rated as having excellent aquatic insect producing habitat, however, the ratings for food production were generally better than for spawning in any given stream (Table 4-7). The food production habitat in two streams, North Fork Indian Creek and Con Creek, was rated as good throughout the surveyed reach. Both of these streams had evidence of course sediment deposition. While these substrates may provide good insect production at low flows, they may also be unstable and tend to scour easily at high flows, making them less appropriate for spawning. Poor insect production may limit the carrying capacity of the stream, especially when stream temperatures are high. A fish's metabolic rate requires more food to maintain body weight or grow as stream temperatures increase.

Observed water temperatures during our field survey did not appear to be strongly correlated with coho presence (see Table 4-4). Maximum temperatures measured in streams with coho ranged from 13 to 20.5^{o}C, while steelhead were present in streams with maximum measured temperatures ranging from 13 to 23^{o}C. None of the water temperatures in the pools that were sampled were stratified, meaning there was no cold

Table 4-6. Spawning Substrate Ratings by Stream.

	% of Riffle Habitats Rated As			
Stream	**Poor**	**Fair**	**Good**	**Excellent**
Mainstream Navarro	55	45		
Marsh Gulch*	50	50		
S. Branch N. Fork Navarro (reaches 1&2)	19	43	28	
S. Branch N. Fork Navarro (reaches 3a&b)	100			
N. Branch N. Fork Navarro*	35	5		60
Little N. Fork Navarro*	68		32	
John Smith*	32	68		
Mill (reach 3)	13		87	
Mill (reach 4a&b)	51	16	32	
N. Fork Indian		38	62	
Con	46	54		
Bear Wallow	40	60		
Beasley	75	25		

* Coho observed.

Table 4-7. Food Production Ratings for Riffle Habitats by Stream.

	% of Riffle Habitats Rated As			
Stream	**Poor**	**Fair**	**Good**	**Excellent**
Mainstream Navarro	89	11		
Marsh Gulch*	3	63	34	
S. Branch N. Fork Navarro (reaches 1&2)	45	55		
S. Branch N. Fork Navarro (reaches 3a&b)	54	7	39	
N. Branch N. Fork Navarro*	50	50		
Little N. Fork Navarro*	64	4	32	
John Smith*	100			
Mill (reach 3)	87	13		
Mill (reach 4a&b)		68	32	
N. Fork Indian			100	
Con			100	
Bear Wallow		80	20	
Beasley	56	13	31	

*Coho observed.

water refuge habitat at the bottom of pools. These water temperatures recorded by field crews, represent only a one-point-in-time measurement.

Several of the survey streams (Mainstem Navarro, South Branch of the North Fork Navarro, North Branch of the North Fork Navarro, North Fork Indian, Con, and Bear Wallow) were monitored throughout the summer (1995, 1996, and/or 1997) by the MCWA (Appendix E). This automated monitoring consisted of continuous, water temperature readings at 1½ hour intervals over a four month period. North Branch of the North Fork Navarro, the only stream which was monitored by MCWA in which coho were observed, had the coolest maximum water temperature and the smallest daily fluctuations (see individual stream summaries). In many of the streams monitored by the MCWA, the daily temperature fluctuations were very high (as much as 15^{o}F in some cases). The magnitude of the diurnal fluctuation is likely detrimental to salmonid juveniles rearing in these streams, because of the short acclimation time available. High water temperatures and/or large daily temperature fluctuations will likely limit the potential for habitat improvement success if management activities specifically designed to improve temperature conditions are not addressed. The influence of water temperatures in streams monitored by the MCWA is evaluated and integrated with the sediment production and channel conditions studies in Section 5.0.

Stream gradient appeared to be the best indicator of salmonid presence in the streams surveyed. Coho were not present in streams with a gradient steeper than 2.0 percent, while steelhead were not present in streams with a gradient steeper than 8.0 percent.

4.2 SALMONID LIFE HISTORY

Understanding of salmonid life history and habitat requirements is essential to determining potential habitat limiting factors. Two salmonids utilize the Navarro River watershed on a regular basis; coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*). Priority for managing these species and their habitat has always been high, however recent actions to list these species under the Endangered Species Act (ESA) has elevated the level of interest in these species in the Navarro River basin. Coho salmon are currently listed by the National Marine Fisheries Service (NMFS) under the ESA. Populations in the Central California Coast Ecologically Significant Unit (ESU), which includes the Navarro River, are listed as "threatened". Steelhead were proposed for federal listing as "endangered" by the NMFS in all ESU's south of and including the Russian River watershed and as "threatened" in the ESU's north of the Russian River, including the Navarro River. However, in March 1998, NMFS did not list steelhead north of the Russian River as threatened.

4.2.1 COHO SALMON

Coho salmon are anadromous fishes, spending their adult life in the ocean, migrating up freshwater streams to spawn, rearing at least partially in freshwater, and migrating to the ocean as juveniles. Most coho salmon from California streams spend 18 months in freshwater and 18 months in the ocean, returning to spawn in their natal stream in their third year (Shapovalov and Taft 1954). Unlike other Pacific salmon in California, this three year cycle is fairly rigid and spawning years with relatively poor reproductive success can result in poor spawning runs three years later (Shapovalov and Taft 1954). Upstream migration is usually triggered by an increase in outflow to the ocean and spawning usually occurs in late fall and early winter (Shapovalov and Taft 1954).

Coho salmon usually spawn at the heads of or in riffles with gravel substrate (Moyle 1976). Females dig pits in the gravels where she deposits her eggs and often more than one male will fertilize the eggs before the female covers the eggs with gravel, creating a redd (Moyle 1976). Following spawning, adult coho die. Juveniles emerge from the gravels the following spring and usually rear in the stream for one year before they migrate to the ocean (Shapovalov and Taft 1954).

While in the stream, juvenile coho often occupy habitat at the heads of pools, which generally provide an optimum mix of high food availability and good cover with low swimming effort (Jenkins *et al.* 1970, Nielsen 1992). Juveniles depend on cool water and abundant invertebrate food to rear successfully. Temperatures between 12 and 14^{o}C (53.6 and 57.2^{o}F) are considered optimal for coho (Brett 1952, Moyle 1976). The critical thermal maximum (CTM, the temperature at which a fish loses equilibrium and dies) for coho varies among streams, but has been shown to be as high as 29.2°C (84.6°F) (Konechi *et al.* 1995). Warmer water requires more abundant food resources for fish survival, because of the resultant increase in their metabolic rate (Brett 1971, Fausch 1984).

Wild stock of coho have declined or disappeared from all streams for which there are data (Brown *et al.* 1995). Reasons for the decline of coho salmon in California include: loss of habitat above dams and habitat degradation, breakdown of genetic integrity of wild stocks, introduced diseases, over-harvest, and climatic change (Brown *et al.* 1995). Historical information has been collected on the distribution of coho in the Navarro River watershed, however, this information is relatively sparse and concentrated in drainages where coho have already been known to occur.

Distribution of juvenile coho salmon in the Navarro River system can vary dramatically between years as a consequence of the number of spawners entering the watershed, and the magnitude and duration of fall and winter stream flow. In years when there are large numbers of spawners and adequate stream flows to provide good access to spawning sites throughout the watershed, the distribution of juvenile coho salmon the following summer will be widespread. In contrast, if a small number of spawners enter the stream during a winter with low stream flows, the summer distribution of juvenile coho salmon will be restricted to only a limited number of streams. Also, because coho have a rigid three year maternal life history pattern, high abundance in one year does not necessarily mean high abundance the following year, even if habitat and stream flow conditions are good. In addition, successful spawning of adult coho salmon may not produce large numbers of young-of-the-year (YOY) if subsequent floods result in the movement of large amounts of sediment that either scour or bury eggs in the spawning beds.

4.2.2 STEELHEAD TROUT

Steelhead trout, an anadromous form of rainbow trout, usually spend one to two years in the ocean before returning to spawn for the first time (Shapovalov and Taft 1954). Unlike other anadromous pacific salmonids, steelhead may survive spawning, return to the ocean and spawn in a later year (Shapovalov and Taft 1954, Moyle 1976). Steelhead typically migrate upstream in California coastal streams between January and March (Moyle 1976). Steelhead and coho spawn in similar habitat, except the gravels that steelhead use for spawning may be smaller (Moyle 1976).

In California, juveniles generally spend one to three years in freshwater before migrating to the ocean, usually between March and June (Shapovalov and Taft 1954). Larger steelhead, usually yearlings or older (1+), have been observed to use heads of pools for feeding (Cunjak and Green 1983, Baltz and Moyle 1984). YOY steelhead often utilize riffle and run habitat during the growing season and move to deeper, slower water habitat during the high flow months (Baltz and Moyle 1984, Hearn and Kynard 1986). In these ways, steelhead are more habitat generalists than coho. In addition, juvenile steelhead can typically tolerate warmer temperatures than coho (Moyle 1976). Preferred temperatures range between 12.8 and 15.6^{o}C (55.0 and 61.1^{o}F) (Rich 1987), with a CTM up to 29.4^{o}C (84.9^{o}F) (Lee and Rinne 1980).

Steelhead trout populations have declined throughout their range in California, but especially those south of Monterey Bay (McEwan and Jackson 1996). In the Navarro River watershed, it appears that they have not been as affected as coho salmon. Their variable life history; ability to utilize fast water habitat types, in addition to pool habitat, for rearing; ability to spawn multiple times; and their tolerance to warmer water temperatures enable steelhead to be more resilient than coho to adverse environmental conditions.

4.3 METHODS FOR ASSESSING SALMONID HABITAT

Field data were collected on stream habitat features and fish populations in the stream reaches identified in Table 4-2. Each reach was subsampled. Typically, a subsample consisted of ten channel widths, although longer or shorter reaches were adopted in some instances for surveying expediency. Every other reach subsample was surveyed. Habitat units, within surveyed subsampled segments, were identified by habitat type (Flosi and Reynolds 1994). The physical and geomorphic features (such as large woody debris or bedrock outcrops) that formed and maintains the pools were also identified. The length and width of each habitat unit was measured.

Percent spawning habitat area and rating (poor, fair, good, excellent) was determined in riffle habitat. Percent food production area and rating was determined in non-pool habitats. High flow refuge habitat type (floodplain, backwater, side channel, in-channel structure, and edge of channel) and relative amount (high, medium, and low) was recorded every 10 channel widths or when dramatic changes in refuge habitat occurred. Canopy closure type (conifer, hardwood, and riparian) and relative amount (high = 100-

65%, medium = 64-30%, and low = 29-0%) was recorded every 10 channel widths or when dramatic changes in canopy closure occurred.

At randomly selected pools additional data was collected. Maximum and average pool depth and pool tail crest depth was recorded. Surface and bottom temperatures were recorded. In-stream cover as a percent of total surface area was determined and percentages of cover types (rooted tree, undercut bank, vegetated bank, woody debris, boulders, in-stream vegetation, overhanging vegetation, and floating debris) were recorded. Types of high flow refuge habitats present were recorded. Percent canopy closure by types and relative ages (young, mature, old) were determined. Fish presence was assessed by visual in-stream observations (snorkeling) and amphibian presence was assessed by visual observations of the stream banks.

4.4 DESCRIPTION OF HABITAT CONDITIONS IN REACHES SURVEYED

Possible limiting factors for each stream or reach are suggested based on the habitat surveys conducted during the summer of 1996. It should be noted, however, that these limiting factors are based on stream habitat, and other limiting factors are likely present for the Navarro River basin as a whole. Because of habitat degradation in the past, one of the main limiting factors to abundant salmonid production in the system today is likely the lack of returning adults to seed current habitat.

4.4.1 MAINSTEM NAVARRO RIVER

Reach Locations: The mainstem Navarro was surveyed 1.0 mile upstream and 1.0 mile downstream of the confluence with the North Fork Navarro River.

Spawning and Food Production

Both spawning and food production habitat were rated as poor throughout most of the surveyed reach of the mainstem Navarro River. Small gravels and sand or just sand was the dominant substrate of most of the fast water habitat. The gravel bars which may be used for spawning during high flows were made up of gravels with sand which are not good for salmonid spawning. At low flows there was only a small amount of fast water habitat for aquatic insect production.

Rearing Habitat

Pools were more abundant in the mainstem than in most tributary streams and LWD formed many of the pools. Pools contained a moderate amount of cover relative to the large pool surface area (between 10 and 40 percent) and much of the cover was associated with undercut banks, tree roots and woody debris. Many pools were relatively deep, up to 5 feet, providing some cover. Riffles were rare; glides and pools were the most common habitats in this reach of the mainstem Navarro River.

In the reach upstream of the North Fork Navarro River in half of the habitat there was a moderate amount of high flow refuge habitat and the other half contained a high amount.

High flow refuge habitat was rated as low in the reach downstream of the confluence with the North Fork Navarro River. In the upstream reach the high to moderate amount of refuge habitat was provided by flood plain, side channels and in-stream structure (much of which was LWD). Downstream of the North Fork confluence, the flood plain was less expansive and fewer side channels and woody debris were present.

Temperature and Canopy Closure

The canopy closure was rated as low throughout both reaches upstream and downstream of the North Fork Navarro. A riparian zone is present along most of the length of the mainstem Navarro, however, it is set back from the active channel and provides little shade for the low flow channel. Stream temperatures during the survey ranged from 19^{o}C (67^{o}F) in the morning to 24^{o}C (75^{o}F) in the afternoon. Stream temperatures in the Navarro monitored at Hendy Woods (approximately 8.5 miles upstream of the upper reach) between 31 May and 27 September 1996 averaged 24.5^{o}C (68.9^{o}F). The maximum and minimum temperatures during that period were 27.8^{o}C (82.0^{o}F) and 15.1^{o}C (59.2^{o}F), respectively. Stream temperatures monitored between 31 May and 27 September 1996, at the USGS gage station on the mainstem Navarro (approximately 1 mile downstream of the lower reach) averaged 19.3^{o}C (66.7^{o}F) and ranged between 23.8 and 14.8^{o}C (74.8 and 58.7^{o}F) (data provided by the MCWA).

Fish Presence

Both YOY and 1+ steelhead were abundant in the reach upstream of the North Fork Navarro River. Up to 40 YOY steelhead and 20 1+ steelhead were observed in a single pool. Few YOY steelhead and no 1+ steelhead were observed downstream of the North Fork Navarro River confluence. Roach were abundant (up to 200 per pool) in both reaches. A few sculpin were observed in the downstream reach. No coho were observed in the mainstem Navarro during the survey.

Possible Limiting Factors

Summer stream temperatures likely limit coho presence in the mainstem Navarro River. Increased canopy closure would likely help reduce stream temperatures if the water temperature of inflow from tributaries is not too high. Fine sediment accumulation likely limits both spawning potential and success as well as aquatic insect production in the mainstem. Poor food production limits rearing carrying capacity, especially given the high water temperatures.

4.4.2 MARSH GULCH

Reach Location: Marsh Gulch was surveyed from its confluence with the mainstem Navarro River to a point approximately 1.0 mile upstream. The reach was subdivided into six subreaches based on alternating pattern of streambed morphology (forced pool-riffle and step-pool) and channel confinement (moderately confined to confined).

Spawning and Food Production

There is not abundant fine sediment in the gravels in Marsh Gulch compared to many of the other streams surveyed. However, spawning and aquatic insect producing areas were rated as poor to fair because most of the substrate in riffle habitats was composed of large gravels to cobbles, unsuitable for coho and steelhead spawning. In addition, there was abundant cascade or step pool habitat with boulder substrate, because of the steep gradient of much of the stream that was surveyed. There were some large woody debris jams causing gravel retention upstream and providing some isolated good areas of spawning and insect production. In addition, the large woody debris may be providing a surface for aquatic insect production in this stream.

Rearing Habitat

There was more LWD loading in Marsh Gulch than in the other streams surveyed. LWD however, was not the main pool forming feature in this stream. It did provide some low flow in-stream cover in the individual pools surveyed, however, few LWD pools were selected during the random selection of pool habitats to be surveyed. Much of the low flow cover in the pools surveyed was provided by boulders. There was a moderate amount of high flow refuge habitat throughout most of the surveyed section. The lack of abundant high flow refuge habitat was primarily due to the lack of a flood plain in this confined channel.

Temperature and Canopy Closure

The canopy closure was fairly high (greater than 65%) in Marsh Gulch and comprised of mostly young redwoods. Instantaneous stream temperatures taken during the survey were low compared to other streams surveyed, ranging from 12^{o}C (54^{o}F) in the late morning to 13^{o}C (55^{o}F) in the late afternoon.

Fish Presence

The few fish observed in Marsh Gulch were in the lower approximately 1000 feet of stream, downstream of the steep gradient section. Snorkeling was difficult due to the dense canopy closure and low light, but approximately 5 YOY steelhead were observed in each of the pools surveyed in the downstream most subreach of stream. A CDFG electrofishing crew found both steelhead and coho in the lower section of Marsh Gulch this year and last year.

Possible Limiting Factors

Stream temperatures and pool habitat frequency are better in Marsh Gulch and are more optimal for salmonids compared to most of the other streams surveyed. However, the steep gradient likely limits adult coho migration upstream and the availability of spawning sites. Steelhead are more likely to migrate up and inhabit steeper reaches of stream, providing that flows are high enough to permit access. Some reaches of Marsh Gulch are so steep that they form barriers to upstream migration even for steelhead.

4.4.3 SOUTH BRANCH NORTH FORK NAVARRO RIVER: REACHES 1 & 2

Reach locations: Reach 2 extends from Bailey Gulch to a point approximately 1.3 miles downstream. Reach 1 extends from the lower boundary of Reach 2 downstream to a point approximately 0.2 miles upstream of the summer dam at the mouth of the South Branch North Fork Navarro River.

Spawning and Food Production

Much of the substrate in these reaches is dominated by cobble or course gravel which was often embedded with fine sediments. This embedded substrate provides only poor to fair spawning habitat throughout most of both reaches. In addition, aquatic insect production was rated as poor to fair throughout both reaches and there is little overhanging vegetation to provide terrestrial insect input into the stream.

Rearing Habitat

The amount of high flow refuge habitat in these reaches ranges from low to moderate. In areas containing only a low amount of high flow refuge habitat, some in-channel structures provide refuge, but the channel margins likely provide most of the slower velocity water for refuge habitat during high flows. Where there was a moderate amount of high flow refuge habitat a broader flood plain existed. In one section of stream there was a side channel adding high flow refuge habitat.

The lack of pools and lack of cover in the pools also limited high flow refuge in both reaches. The pool spacing in these reaches was less than expected in forested streams. Limited pool habitat and minimal cover for fish during low flows (cover was less than 25% in 6 of the 9 pools sampled), reduces the carrying capacity for coho and 1+ steelhead in these reaches. However, all types of in-stream cover (rooted trees, undercut banks, vegetated banks, woody debris, boulders, and in-stream vegetation) and overhead cover (overhanging vegetation, floating debris) were present in small amounts.

Temperature and Canopy Closure

The canopy closure was low (less than 30%) throughout most of both of these reaches and was often mostly from deciduous trees. This was evidenced by abundant algae growth in many areas and high stream temperatures. Instantaneous temperatures during the survey (taken in the morning and early afternoon) ranged from 17-20^{o}C (63-68^{o}F). Temperatures monitored between 03 July and 25 September 1995, averaged 17.6^{o}C (63.7^{o}F) and ranged between 14.0 and 23.1^{o}C (57.3 and 73.5^{o}F), with daily fluctuations up to 4.5^{o}C (8^{o}F) (data provided by the MCWA).

Fish Presence

Only steelhead and California roach were observed during our survey of South Branch North Fork Navarro River, reaches 1 and 2. Generally, there were few steelhead in individual pools (less than 15 fish) and few of these were 1+ steelhead. No coho were observed in these reaches during this survey.

Possible Limiting Factors

Average daily water temperatures in these reaches during summer, are higher than optimum for both coho and steelhead in these reaches. This is especially detrimental to fish survival and growth when food sources are limited. Reduction of summer water temperatures and/or fine sediments in the system would likely increase steelhead carrying capacity. The lack of pools and limited amounts of woody debris in combination with high temperatures likely preclude use by coho salmon.

4.4.4 Upper South Branch North Fork Navarro River: Reaches 3a & b

Reach Locations: Reach 3a extends from McGarvey Creek confluence downstream to Shingle Mill Creek confluence (1.0 mile). Reach 3b extends from Shingle Mill Creek confluence to Bridge Creek confluence, approximately 1.0 mile downstream.

Spawning and Food Production

Much of the substrate in these reaches is dominated by cobble or course gravel which, unlike the downstream reaches, is not embedded with fine sediments. However, because of its relatively large size and the presence of bedrock outcrops, which may limit substrate depth, the substrate was rated as mostly fair for spawning. Aquatic insect production in these reaches was rated as good and does not appear to be limiting as further downstream in reaches 1 and 2. In addition, some overhanging vegetation was present in a few areas to add to the terrestrial insect input into the stream.

Rearing Habitat

There was a low amount of high flow refuge habitat in these reaches. Due to the confinement of the channel, there is minimal floodplain/terrace area to function as refuge habitat at high flows and there is little in-stream structure to add high flow refuge habitat. In addition, there is little pool habitat which can act as high flow refuge habitat and within the pools that do occur there is little cover for fish. Woody debris was rare in these reaches.

Limited pool habitat and minimal cover for fish during low flows reduces the summer carrying capacity for coho and 1+ steelhead in these reaches. Only three of the 15 pools sampled had more than 30% cover and 10 of the 15 pools had 20% cover or less.

Temperature and Canopy Closure

The canopy closure was rated as moderate (30-64%) throughout most of both of these reaches and more of it was from conifers, hardwoods, and topography than further downstream, however, stream temperatures were still fairly high. Instantaneous temperatures during the survey (taken in the late morning to late afternoon) ranged from 18 to 23^{o}C (64 to 73^{o}F). Temperatures monitored between 03 July and 25 September, 1995, averaged 18.0^{o}C (64.5^{o}F) and ranged between 12.9 and 24.4^{o}C (55.3 and 75.9^{o}F), with daily fluctuations up to 7^{o}C (12^{o}F) (data provided by the MCWA). It is unclear why temperatures appear to be slightly higher in these upstream reaches than further downstream, given the increased canopy closure in these reaches.

Fish Presence

Only steelhead and California roach were observed during the survey in these reaches. Generally, there were more steelhead in individual pools (usually 20-30 fish) than further downstream. Few of the steelhead appeared to be 1+ aged fish. It is likely that with abundant food and high temperatures, steelhead from these reaches grow large enough to smolt in one year or they move downstream to the mainstem or estuary to rear. No coho were observed in these reaches during this survey, but they have been documented in this reach of stream previously (Rich 1989).

Possible Limiting Factors

Mean daily summer water temperatures in these reaches are higher than optimum for both coho and steelhead. These temperatures and lack of pools likely restrict the presence of coho. Reduction of summer water temperatures in the stream would likely increase steelhead carrying capacity.

4.4.5 North Branch North Fork Navarro River

Reach Location: North Branch North Fork Navarro River was surveyed from Dutch Henry Creek confluence to a point approximately 300 feet downstream of Cook Creek confluence (1.0 mile). For 1000 feet at the upstream end and 500 feet at the downstream end, the channel is moderately confined (reach a); between these segments, a distance of approximately 3800 feet, the channel is confined (reach b).

Spawning and Food Production

Spawning habitat rating varied greatly during the survey of North Branch North Fork Navarro River. In some areas spawning habitat was poor because of abundant fines and infrequent riffle habitat. In other areas, spawning habitat was rated as good to excellent because of abundant appropriate sized gravel in bars that would be inundated during the spawning season. Food production during the survey was rated as poor to fair because of the amount of fines in riffle and run habitats at low flows and because of the abundant algae growth on the substrate.

Rearing Habitat

There was a moderate amount of high flow refuge habitat throughout the entire surveyed reach of the North Branch of the North Fork Navarro River. There was limited flood plain for high flow refuge because most of the survey reach was confined. flow refuge habitat. In addition, there is little pool habitat which can act as high flow refuge habitat and within the pools there is little cover for fish. Woody debris was rare in the surveyed section of this stream.

Limited pool habitat and minimal cover for fish during low flows reduces the summer carrying capacity for coho and 1+ steelhead in these reaches. Only one of the sampled pools had more than 20% cover to improve low flow habitat.

Temperature and Canopy Closure

Canopy closure was rated as low (>30%) throughout the survey reach. Canopy closure was provided in nearly equal amounts by young conifers, mature hardwoods, young riparian trees and topography. Stream temperatures taken in the afternoon during the survey ranged from 18 to 20^oC (65 to 68^oF). Stream temperature gage data recorded by Louisiana-Pacific between 3 July and 25 September 1995, indicated that the average stream temperature was 18.2^oC (64.7^oF). Maximum and minimum temperatures during that same time period were 21.2^oC (70.2^oF) and 15.6^oC (60.1^oF), respectively.

Fish Presence

Both YOY steelhead and coho were relatively abundant (up to 20 per pool) in the pools sampled in this stream. No 1+ steelhead were observed during this survey. California roach, sculpin and stickleback were also observed.

Possible Limiting Factors

Based on the habitat assessment it is unclear why salmonids, especially coho, are present in this stream. It is possible that juveniles produced in upstream tributaries moved downstream into this reach to rear or that the abundant spawning habitat insured success in this reach. LWD loading and improved canopy closure would improve rearing habitat for both steelhead and coho.

4.4.6 LITTLE NORTH FORK NAVARRO RIVER

Reach Location: The Little North Fork of the Navarro River was surveyed from its confluence with John Smith Creek to a point approximately 1.0 mile upstream.

Spawning and Food Production

Approximately half of the surveyed reach was rated as good for both spawning and insect production. The other half of the section was rated as poor, because the gravels were small and there was some fine sediment deposition. Spawning and food production areas were generally better at the upstream end of this reach and poorer towards the downstream end of this reach.

Rearing Habitat

Pools were infrequent in this reach and few pools had associated cover for fish habitat during low flows. Most pools were formed at bedrock outcrops and little woody debris was present in this reach. In over half of the pools sampled there was essentially no cover variable present (less than 5% of pool surface area). A few of the pools were isolated with flow going subsurface at upstream riffles.

Approximately three-fourths of the reach contained little high flow refuge habitat. The remainder of the reach contained a moderate amount of high flow refuge habitat from the limited floodplain development and some in-stream boulders, and refuge habitat provided by the channel margins.

Temperature and Canopy Closure

Canopy closure was rated as moderate (30-64%) throughout the reach and was composed of conifers, hardwoods, and riparian (deciduous) trees as well as topography. Stream temperatures during the survey ranged from 19 to 21^{o}C (67 to 70^{o}F).

Fish Presence

Both coho and YOY steelhead were relatively abundant in the pools sampled. Between 20 and 30 of each species were counted in pools. Only one 1+ steelhead was observed. California roach were also abundant in sampled pools. Up to 50 roach were observed in a single pool.

Possible Limiting Factors

As with North Branch of North Fork Navarro, it is unclear why juvenile salmonids are as abundant in this reach. This may possibly be the result of abundant production upstream. Spawning areas are good in part of the reach and may have produced enough juvenile fish to seed the available habitat. Likewise food production in the upper part of this reach was good and may be providing enough to allow for rearing success despite the lack of pools for coho rearing. Still, large woody debris and pools in general are lacking from the Little North Fork. Additional pool habitat would improve habitat conditions in the Little North Fork Navarro, which is especially important since it appears that there is adult stock to seed the area.

4.4.7 JOHN SMITH CREEK

Reach Locations: Upper John Smith Creek was surveyed from Johnson Creek confluence to a point approximately 0.5 miles downstream. Lower John Smith Creek was surveyed from Masonite Road to a point approximately 0.5 miles upstream.

Spawning and Food Production

Spawning habitat is rated as fair throughout the surveyed section. During higher flows, likely present during the salmonid spawning season, the bar areas would be used for spawning. Most of bars were composed of cobble with some gravel interspersed. Slightly smaller substrate would likely be more appropriate for steelhead and possibly be more appropriate for coho.

Food production areas were rated as poor throughout the reach. The flow was subsurface in many riffle habitats which reduced the quality of the aquatic insect producing habitat. There was, however, abundant overhanging vegetation which likely added to the terrestrial insect input into the stream.

Rearing Habitat

Many pools in the survey reach were formed by LWD structures placed by the California Conservation Corps. These structures have improved the amount of cover present in the pool habitats, still the amount of cover in the pools sampled was not that high. Cover was between 5 and 40 percent of the pool surface area in the pools sampled. This cover was provided by woody debris and undercut banks in most of the sampled pools. There was a low amount of high flow refuge habitat throughout the entire survey reach. Minimal flood plain was present in the moderately confined channel and the stream terraces are likely not flooded during normal water years. High flow refuge habitat was primarily provided by in-stream structures in pools such as woody debris and by the edges of the channel.

Temperature and Canopy Closure

Canopy closure was moderate to high throughout the surveyed area. It was provided by a combination of young conifers, young and mature hardwoods, topography and some riparian tree canopy in the lower reach. In the upper reach a young riparian canopy provided more closure than downstream, but it was still sub-dominant to conifers and hardwoods. Stream temperatures during the afternoon survey ranged from 17 to 19^{o}C (63 to 67^{o}F). These temperatures were cool given that the survey was conducted on the warmest day survey day when air temperatures reached nearly 38^{o}C (100^{o}F).

Fish Presence

Coho were more abundant than YOY steelhead in all the sampled pools. Coho densities in individual pools ranged from 5 to 15. YOY steelhead densities in individual pools ranged from zero to 5. One 1+ steelhead was observed. Sculpin and stickleback were also observed in John Smith Creek.

Possible Limiting Factors

Stream temperatures in John Smith Creek are cooler than most of the other streams surveyed. More frequent pool habitat and more abundant cover associated with large woody debris would improve rearing carrying capacity. Coho were observed in greater abundance in pools with woody debris. Improvement of aquatic insect production would also greatly improve the rearing habitat for salmonids in John Smith Creek. It is unclear, however, if this is possible given the low flow conditions in the stream during the summer.

4.4.8 MILL CREEK: REACH 3

Reach Location: Reach 3 of Mill Creek extends from Meyer Gulch confluence to a point approximately 0.5 miles upstream.

Spawning and Food Production

Spawning habitat was rated as good throughout almost this entire reach. Most of this good spawning habitat is associated with bars which were not inundated during the low flows present at the survey time. Food production throughout the majority of the reach was rated as poor, with about 10 percent rated as fair. Much of the substrate with flowing water during the survey was composed of cobble, boulder or bedrock which generally provide less aquatic insect habitat than does gravel-cobble substrate. In addition, there was little riffle habitat. Most of the shallow water habitat was classified as riffle-run, run or glide, which are not generally considered optimal insect production habitat.

Rearing Habitat

Relative deep pools (up to approximately 4 feet) are present in the survey reach, however, few pools contain low or high flow cover habitat for fish. Cover ranged from 10 to 30 percent of pool surface area, but was primarily associated with boulders. Large woody debris is essentially absent from this reach and pools are formed primarily from bedrock outcrops or boulders, or by stream meanders. The majority of the habitat was glide or fast run which is not considered optimum rearing habitat for salmonids.

High flow refuge habitat was low throughout the reach. The confined channel which results in a limited flood plain, combined with the lack of in-stream structure in the form of woody debris and the presence of bedrock banks affords little high flow refuge habitat for juvenile or adult fish.

Temperature and Canopy Closure

Canopy closure was rated as high (>65%) throughout the reach. Canopy closure percentages recorded at sampled pools ranged from 60 to 90 percent and was composed of primarily young conifers and mature hardwoods, in addition to some riparian (deciduous) trees and topography. Stream temperatures taken during the survey ranged from 18 to 20^{o}C (65 to 68^{o}F).

Fish Presence

YOY steelhead were relatively abundant in sampled pools. Approximately 10 to 25 YOY steelhead were observed in each sampled pool. California roach were also present in some of the pools sampled. No coho or 1+ steelhead were observed during the survey.

Possible Limiting Factors

High flow refuge habitat as well as pools are likely limiting in the surveyed reach. Large woody debris input is minimal and is not contributing to formation of pool habitat and is not providing cover for fish during low and high flows.

4.4.9 Mill Creek: Reaches 4a & b

Reach Locations: Reach 4a extends from Red Hill Gulch to a point approximately 0.5 miles downstream. Reach 4b extends from Red Hill Gulch upstream approximately 0.8 miles approximately to the confluence with Hungry Hollow.

Spawning and Food Production

In about half of the combined length of these reaches the spawning habitat was rated as poor. In the remaining half of the surveyed section the rating for spawning habitat was split approximately equally between fair and good. Poor habitat was comprised of either gravels with abundant fines or of areas without good gravels where cobbles and boulders were dominant.

Food production was rated as fair for about three-fourths of the survey section and good for the remainder of the section. Riffle and riffle-run habitat was relatively abundant for insect production in the wetted area of the channel.

Rearing Habitat

Pools are more frequent than in Mill Creek reach 3, as is LWD, however, both are still less abundant than expected in a forested stream. Riffle-run habitat was common. Cover in pools was relatively low, less than 20 percent of the pool surface area in all but four of 13 pools sampled. In addition, most of the cover was associated with boulders, rather than complex cover attributes such as woody debris or tree roots.

Ratings for high flow refuge habitat were split nearly equally between low and moderate. High flow refuge habitat was comprised of primarily in-stream boulders and some channel edge refuge. Little flood plain was present because of the confined to moderately confined channel.

Temperature and Canopy Closure

Canopy closure was primarily rated as moderate (30-64%), although it was rated at low at the upstream most few hundred feet. Canopy was composed mostly of young conifers and mature hardwoods with some topography. Canopy closure from riparian (deciduous) tress was minimal. Stream temperatures taken during the survey ranged from 17°C (63°F) in the morning to 19°C (67°F) in the afternoon.

Fish Presence

YOY steelhead were relatively abundant in the sampled pools. Up to 20 YOY steelhead were observed in an individual pool habitat. Only a few 1+ steelhead were observed in this reach and no coho were observed. California roach were observed in only one of the sampled pools.

Possible Limiting Factors

Coho may be absent from this reach of Mill Creek primarily because of the stream gradient. Steelhead abundance would likely be improved with improved cover habitat in pools and improved insect production.

4.4.10 North Fork Indian Creek

Reach location: North Fork Indian Creek was surveyed from a road crossing located near its downstream end to a point approximately 1.5 miles upstream.

Spawning and Food Production

Much of the substrate in these reaches is dominated by cobble or course gravel and there is little fine sediments. However, because of its relatively large size in a few areas, the substrate was rated as only fair to good for steelhead spawning. Aquatic insect production in these reaches was rated as good.

Rearing Habitat

The high flow refuge habitat in this reach was considered medium to high. Numerous point bars allow for slow velocity water in the floodplain at high flows. There is some in-stream structure present in some pools, mostly in the form of large redwood tree roots, which offer some high flow refuge and low flow cover. Overall, cover in pools is fairly low, ranging from 2 to 50% and six of the 11 pools sampled had less than 25% cover. Pools abundance was lower than expected for forested streams.

Temperature and Canopy Closure

The canopy closure was rated as low (less than 30%), primarily because of the wide channel and limited new growth on the near stream gravel bars. The large redwood tree roots forming some of the pools, were from logged trees that provided no canopy closure. There were few riparian trees that were large enough to provide canopy closure.

Instantaneous stream temperatures taken during the survey in the afternoon ranged between 21 and 26°C (69 and 78°F). These temperatures are above the optimal stream temperatures for both coho and steelhead and are nearing the CTM for both fish. Temperatures monitored by MCWA between 04 June and 01 October 1996, averaged 18.7°C (65.7°F) and ranged from 13.3 to 23.3°C (55.9 to 77.6°F).

Fish Presence

Only steelhead and California roach were observed during the survey in these reaches. Both roach and YOY steelhead were abundant. Roach often numbered between 30-40 per pool, and YOY steelhead numbered up to approximately 70 fish in one pool and usually ranged between 30-40 per pool. Yearling steelhead were less abundant, usually ranging between 5 and 15 per pool. It is likely with abundant food and high summer temperatures, that steelhead from this stream grow large enough to smolt in one year or they move downstream to rear. No coho were observed in this stream during this survey, nor have they been documented this far upstream in the Indian Creek basin previously.

Possible Limiting Factors

Summer water temperatures and lack of abundant pools likely restrict the presence of coho in North Fork Indian Creek. Reduction of summer water temperatures in the stream would likely increase steelhead carrying capacity, however with the wide channel it will be difficult to lower water temperatures through increased canopy closure in the near future. However, recruitment of riparian vegetation on the abundant gravel bars in this stream will eventually increase canopy closure and provide future woody debris recruitment potential. More frequent pool habitat formed from woody debris loading will also likely increase carrying capacity for salmonids in North Fork Indian Creek.

4.4.11 CON CREEK

Reach Locations: Con Creek was surveyed 1250 feet downstream and approximately 2000 upstream of an unnamed tributary that enters from the north side of Con Creek. The mouth of this tributary is located approximately at the 13W/14W range boundary (see Boonville, CA 7.5 minute topographic map). Reach A is a moderately confined, forced pool-riffle stream. Reach B is a confined, step-pool stream. Channel morphology alternates between these two reach types throughout the length of channel surveyed.

Spawning and Food Production

Spawning habitat in Con Creek was rated as approximately half poor and half fair. Large cobbles and boulders dominated the active low flow channel and fine substrates were abundant in bars. Because of their large size large cobbles and boulders provide relatively poor spawning habitat. The small pebbles dominant on bars likewise provide poor spawning habitat because they often scour during the high flow events that typically occur during coho and steelhead spawning or they do not allow oxygenation of eggs, resulting in egg loss. The aquatic insect production in Con Creek was rated as good. The cobbles present in the low flow channel allowed for abundant substrate for insect production because they were not typically embedded with fines.

Rearing Habitat

Most of the pools in the surveyed reach of Con Creek were formed from boulders, creating a step-pool morphology. LWD also formed pools in Con Creek. These pools had 20 to 30 percent more cover for fish at low flows than pools formed by other features. During low flows, pools were fairly shallow ranging from 0.4 to 1.1 feet average deep. The maximum depth of the deepest pool sampled was only 2.1 feet. There was a low amount of high flow refuge habitat throughout the entire surveyed reach. Most of flow refuge was from in-stream structures, primarily boulders, and channel edges. There was almost no flood plain area because of the high degree of channel confinement, especially in the upper section of the survey reach.

Temperature and Canopy Closure

Canopy closure was rated as low throughout most of the reach. One isolated area of moderate canopy closure was documented. Canopy closure was provided by young conifers, young to mature hardwoods, and in a few places young riparian trees, as well as topography. Temperatures during the survey ranged from 20 to 24^{o}C (68 to 75^{o}F). Temperatures monitored by MCWA between 22 June and 05 October 1995 averaged 18.0^{o}C (64.4^{o}F), with a maximum of 26.5^{o}C (79.8^{o}F) and a minimum of 12.6^{o}C (54.7^{o}F). In 1996 temperatures monitored between 03 June and 30 September averaged 16.1^{o}C (61.1^{o}F) with a maximum and minimum of 23.8 and 10.9^{o}C (74.8 and 51.7^{o}F), respectively.

Fish Presence

YOY steelhead were the only fish observed in Con Creek during the survey. Abundance ranged from about 5 to 10 per pool, which is a moderate number given the small size of the pools during the low flow season. No coho or 1+ steelhead were observed.

Possible Limiting Factors

It is likely that stream gradient accounts for the absence of coho in Con Creek. Stream temperatures are also fairly high for coho, despite the good food production. Frequency and size of pool habitats likely limits steelhead abundance during the low flow season. In addition, poor spawning habitat likely limits steelhead production in Con Creek.

4.4.12 Bear Wallow Creek

Reach Locations: Bear Wallow Creek was surveyed from Honey Creek to Rancheria Creek, a distance of approximately 1.0 miles. Throughout the reach surveyed, the channel is confined and has a step-pool bed morphology.

Spawning and Food Production

Approximately half of the spawning habitat was rated as poor and the other half was rated as fair. Aquatic insect production was rated similarly. Abundant fines in gravel areas precluded it from being good for either spawning or insect production. In addition, in much of the reach the boulders were dominant in the low flow channel, reducing the aquatic insect production capacity.

Rearing Habitat

Most of the pools were plunge pools formed from boulders and offered little in-stream cover during low flows. In addition, during low flows pools were fairly shallow ranging from 0.8 to 1.1 feet average deep. A few deep pools with maximum depth up to 2.5 feet were present. High flow refuge habitat was rated as approximately half low and half moderate with a few areas rated as high. Most of the high flow refuge was from in-stream structures, primarily boulders, and channel edges. There was almost no flood plain area because of the high confinement of the channel. There were a few log jams present which would provide refuge at very high flows. These jams were also the sites of large drops (averaging about 20 feet high) in the stream and also tended to cause local accumulation of large amounts of gravels upstream of the jams.

Temperature and Canopy Closure

Canopy closure was rated as either high or moderate throughout most of the reach. Isolated areas of low canopy closure occurred where the banks were not as high and where riparian vegetation had been removed from the bank because of land slides. Temperatures during the survey ranged from 18 to 20°C (64 to 68°F). Temperatures monitored by MCWA between 26 June and 16 October 1995 averaged 13.4°C (56.2°F), with a minimum of 10.9°C (51.7°F) and a maximum of 16.2°C (61.2°F). In 1996 temperatures monitored between 31 May and 27 September averaged 16.6°C (61.8°F) with a minimum and maximum of 11.9 and 21.6°C (53.3 and 70.8°F), respectively.

Fish Presence

Fish abundance was low during the survey. Half of the sampled pools contained between 5 and 10 steelhead, the other half contained less than 5 steelhead. YOY steelhead made up approximately 75% of the catch, while 1+ steelhead made up the other 25%. No other species were observed.

Possible Limiting Factors

Stream gradient seems to be the most important limiting factor to coho in Bear Wallow Creek (approximately 5%). High flow refuge habitat can only be increased through woody debris recruitment because of the confined channel. Introduction of more woody debris into pool habitats would also improve low flow cover. Reduced fine sediment in the gravels would improve low flow rearing habitat because it would improve aquatic insect production.

4.4.13 BEASLEY CREEK

Reach Locations: Beasley Creek was surveyed from its confluence with Rancheria Creek upstream for a distance of 0.5 miles to a confluence with an unnamed tributary.

Spawning and Food Production

Both spawning habitat and food production in Beasley Creek were rated as poor to fair during our surveys. There were abundant of fines causing embedded gravels in many areas and bedrock or large cobbles in other areas; which are all poor areas for spawning and insect production. In short a subreach insect production was rated as good.

Rearing Habitat

Even in the above normal water year in which the surveys were conducted, water flows subsurface near the confluence with Rancheria Creek, thus providing poor fish habitat. The pool frequency is low and there is little over winter or over summer cover habitat. In addition, the Beasley Creek channel is confined and there is little flood plain for high flow refuge habitat. There were, however, a few deep pools (up to 3.7 feet deep) relative to the size of the creek.

Temperature and Canopy Closure

Canopy closure was rated as mostly high (greater than 65% canopy closure) and was composed of deciduous trees and hardwoods, few conifers were noted. Water temperatures during the survey were cool compared to many of the other streams surveyed. Instantaneous water temperatures during the survey ranged from 16^{o}C (61^{o}F) in the morning to approximately 18^{o}C (64^{o}F) in the early afternoon.

Fish Presence

Only steelhead were observed in Beasley Creek during the survey, only one of which was a 1+ fish. YOY steelhead were relatively abundant, up to approximately 30 per pool, relative to the small size of this stream. No coho or California Roach were observed.

Possible Limiting Factors

Water temperature does not appear to be a factor in fish abundance in Beasley Creek. Even with low stream flows and poor insect production, YOY steelhead abundance was relatively high. Improved substrate conditions in riffle habitat, for spawning and insect production, would likely improve conditions for fish in Beasley Creek. Improved cover in pools and increased pool habitat from large woody debris (LWD) loading would increase fish habitat in this stream. A good riparian corridor exists, consisting of young to mature trees, but little opportunity for immediate woody debris loading exists. Stream gradient may limit coho production in this stream.

4.5 LIMITING FACTOR DISCUSSION

In order to determine possible limiting factors for salmonid distribution and abundance in the Navarro River watershed, the requirements for each life history phase of both coho and steelhead need to be taken into account. It should be emphasized that the limiting factors discussed below are based upon the physical condition of the aquatic habitat within the surveyed stream channels.

Limiting factors other than those discussed below exist for the Navarro River basin as a whole. In particular, the distribution of coho salmon does not appear to be limited strictly by habitat conditions, but is also related to the limited dispersion of adults into the watershed which may be more a function of the small numbers of the returning adult population. It also appears that the excess amount of sediment stored in reaches of the mainstem Navarro River, Rancheria Creek, and Anderson Creek must be addressed to achieve a successful restoration program. Efforts to restore fish habitat or conduct revegetation efforts to reduce water temperatures may be most effective in medium to small-sized tributaries. Efforts to restore habitat and improve fish production are also likely to be most cost-effective in streams that already provide fair to good habitat conditions.

4.5.1 ADULT SALMONID HABITAT

Adult coho and steelhead require spawning gravels, pool holding and resting habitat, and sufficient streamflow for upstream passage. In the Navarro River watershed, many of the streams surveyed had gravels with abundant intrusion of sand or fine sediments. Sand in gravels can cause the gravels to become embedded. Some sands will react with the water and substrate resulting in a cementing of the gravels, forming a tough veneer of hardened substrate making spawning difficult and spawning success poor. Sand can infiltrate also into the spaces between the gravels reducing the intergravel flow of water thereby reducing egg survival or making emergence of fry from the gravel extremely difficult. This lack of good quality spawning habitat may have been a cause of the decline of the coho and steelhead populations in the Navarro River watershed. However, with the few numbers of adults returning to the watershed currently, poor spawning gravels may not be limiting populations at this time. It is likely that in most of the streams surveyed, there is enough fair quality spawning gravel available for the few adults returning to spawn. Still, improvements to reduce fine sediment input and resultant improvements to spawning substrate will likely benefit salmonid populations in the long term.

In most of the streams surveyed the pool frequency was low and fast water habitat frequency was high. This lack of sufficient pool resting habitat may lead to pre-spawning mortality. In addition, lack of cover in all habitat types may lead to increased predation of adults migrating through the system.

The different life history patterns of coho and steelhead can have a bearing on their relative abundance in the different streams. In California, coho salmon enter streams from late fall through mid winter whereas steelhead begin entering streams in early winter and continue through spring. While it is unlikely that low streamflows are completely limiting access to streams in the Navarro River watershed, in dryer years when storm events are delayed until late winter, access for coho salmon may be restricted to mainstem sites or tributaries in the western portions of the watershed. Typically, coho salmon will spawn in late fall or early winter. Subsequent high flows that may occur during winter floods can scour redds resulting in poor survival of the young. The majority of the steelhead spawning occurs in the late winter or spring after the highest probability of flooding events has passed.

4.5.2 Juvenile Salmonid Habitat

Juvenile coho and steelhead require slow, shallow water habitat when they first emerge; coho and 1+ steelhead require pool habitat with sufficient flow and upstream food sources; while YOY steelhead utilize riffle habitat for feeding. Juveniles also require sufficient streamflow for downstream passage. Because of the lack of pool forcing features, primarily LWD, the number of pools with cover and the amount of back water areas may be limiting in many of the streams in the Navarro River watershed. In addition, embedded and/or sandy riffle areas generally are poor insect producing areas, which may limit juvenile rearing success in many of the streams surveyed.

The available stream temperature data (Appendix E) indicate that high average daily summer stream temperatures and large daily fluctuations likely reduce juvenile salmonid success over a considerable portion of the watershed. Higher stream temperatures are a result of wide, shallow channels, reduced riparian shading, and low or subsurface streamflows. High stream temperatures are of particular importance when insect production is low. Salmonids require a greater abundance of food to support the increased metabolic rates that occur as stream temperatures increase. Excessive fine sediments in the channel may be reducing insect production, limiting the food base available to fish. Under conditions of both increased stream temperatures and reduced food availability, the ability of salmonids to survive is compromised. Management activities to improve riparian shading and increase summer low-flows are recommended to improve stream temperature conditions over the long term. Further description of stream temperature conditions in each of the major drainage basins and discussion of the importance of stream temperatures to watershed-wide recovery of the fishery is provided in Section 5.0.

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5.1 INTRODUCTION

Previous sections form the scientific basis for establishing restoration and conservation priorities for the Navarro River Watershed. Information from Chapters 2, 3, and 4 are integrated in this section to provide a characterization of the conditions, limiting factors, and restoration potential within each of the watershed's major drainage basins. These characterizations are used to establish objectives and priority actions for meeting the project's goals of improving water quality and restoring the Navarro's anadromous fishery. This includes a screening process to identify those streams and basins most important for recovery of coho salmon and steelhead trout populations.

5.2 WATER QUALITY AND AQUATIC HABITAT CONDITIONS

A summary description of present-day habitat and water quality conditions is provided for each of the major basins in the watershed[6]. The summaries include: stream temperatures, streamflow, land-use, sediment production sources, channel condition (pool frequency and depths, amount of large woody debris), and importance to sustaining or recovering the target fisheries (historical records of fish presence/absence, spawning & rearing conditions). More detailed information on each basin is provided in Section 4.0 *Fish Habitat,* and Appendix A.

[6]Conditions found in localized areas within the major drainage basins were extrapolated to other nearby or similar areas of the basin, but not all locations in the watershed were visited and the ability to extrapolate is sometimes constrained. For the Navarro sediment production investigation, we extrapolated from known, representative areas, to unknown areas throughout the watershed. This extrapolation process was based on stratifying the watershed into similar areas of geology, soil type, vegetation, land use, and stream-order. The stratification and extrapolation process relied on field observations (including aerial overflights), examining recent aerial photographs, and by using geologic and topographic maps. However, extrapolating other physical and biological attributes, including flow regimes, water temperature regimes, aquatic habitat conditions or fish utilization is not nearly as straightforward. Certain assumptions and inferences can often be made regarding the similarities of these factors, but a thorough site visit is often necessary to verify similarities or identify differences. Where our confidence in these extrapolations is in question, we have recommended additional field work to verify suitability for conservation and restoration. These streams and sub-basins are listed in this report (Section 5.2) and have not been included in the prioritization process for the purpose of rating their importance to restoration actions.

5.2.1 NORTH FORK NAVARRO RIVER BASIN

Stream Temperatures

In general, stream temperatures in the North Fork Navarro River basin are suitable for coho salmon and steelhead (Figure 5-1). The most suitable temperatures for coho salmon in the Navarro River watershed are generally associated with the North Fork Navarro River basin since it is most strongly influenced by its proximity to the coast. Marginal temperatures for coho salmon may occur during brief periods in the summer in portions of the South Branch of the North Fork. Most of the tributaries to the North Fork Navarro, such as John Smith Creek and Flynn Creek, also have suitable summer water temperatures for coho salmon and steelhead.

Stream Flows

Summer base flows are typically low for the watershed, approximately .03 cfs per square mile over the entire basin as measured above the confluence with the mainstem Navarro. However, stream flows appear adequate to support juvenile coho salmon and steelhead in most streams in the North Fork Navarro River. Because timber operations are the primary land-use, water diversions do not appear to be a factor affecting salmonid habitat during summer low-flow conditions.

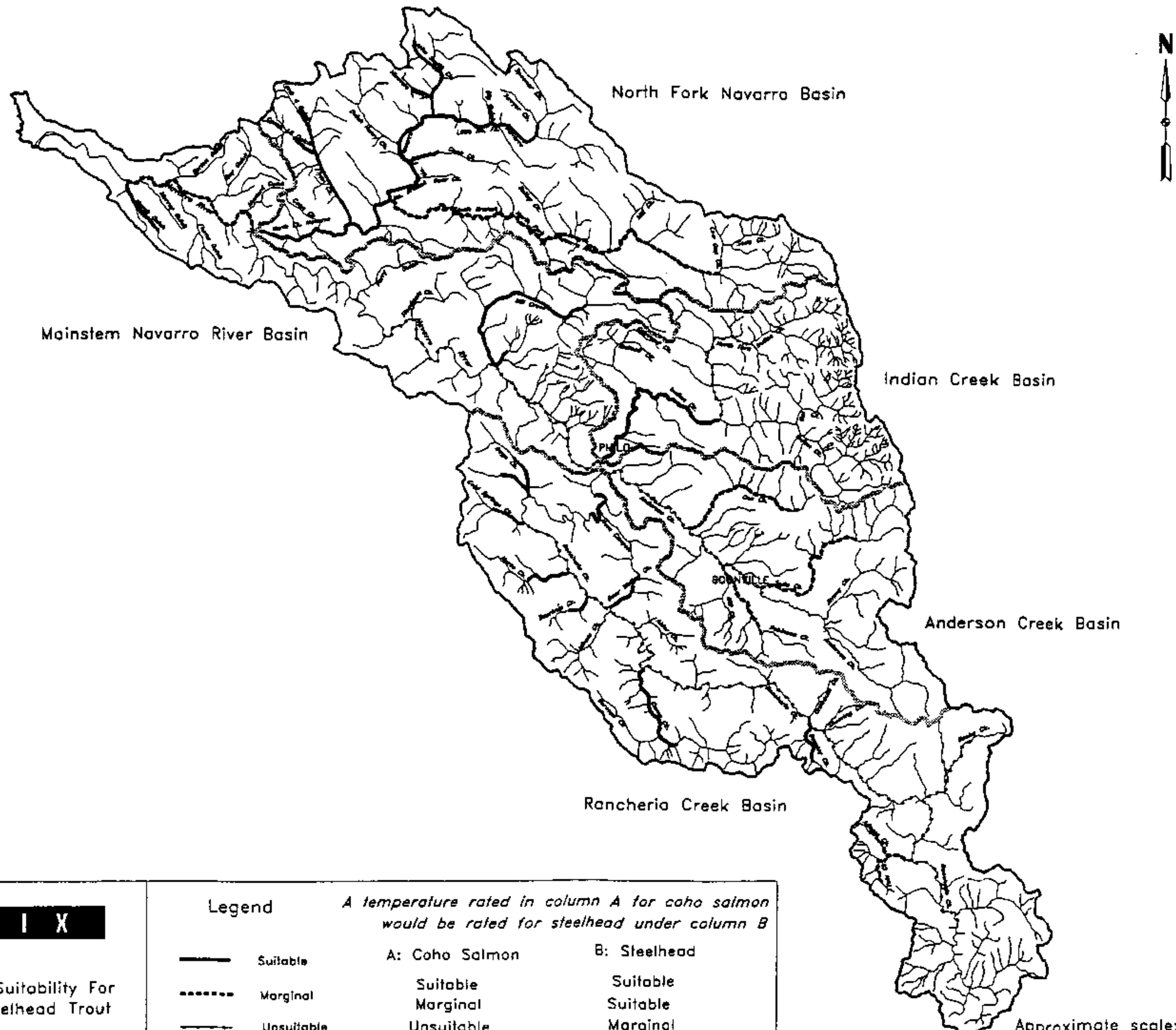
Land Use

Land use is primarily for timber harvest, with some rural residential and vacation homes.

Sediment Production

The North Fork Navarro is the most densely roaded basin in the watershed (see Section 3.0). Road-related erosion is responsible for about 60% of the total sediment production. Roads are readily amenable to erosion control treatments. A comprehensive road remediation program presents a cost-effective opportunity to minimize accelerated sediment production, and thereby reduce fine sediment deposition in channels.

Most of the North Fork Navarro basin is within the forested Coastal Belt geology. Bank erosion and shallow landslides in both small and large channels account for about 40% of total sediment production in the basin. These erosion processes are widespread. On a basin-wide scale, near-term active restoration treatments may be technically difficult to implement, and are likely to be costly, depending upon site-specific conditions. Over the long-term, programs which protect the sensitive riparian corridor and inner gorge slopes, such as riparian buffer strips, will be a cost-effective means to reducing shallow landslides and bank erosion.



ENTRIX

Figure 5-1

Stream Temperature Suitability For Coho Salmon and Steelhead Trout

Navarro Watershed Restoration Plan

Legend

A temperature rated in column A for coho salmon would be rated for steelhead under column B

		A: Coho Salmon	B: Steelhead
———	Suitable	Suitable	Suitable
- - - - -	Marginal	Marginal	Suitable
———	Unsuitable	Unsuitable	Marginal

Approximate scale: 1" = 16,250'
1:195,000

Channel Conditions

Channel conditions vary according to the specific tributary. Several second order tributaries, such as John Smith Creek and Flynn Creek, provide relatively good pool habitat with large woody debris. Dutch Henry Creek is believed to have similar habitat conditions, however there is no available data on this sub-basin. The North Branch of the North Fork has a more complex, branching channel pattern, compared to the South Branch of the North Fork. Spawning sites in tributaries are not as prone to scouring compared to sites with similar gravel sizes in the larger channels. The North Branch of the North Fork is likely to provide better incubation and over-winter habitat due to more stable channel beds. Most of the channels are relatively low gradient streams trending either northwest or northeast. Good spawning habitat was observed during field surveys on the Little North Fork Navarro River.

Overall, habitat conditions are considered to be suitable, and are presently supporting the main population of coho salmon in the Navarro River watershed. The North Fork basin also supports steelhead populations.

Fisheries

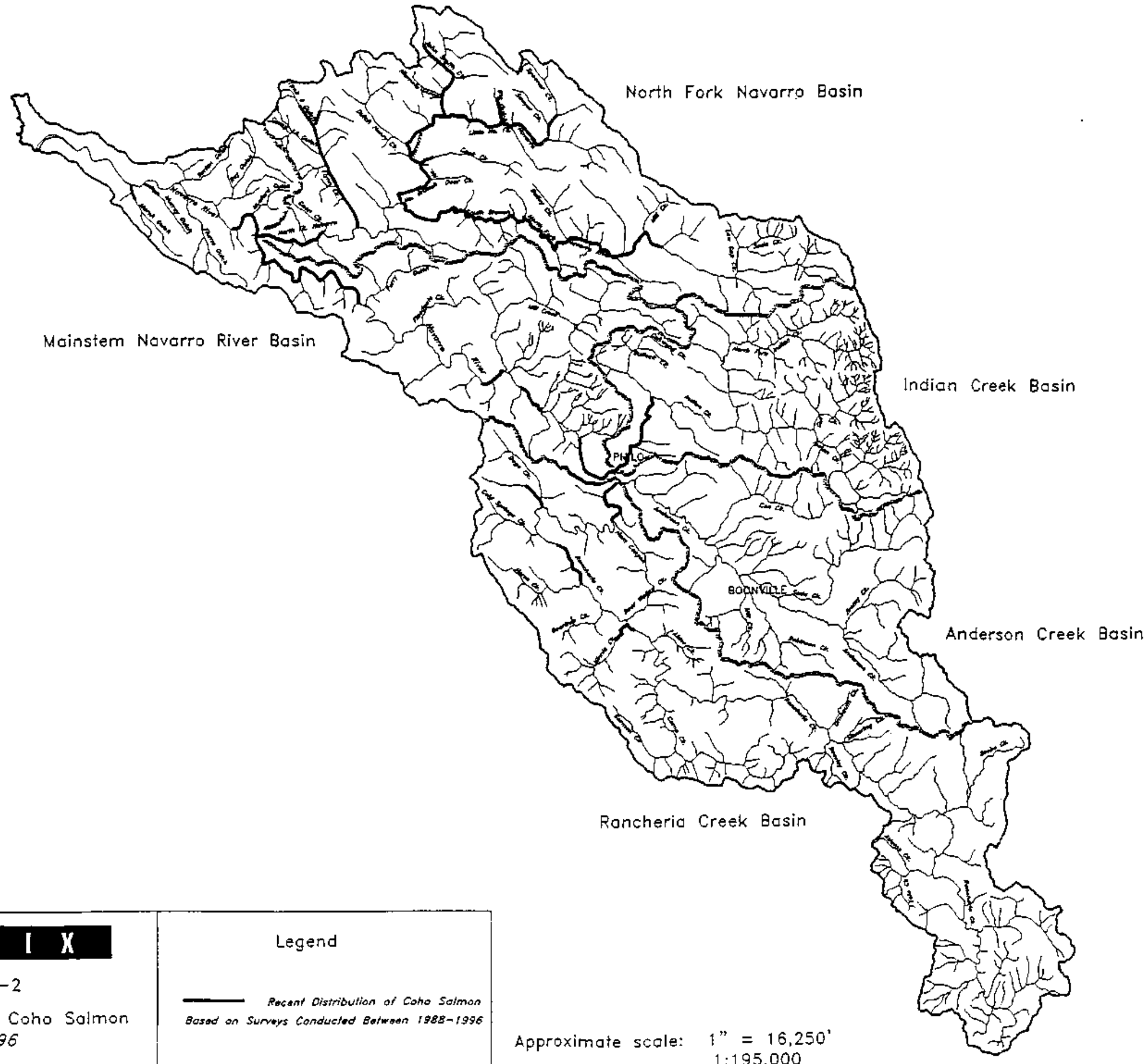
Coho salmon and steelhead have recent and historical records of occurrence in this basin. Coho salmon are known to occur in Dead Horse Gulch, Flynn Creek and tributaries, North Fork Navarro, North Branch of the North Fork, Cook Creek, John Smith Creek, and the Little North Branch of the North Fork up to the confluence with Bottom Creek (Figure 5-2). Steelhead, but no coho salmon, have been recently observed in Bottom Creek and Low Gap Creek. The South Branch of the North Fork had coho salmon in the late 1980's up to the Sawyer Creek confluence, but surveys conducted in the mid-1990's found coho salmon in the South Fork only near the confluence with the North Branch North Fork.

The North Fork Navarro sub-basin is presently supporting the majority of the coho salmon population using the Navarro River system. There is no other basin that is consistently used by juvenile coho salmon within the Navarro watershed. Therefore, it is important to maintain the habitat in these streams for the long-term conservation of coho salmon and steelhead and to improve habitat conditions to increase production of anadromous fish. Coho salmon from this basin may ultimately provide the "seed" fish to re-establish coho salmon runs in other basins of the watershed.

5.2.2 ANDERSON CREEK BASIN

Stream Temperatures

In the Anderson Creek basin, summer stream temperatures are generally too warm, often with extreme daily fluctuations, or streamflows are not persistent at locations where temperatures are suitable to provide conditions that would support coho salmon. Stream temperatures are considered to be marginal to unsuitable for steelhead in much of the



ENTRIX

Figure 5–2

Recent Distribution of Coho Salmon

1988–1996

Navarro Watershed Restoration Plan

Legend

Recent Distribution of Coho Salmon Based on Surveys Conducted Between 1988–1996 lower and upper mainstem of Anderson Creek. Temperatures in Con Creek are unsuitable for coho and marginal for steelhead. Temperatures may be more suitable for steelhead in Jimmy Creek and in Anderson Creek above the confluence with Jimmy Creek, however, no temperature data is available for these upper watershed reaches. In Robinson Creek temperatures are unsuitable for coho salmon, and appear to be marginal for steelhead.

Stream Flow

Stream flow is very low during the summer months and occasionally influenced by the diversion of surface or sub-surface flow. Mainstem Anderson Creek has the lowest streamflow accretion rate, approximately .01 cfs/mi^2 (based on 1995 data). Streamflow monitoring indicates that diversions in lower Anderson Creek reduce surface flow to 0 cfs, leaving isolated pools. Loss of surface flow has serious consequences for fish which are forced into crowded pool habitats where oxygen depletion can occur. In Robinson Creek, streamflow dried up early in the summer season (1995), and may therefore be insufficient to support summer habitat for steelhead. Streamflow monitoring indicates that upper Soda Creek (at Soda Spring) also went dry in 1995. Streamflow in Con Creek (near confluence with Anderson Creek) was low, but probably sufficient to support summer habitat for steelhead upstream of the alluvial valley reach.

Land Use

This is the most urbanized area in the Navarro River watershed. Grazing of open oak woodlands by sheep and cattle, orchards, row crops and viticulture are common, widespread agricultural uses.

Sediment Production

Much of the Anderson Creek basin is in the melange-grassland terrane, which has the highest sediment production rates in the watershed, approximately 2,000 tons/mi^2/yr (see Section 3.0). Bank erosion and shallow landsliding along larger streams (3rd to 6th order) are the principal sources of sediment production, responsible for about 50% of sediment production in the basin. Gullies are the next largest source, accounting for about 23% of total sediment production.

Anderson Creek is actively aggrading with coarse sediments, and as a result, is eroding its streambanks. In-channel structures to improve fish habitat are likely to be ineffective restoration treatments on the mainstem Anderson Creek in Anderson Valley, and are therefore not recommended. The best means to reduce active aggradation and bank erosion in Anderson Creek is to reduce sediment production delivered from upstream tributaries. Therefore, streambank stabilization treatments on tributary streams such as Con Creek, Soda Creek, and Jimmy Creek will become important erosion control measures. Gully erosion control treatments in the melange grassland terrane should also be established to reduce sediment production to Anderson Creek as well as to the tributary streams.

Channel Conditions

Along much of the lower portions of Anderson Creek, the channel has widened and aggraded, causing unstable bars and bank erosion. Pool habitat is present, but not abundant. Large woody debris is not typically a feature found in the streams draining the Anderson Creek basin since the vegetative community is predominantly comprised of oak woodland or grassland. Tributaries and portions of Anderson Creek upstream of the alluvial valley reaches provide suitable habitat for steelhead, but are likely too warm during summer and do not have sufficient pool habitat and woody debris to support coho salmon.

Fisheries

There are current records for steelhead, but no recent or historical records for coho salmon in this basin. Steelhead are not part of the summer fish fauna in the reach of Anderson Creek near Boonville. Low flow, warm temperatures, and barriers to some tributaries may limit the extent of steelhead habitat. In Con Creek, habitat is generally suitable for steelhead, but there may be a barrier at the confluence with Anderson Creek preventing access to anadromous fish. It is important to maintain and improve spawning and rearing habitat for steelhead in the Anderson Creek basin to prevent fragmentation and potential loss of steelhead habitat. All information examined in our assessment of conditions in the Anderson Creek watershed indicate that it is not likely a suitable stream to support coho salmon. However, there may be locations within the basin that could provide spawning and incubation habitat. It would be of value to manage locations that may provide spawning opportunities for coho salmon for future use, if the existing coho salmon population can be increased to the point that such a spawning area would provide some value to the Navarro River Watershed.

Tributaries such as Con Creek are extremely steep (6% gradient) and are unlikely to be suitable for coho salmon, but provide steelhead habitat. Frequency and size of pools and poor spawning habitat probably limits the present-day steelhead population in Con Creek. Soda Creek has been documented to have steelhead, however very low flows probably limit summer rearing habitat in upper Soda Creek.

Sub-basins Which Require Additional Information

Information on temperatures, streamflow, and habitat conditions were insufficient in the Jimmy Creek, Donelly Creek, and upper Anderson Creek (above Jimmy Creek) sub-basins to consider in the prioritization screening process. Additional surveys should be performed in these areas to identify their appropriateness for management and restoration as steelhead streams.

5.2.3 INDIAN CREEK BASIN

Temperature

Stream temperatures appear to be suitable for coho salmon and steelhead in mainstem Indian Creek between the confluence of Parkinson Gulch and the mouth of Indian Creek. Temperatures in the remaining portion of Indian Creek, including the North Fork, appear to be unsuitable for coho and marginal for steelhead.

Stream Flows

Stream flows are adequate in much of mainstem Indian Creek and in the North Fork to sustain steelhead populations during the summer months. Summer streamflows in the lower reaches of Indian Creek are adequate to support coho salmon. Streamflow accretion rate for the basin, as measured above the confluence with the mainstem Navarro, was .09 cfs/mi^2 (August 1995 data), somewhat higher than the other major drainage basins, except lower Rancheria Creek.

Land Use

Portions of the upper watershed in the North Fork of Indian Creek are used for timber production. Hunting clubs, ranching and open space are the primary land uses in the remainder of the watershed. Road density in the watershed is about evenly divided between very low (2.5mi/mi^2), moderate (5.2mi/mi^2), and high (6.6mi/mi^2). The floodplain along the lower reaches of Indian Creek include vineyards and the town of Philo.

Sediment Production

Bank erosion and shallow landslides to larger channels are responsible for about 38% of sediment production in the basin. Bank erosion and shallow landslides to smaller channels account for approximately 25% of sediment production and gullies also account for about 25% of the total sediment production. Roads are the smallest sediment production source in the Indian Creek basin, accounting for about 10% of all sediment delivery to channels. However, in the higher density roaded areas in the Indian Creek basin (see Section 3.0), road erosion control programs should be a component of reducing sediment production.

Based on our field observations, North Fork Indian Creek does not have a pervasive fine sediment deposition problem as typically found in the other major drainage basins. Rather, coarse sediment loading predominates in this stream reach.

Channel Conditions

The channel along most of North Fork Indian Creek is wide and exposed due to aggradation from coarse sediments and poor canopy closure (less than 30%), causing significant temperatures problems during summer low flows. A majority of the upper

North Fork Indian Creek and portions of Indian Creek downstream to the confluence with Parkinson Gulch are filled with large sized sediment making the bars less resistant to moving during floods. There is a pervasive lack of LWD along the North Fork, reducing the frequency and quality of pools. This indicates that even if temperatures were suitable for coho salmon, other habitat features may be limiting. Habitat for spawning and food production ranged from fair to excellent. Recruitment of LWD should be encouraged by protecting streamside forests. Widened channels make it unlikely that riparian growth will develop a closed canopy that will assist in shading the channel and thereby reduce stream temperatures in the near future. In lower Indian Creek, habitat conditions appears to be suitable to support coho salmon.

Fisheries

Coho salmon are still common in Indian Creek in the mid 1960's, but by the late 1980's they were present only in the reach downstream of the confluence with North Fork Indian Creek. Steelhead are present throughout Indian Creek, occurring in the main stem and well up into the North Fork. The West Fork of Indian Creek only supports steelhead in its lower reaches. There is limited information on the fishery of Indian Creek upstream from the confluence with the North Fork.

Sub-basins Which Require Additional Information

Previous surveys of the West Branch Indian Creek sub-basin (tributary to mainstem Indian Creek) did not indicate the presence of either coho salmon or steelhead. Since there is no other information regarding habitat conditions in this portion of the Indian Creek basin, we recommend additional information be collected on temperatures and habitat conditions in consideration of the need for restoration activities. Information on temperatures, streamflow, and habitat conditions were also inadequate in the following sub-basins: Gut Creek, mainstem Indian Creek upstream of Gut Creek, and the headwaters area of the North Fork (upper 3.0 miles). Additional surveys should be performed in these areas to identify their appropriateness for management and restoration as coho salmon and steelhead streams.

5.2.4 Upper and Lower Rancheria Creek

The upper portion of Rancheria Creek is defined as the reach and associated tributaries located upstream of the Camp Creek confluence. The lower portion is defined as the reach and tributaries downstream from Camp Creek to the confluence with Anderson Creek.

Temperature

Stream temperatures in the upper mainstem Rancheria Creek appear to be marginal for steelhead and unsuitable for coho salmon during the warm summer months. Because portions of the larger mainstem streams, including Anderson Creek, Indian Creek, Rancheria Creek and mainstem Navarro River have widened due to loss of riparian habitat and excess sediment supply, even a well-developed riparian corridor cannot be expected to provide the canopy closure and associated shading necessary to help reduce stream temperatures in these reaches. Other streams tributary to Upper Rancheria Creek, including Beasely, Yale, and Adams Creek provide suitable temperatures to support steelhead and perhaps coho salmon.

The lower reach of Rancheria Creek also has warm summer temperatures resulting in marginal conditions for steelhead and unsuitable conditions for coho salmon. Some monitored tributaries to lower Rancheria Creek appear to have suitable temperatures for both steelhead and coho salmon and indicate that other streams in this forested Coastal Belt terrane may also provide suitable temperatures. These streams include Dago Creek, Cold Springs Creek, Horse Creek, Minnie Creek, Camp Creek, and Ham Canyon. Other streams tributary to Upper Rancheria Creek provide suitable temperatures to support steelhead and could perhaps support coho salmon but more information is needed. These streams include Beasley, Yale and Adams Creek.

Stream Flows

Stream flow in the upper mainstem of Rancheria Creek becomes very low during the summer. Much of the upper mainstem reach goes dry, retaining only isolated pools. The streamflow accretion rate during baseflow conditions is typical of the other basins in the watershed, about 0.035 cfs/mi^2. The lower reach usually retains some surface flow and has the highest streamflow accretion rate, approximately 0.14 cfs/mi^2 averaged over the whole basin. Larger tributaries maintain surface flow during most summers, but smaller tributaries, such as Beasely Creek, had only subsurface flow near the confluence with Rancheria Creek, resulting in poor summer rearing habitat.

Land Use

Land use in the upper watershed includes grazing and open space. Land use in the lower portion of Rancheria Creek includes ranching, logging, open space, and rural residential homes. Highway 128 is a major feature along the upper reach of this channel.

Sediment Production

Most sediment production, approximately 40%, is due to bank erosion and shallow landslides along the larger channels (see Section 3.0). Gullies account for 23% of all sediment production, but are undoubtedly more significant within the portion of the watershed underlain by the melange-grassland geology (see Section 3.0, Figure 1-1). Deep-seated landslides occur infrequently in the Navarro watershed, however most are located in the lower Rancheria Creek basin, within the inner gorge. Road density is very high in the lower reach, primarily attributable to forest timber harvest operations. It is likely that road improvements would substantially reduce total sediment delivery to stream channels in this portion of the basin. Deep-seated landslides account for only 10% of sediment production in the basin, however they may be locally important where they do occur within the inner gorge, such as the recent slides in Ham Canyon.

Channel Conditions

Segments of the upper mainstem channel of Rancheria Creek are filled with fine sediment, and the bed is wide and exposed. Upper Rancheria Creek stream banks are eroding from the widened bed. Woody debris is infrequent and the widened channels reduce their effectiveness to scour pools and to provide cover. In reaches where Rancheria Creek is confined and controlled by bedrock, fine sediment is not deposited. These are the inner gorge reaches, which provide deep pools and overall habitat quality is better.

CDFG surveys on Dago Creek and Horse Creek indicate that pool habitat and overall habitat complexity created by LWD is lacking in these streams. In addition, canopy closure should be encouraged by re-vegetation treatments and by protection of riparian forests. Beasley Creek has aquatic habitat conditions similar to these forested Coastal Belt terrane streams, however, the drainage area is comparatively small. Other sub-basins which are likely to have similar habitat conditions in this section of lower Rancheria Creek include Cold Springs Creek, Minnie Creek, and Camp Creek.

Fisheries

Upper Rancheria Creek historically produced, but did not support, juvenile coho salmon and steelhead. Because this section of Rancheria Creek typically goes dry, any fish spawned in this area must move into tributaries or downstream to permanent water sites to survive. Juvenile coho salmon and steelhead were collected from this section of the stream in the late 40's, early 50's, and early 70's. The coho salmon captured in the early 70's were all small juveniles taken in the spring, indicating that spawning, incubation and emergence had occurred upstream of the trap site near Maple Creek. Trapped juvenile fish were moving out of upper Rancheria Creek into permanent habitat. Department of Fish and Game documents noted high salvage numbers of coho salmon and steelhead from this part of Rancheria Creek in the late 1940's and early 1950's as the stream dried up in early summer. Juvenile coho salmon were collected from Dago Creek in the late 1980's in the lower Rancheria Creek basin. Limited sampling that occurred in 1996 did not locate coho salmon in Dago Creek, lower Rancheria Creek, or other tributaries sampled in this basin. Steelhead occur throughout the Rancheria Creek system. They were abundant in 1996 in Yale and Adams Creeks and adults were reported spawning in the spring of 1997 in the vicinity of the Elkhorn Road bridge.

Many of the streams draining the north slopes of upper Rancheria Creek, including Maple, Shearing, and Beebe Creek are located in the melange-grassland terrane. These sub-basins are generally too steep, with limited inputs of large woody debris, and relatively small watershed areas, to provide year-round habitat for coho and probably provide only marginal opportunities for steelhead habitat.

Lower Rancheria Creek tributaries on the southwest side of the basin, within the forested Coastal Belt terrane include Dago, Cold Springs, Minnie Creek, Horse Creek, Camp Creek, and Beasely Creek. These streams are likely to have suitable temperatures and have the potential for recruitment of LWD to support coho and steelhead habitat. These sub-basins are good candidates for restoration in order to establish suitable coho habitat conditions and a coho population outside of the North Fork drainage.

Sub-basins Which Require Additional Information

Information on temperatures, streamflow, and habitat conditions were insufficient in the Alder Creek and German Creek sub-basins in lower Rancheria Creek and several unnamed tributaries in upper Rancheria Creek above the Beebe Creek confluence. Additional surveys should be performed in these areas to identify their appropriateness for management and restoration as steelhead streams.

5.2.5 MAINSTEM NAVARRO RIVER

Temperature

High summer stream temperatures and large daily temperature fluctuations on the mainstem Navarro are unsuitable for coho and marginal for steelhead. Temperatures in many of the first order tributary streams are likely suitable for both species, but summer flows may be limiting. Water temperatures in Mill Creek appear to be suitable for both steelhead and coho salmon. Temperatures near the mouth of Mill Creek may become marginal for coho salmon during the summer. Some of the smaller tributaries downstream of the confluence with the North Fork, including Marsh Gulch and Ray's Gulch, do provide temperatures suitable for coho salmon and steelhead. Upstream of the North Fork confluence, Lazy Creek, when it is flowing, has suitable temperatures for coho salmon and steelhead.

Stream Flows

Stream flow appears adequate to sustain habitat in the mainstem Navarro River and Mill Creek during the summer for coho salmon and steelhead. Surface flow near the mouth of Mill Creek may become limiting during summer. The streamflow accretion rate in the Mill Creek drainage during baseflow conditions is typical of the other basins in the watershed, about 0.03 cfs/mi^2. Streamflow accretion rates on the mainstem Navarro are a little higher, about 0.05 cfs/mi^2. Many of the smaller tributaries, such as Lazy Creek, do not provide adequate stream flows by late summer.

Land Use

Rural homes, vacation homes, roads, former logging and lumber mill, vineyards, orchards, and open space are the primary land uses in the mainstem Navarro basin.

Sediment Production

Bank erosion and shallow slides to large channels account for 34% of the total sediment production. Roads are responsible for approximately 32% of the sediment production in the mainstem Navarro basin. Sensitive road locations, such as the inner gorge or riparian roads tend to deliver a greater portion of the road-related erosion to stream channels. Deep-seated landslides in the forested Coastal-Belt terrane (such as the Floodgate landslide) generate approximately 17% of all sediment production in the basin. Active deep-seated landslides tend to be relatively few in number and are concentrated along the inner gorge areas.

Channel Conditions

Habitat conditions in the mainstem of the Navarro are poor. The channel is widened and exposed with abundant fine sediments. Pool habitat is limited and pools that do occur do not provide complex habitat that would favor coho salmon. A major function of this reach of the Navarro River is to serve as a migration corridor for both species of anadromous fish. Mill Creek channel is dominated by riffles and runs with relatively low amounts of pool habitat. Pools are located at bends in the stream or are associated with redwood stumps that are anchored in the bank. The channel is confined with long, straight reaches and little woody debris. Most other streams tributary to this portion of the Navarro River are small first-order channels such as Ray's Gulch and Marsh Gulch, that are steep and likely to be inaccessible to steelhead and coho salmon throughout a large portion of their reach. The estuary provides rearing habitat for steelhead during the late spring, summer and fall, and also serves as a migration corridor for anadromous fish (Navarro Estuary and Lagoon Study 1996-1997, see Appendix F).

Fisheries

Steelhead are found in the mainstem Navarro River and they are likely present throughout most of the Mill Creek drainage. Juvenile steelhead were also taken from the estuary during every sampling period in 1996 and 1997, from the early spring into December indicating hat they use the estuary for rearing year-round. Results of the Navarro Estuary Study field investigation show that juvenile steelhead were the most abundant species captured from the estuary throughout the year. Steelhead are also known to use the smaller first order streams in the lower Navarro River such as Ray, Roller, Mustard, Flume, Murray and Marsh Gulches.

Coho salmon have been found inconsistently in the lower reaches of Marsh and Murray creeks, and have been documented in Mill Creek (Adams *et al.* 1996). However, coho have not been documented to use other areas of the mainstem Navarro or other tributaries for rearing. Coho salmon have not been documented to use the mainstem Navarro River except as a migration corridor to access the North Fork Navarro. They may also use the mainstem above the North Fork to access upstream areas in the remainder of the watershed. In the estuary, coho salmon smolts were collected in early to mid summer, but were apparently absent from the estuary from mid summer through the remainder of the following winter indicating that they do not depend upon the estuary for rearing like steelhead do, but may stay to feed for a short time prior to entering the ocean.

Sub-basins Which Require Additional Information

Information on temperatures, streamflow, and habitat conditions was insufficient in the Perry Gulch sub-basin to consider in the prioritization screening process. Additional surveys should be performed in this subbasin to identify its appropriateness for management and restoration as a coho salmon and steelhead stream. The Navarro Estuary and Lagoon will provide additional data and discussion on the importance of the estuary to steelhead trout and coho salmon when it is completed (see Summary of Study in Appendix F).

5.3 Goals, Objectives, and Priority Actions to Address Factors Limiting the Fishery and Water Quality Impairment

There are two central goals for the Navarro River watershed restoration plan. The first goal is to restore habitat conditions which supported the historic distribution and abundance of coho salmon and steelhead trout. The second goal is to improve water quality, specifically to reduce summer stream temperatures and to reduce sediment loads. These two goals are closely inter-related. The objectives and methods for restoration of fish habitat are often directly applicable to improvement of water quality, and water quality improvement measures will benefit fish habitat conditions.

To achieve these two goals, appropriate land management practices should be implemented in the watershed over the long-term. In addition, there are short-term actions which can result in immediate improvement and progress towards watershed restoration goals. These actions and land management practices will also result in progress towards other related goals for restoration planning in the Navarro watershed, including conservation of soil, increase in biodiversity, ecological stability, and maintenance of the land's productivity and its ability to support a diversified, sustainable, resource-based economy.

Implicit in all of the goals and objectives for restoration of the Navarro watershed is recognition of the rights and responsibilities of private landowners. Goals can best be met by interested landowners voluntarily taking steps to redress past land use practices that may have adversely impacted water quality and fish habitat, and to adjust their present-day land management practices to protect and improve these resources. The purpose of this plan is to inform interested landowners of the reasons for the decline in the salmon and steelhead fishery and water quality, and to assist interested landowners in restoring these natural resources.

Based on the integrated analysis of the watershed presented in Section 5.2, three broad objectives emerge which must be met in order to achieve the two primary goals. These objectives are:

1. increase frequency and depth of pool habitat;
2. decrease summer stream temperatures; and
3. reduce accelerated sediment production.

In general, these three objectives are important in all five drainage basins. The three objectives are inter-related: restoration and land management actions which may be implemented to attain one objective will often assist in achieving the other objectives. For example, one important action for increasing the frequency and depth of pools in forested regions of the watershed will be to establish and protect seral old-growth riparian forests. As trees along the stream corridor mature and senesce, they will become available for recruitment to the stream channel as large woody debris (LWD). LWD provides opportunities for streamflow to exert the hydraulic forces against the streambed and streambanks which create deep pools. The growth of mature riparian forests also provides greater canopy closure which increases shading over the channel and thereby reduces summer water temperatures. Protected riparian forests improve streambank stability as root growth binds soils and rocks, reducing bank erosion and sediment production. LWD also enhances pool habitat for coho and steelhead by increasing the cover elements present in the channel.

Eight priority actions are identified (Table 5-1) to achieve the goals and objectives for restoration of the Navarro watershed. For each priority action there is one primary objective which is met (as indicated by a closed bullet [•]). Other objectives may be secondarily met by the priority actions (as indicated by an open bullet [°]). Priority actions may be considered and implemented by landowners on a watershed-wide basis, wherever it may be feasible to do so. Examples of specific methods which may be used by landowners to fulfill implementation of priority actions are listed in Table 5-2. The methods described here are not meant to be inclusive. There may be other methods which are appropriate for a given set of site conditions and problems.

Sections 5.3.1, 5.3.2, and 5.3.3, describe why each of the objectives are important, and indicate how each of the objectives can be met by the priority actions and the associated methods listed in Table 5-2. Priority action number 8, Recommended Land Management Practices, is a large, "catch-all" category which includes many of the example methods listed above, as well as many land management practices not listed here. As part of the restoration planning, a compendium of recommended land management practices (RLMP's) is provided to guide landowners in the Navarro River watershed. The RLMP's address how to achieve watershed objectives for agricultural, grazing, timber production, and residential development land-uses (see Section 6.0).

5.3.1 INCREASE FREQUENCY AND DEPTH OF POOLS

Salmonids, particularly coho salmon, prefer deep, sheltered, and shaded pools, which provide rearing habitat, thermal refuge, low-flow and high-flow refuge. In deeper pools, water is generally colder with increasing depth, there is greater protection from predators, and during periods of high run-off, there are low-velocity resting areas. The loss of pool habitat is most critical in the forested sub-basins (Appendix G, Vegetation Cover Types) of the Navarro watershed, where it is estimated that pool frequencies have been reduced by one-half to one quarter of their likely historical frequencies (Appendix A).

Table 5-1. Goals, Objectives, and Priority Actions for the Navarro River Watershed.

GOALS

1. Restore Historic Distribution and Abundance of Coho Salmon and Steelhead Trout
2. Improve Water Quality

PRIORITY ACTIONS	***OBJECTIVES***		
	Increase Frequency and Depth of Pools	**Decrease Summer Stream Temperatures**	**Reduce Accelerated Sediment Production**
1. Increase LWD Recruitment	●	○	○
2. Install In-Stream Habitat Structures	●	○	
3. Increase Riparian Shading	○	●	○
4. Increase Summer Baseflows		●	
5. Gully Remediation Measures	○	○	●
6. Reduce Road-Related Erosion	○	○	●
7. Streambank Stabilization Measures	○	○	●
8. Recommended Land Management Practices	○	●	●

Table 5-2. Examples of Methods for Implementing Priority Actions.

Priority Actions	Example Methods
1. Increase LWD Recruitment	Direct introduction of LWD keyed into streambank Re-vegetation Protected riparian buffer strips
2. Install In-Stream Habitat Structures	Log & boulder deflectors, weirs
3. Increase Riparian Shading	Re-vegetation Riparian buffer strips Conservation/protection
4. Increase Summer Baseflows	Water conservation Coordinated scheduling of pumping Peak-flow storage alternatives Reduce groundwater extraction
5. Gully Remediation Measures	De-watering Prevent head-cutting (redwood cribbing, rocking, etc.) Establish vegetation Grazing management/Fencing Check-dams
6. Reduce Road-Related Erosion	Road closures and decommissioning Design standards & locations for new roads Road drainage control features (appropriately sized and placed culverts, rolling-dips, waterbars, etc.) Maintenance practices
7. Streambank Stabilization Measures	Bio-engineering methods (combination of brush layering, willow wattles, crib-walls, rip-rap, geotextiles, etc.) Re-vegetation Protected buffer strips
8. Recommended Land Management Practices	Timber harvest, grazing, agricultural, and urbanizing land management practices as appropriate to achieve objectives

Logging has resulted in removal of stream-side forests and degradation of remaining forests. In addition, past stream management practices resulted in removal of "debris jams" which were once commonly thought to be barriers to fish migration. Today, logging and salvage logging operations continue to remove LWD from streams in the Navarro and its tributaries. Habitat complexity and associated cover for fish is often attributed to large woody debris. Large woody debris is generally defined based on a criteria for minimum diameter. Although there is no single agreed upon standard, any tree component that is 12 inches or more in diameter is generally accepted as large woody debris. Debris piles or log jams constrict the channel and can aid in the development of pools (Lisle 1986, Montgomery *et al*. 1995). Pools with complexity from woody debris provide feeding sites, low flow escape cover, and high flow refuge for salmonids (Baltz and Moyle 1984a). Woody debris may also be important in sediment retention and is therefore important in maintaining spawning and aquatic insect production sites (Lisle 1986, Montgomery et al. 1995). When woody debris has been removed from streams, salmonid populations have declined (Tschaplinski and Hartman 1983, Dolloff 1986).

A larger number of pools with greater depths can be created by two primary means -- increasing the recruitment of large woody debris, and construction of in-stream habitat structures. Over the long-term, LWD will be recruited to forested stream channels if mature riparian forests are established. The natural lateral migration of stream channels over long periods of time eventually erodes streambanks which support old-growth trees. In addition, landslides, windthrow, and natural senescence recruit trees to stream channels. Restoration actions which provide for recruitment of LWD include establishing protected riparian buffer strips, and revegetation in locations where trees have not become established. LWD may also be directly introduced to stream channels by moving fallen trees or logs from floodplains or upland areas to the stream channel. Generally, LWD introduced directly to the channel is keyed or cabled into streambanks to ensure that it will provide the pool-forming characteristics and other habitat benefits to the fishery.

Pools can also be created by the use of in-stream structures such as boulder or log deflectors and weirs which re-direct the hydraulic forces of flowing water so that pools are scoured. The principal is similar to the introduction of LWD, however, in-stream structures are generally more elaborate in their design and installation.

Pool depths can be increased by actions which reduce sediment production in the watershed. As streambank stabilization and gully and road remediation measures take effect, less fine sediment will enter stream channels, and there will be less of a tendency for pools to fill in.

5.3.2 DECREASE SUMMER STREAM TEMPERATURES

Relatively few stream reaches in the Navarro watershed provide suitable water temperatures to support coho salmon, and stream temperatures are often only marginal for support of steelhead. Coho and steelhead tolerance of stream temperatures can vary, depending particularly on the time allowed for acclimation. Studies on pacific salmonids have shown that the preferred temperature range for both coho and steelhead is between approximately 12-14^{o}C (50-58^{o}F) (Bjornn and Reiser 1991). However, both species, and especially steelhead, have been observed in streams at higher temperatures, especially when they are allowed to acclimate slowly. The daily fluctuation of temperatures can also have an impact on survival. Daily fluctuations up to 4.5^{o}C have been shown to increase heat tolerance in rainbow trout, but fluctuations greater than 4.5^{o}C reduced heat tolerance (Threader and Houston 1983).

Reducing stream temperatures during the low-flow summer period will improve water quality and increase the populations and distribution of salmonids. High stream temperatures are due to historic channel widening and shallowing, and to the loss of riparian vegetation. By increasing the canopy cover and riparian shading, stream temperatures can be reduced. Similar to the methods for increasing LWD recruitment, protecting riparian forests and in some locations re-vegetation will increase shading and result in lower stream temperatures. Another priority action which will improve stream temperatures is to increase baseflows, through the use of water conservation actions, development of off-stream storage to capture peak winter flows for summer irrigation use, and reducing groundwater extraction in locations where flow is influent (groundwater flow direction is towards the stream channel).

In addition to increasing riparian shading and increasing summer baseflows, stream temperatures may be improved to a lesser degree by actions which increase pool habitat (increase LWD recruitment, install in-stream structures) or which reduce accelerated sediment production. As described in Section 5.3.1, a larger number of deeper pools will increase opportunities for salmonids to find cooler water.

5.3.3 Reduce Accelerated Sediment Production

Sediment production in the Navarro watershed should be in balance with the transport capacity of the main trunk and tributary stream channels. Currently, excessive fine sediment deposition is widespread in most of the major drainage basins. Some stream reaches such as Anderson Creek and Rancheria Creek, where they flow through their alluvial valleys, and in much of North Fork Indian Creek, also have coarse sediment loads that exceed the streams' capacity to transport this material through the channel.

High fine sediment loads increase water turbidity, and when deposited on the bed, degrade fish habitat. Abundant fine sediment in a stream bottom can have several detrimental effects on fish. Fine sediments can cement the gravels and cobbles making aquatic food production and salmonid spawning difficult, and it can result in poor intra-gravel flow, which results in egg loss from lack of oxygen. Sediment input into a stream channel can change from year to year or over many years. Some sediment input, especially coarse sediment (cobbles and gravels) is necessary for the health of a stream. Excessive coarse sediment loads, however, cause streambeds to aggrade, resulting in lateral instability, eroding streambanks, channel widening, shallowing of pools, loss of surface flow, and higher stream temperatures.

Accelerated sediment production is due to five principal geomorphic process in the Navarro watershed: streambank erosion in larger channels (37%), road-related erosion (26%), gullies (16%), streambank erosion and shallow landslides in smaller channels (15%), and deep-seated landslides (6%). Streambank stabilization measures, road-related erosion control measures, and gully remediation measures are primary actions which would address the vast majority of sediment production in the watershed. The methods for controlling these sources of sediment delivery to stream channels are wide ranging, and include road decommissioning and improved road drainage measures, bio-engineering techniques to stabilize streambanks, and fencing to protect disturbed riparian areas.

5.3.4 Restoration Priorities

Table 5-3 identifies priority actions to achieve the three restoration objectives in each of the five major drainage basins. Although some priority actions are not indicated for some basins, they should be considered a useful and worthwhile approach to water quality improvement and fish habitat restoration in all basins of the watershed. Goals satisfied by priority actions are also indicated in Table 5-3. Because each basin encompasses a large geographic area with diverse geologic, vegetative, and land-use conditions, priority actions may be of greater or lesser importance within specific smaller sub-basin drainage units.

5.4 Priority Stream Basins for Restoring Historic Abundance and Distribution of Coho Salmon and Steelhead Trout

In the previous section, we established objectives and identified actions that can be taken by landowners throughout the watershed to improve water quality and aquatic habitat conditions. In this section, streams are identified that should be given a high priority for actions to restore the coho salmon and steelhead trout fisheries. This is accomplished by establishing a set of screening criteria, which are defined and applied to streams throughout the watershed. The screening process results in identification of the most suitable and critical locations for restoration of coho salmon and steelhead trout habitat. The screening process also provides a basis for developing a watershed-wide strategy to recover the Navarro's anadromous fishery.

Overall, priorities for restoring the Navarro fishery are complimentary with the objectives and priority actions established for general improvement of water quality and aquatic habitat. The screening and selection process, however, allows for identification of those specific streams and sub-basins where restoration and conservation actions should be concentrated in the fisheries recovery program. As a watershed-wide strategy for restoration planning, priority basins should encompass sufficiently large areas of the watershed to provide for the complete fresh water life-cycle needs of coho salmon and steelhead trout. Larger, rather than smaller, planning units have the additional advantage of providing resiliency in case of natural perturbations (for example, deep-seated landslides, drought) which could set-back restoration efforts concentrated in a localized stream reach.

Table 5-3. Priority Restoration Actions By Drainage Basin.

Priority Actions	Drainage Basin					Goals Satisfied	
	North Fork Navarro	Mainstem Navarro	Indian Creek	Anderson Creek	Rancheria Creek	Water Quality	Fish Habitat
1. Increase Recruitment of LWD	•	•	•		(1)		✓
2. Install In-stream Habitat Structures	•	•	•		(1)		✓
3. Increase Riparian Shading	•	•	•	•	•	✓	✓
4. Increase Summer Baseflows				•		✓	✓
5. Gully Remediation Measures			•	•	•	✓	✓
6. Reduce Road Related Erosion	•	•			(2)	✓	✓
7. Streambank Stabilization Measures	•	•	•	•	•	✓	✓
8. Recommended Land Management Practices	•	•	•	•	•	✓	✓

(1) Lower Rancheria Creek is located primarily in the forested Coastal Belt geologic terrane where recruitment of LWD and use of in-stream habitat structures should be considered priority actions to restore and improve coho and steelhead habitat.

(2) Roads in lower Rancheria Creek are a significant contributor to sediment production and should be considered a priority restoration action (see section 5.2.4)

5.4.1 SCREENING CRITERIA

Designation of priority sub-basins for coho salmon and steelhead conservation and restoration is based on consideration and application of five criteria: stream temperature, recent historical evidence for presence of coho, suitability for in-channel restoration treatments, ability to treat sediment production sources, and distribution and abundance of coho salmon and steelhead[7]. Each criterion is described in detail below. The application of the criteria to streams throughout the watershed is presented in Table 5-4.

Stream Temperature

Streams with daily average temperatures less than 15°C (60°F) and with daily fluctuations less than 5°C were considered suitable for both coho and steelhead. Streams with daily average temperatures of 20°C (68°F) and with daily fluctuations no more than 5°C were considered marginal for coho and suitable for steelhead. Streams with daily average temperatures greater than 25°C (77°F) or with daily fluctuations greater than 5°C were considered unsuitable for coho and marginal for steelhead. These temperature criteria are not absolute, but they give an approximation of where we are likely to find these species given the current temperature regime in the Navarro River watershed. Locations where daily average temperatures and daily fluctuations are presently deemed to be suitable for coho are most likely to continue to provide suitable conditions over the long-term. Restoration efforts would need to address other limiting factors (LWD recruitment and fine sediment). Where temperatures are currently unsuitable for coho, restoration efforts may be worthwhile to improve conditions for steelhead, but are not likely to be effective for coho salmon until stream temperatures can be influenced by an adequate riparian canopy created through natural recovery processes, land management prescriptions or active re-vegetation.

We used temperature as an exclusionary criteria for short-term field restoration actions. Short-term restoration actions should not be implemented in locations where temperatures are not currently suitable for coho. Thus, we automatically designated as low priority for short-term field restoration actions locations where there are currently unsuitable temperatures for coho. We used a "Suitable" (S), or "Marginal" (M), or "Unsuitable" (U) designation in the screening process to indicate if temperatures were considered to be suitable, marginal, or unsuitable for both coho salmon and steelhead.

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[7]Long-term restoration actions that are based on land management recommendations are an essential tool for conservation and remediation of aquatic habitat conditions. Appropriate land management practices, tailored to the various land-uses and landscape conditions in the watershed, should be considered equally important to short-term restoration actions. Since land management practices need to be addressed with a comprehensive, watershed-wide approach, they are a priority everywhere in the Navarro watershed. Therefore, a screening process for land management prescriptions separate from the screening process for near-term field restoration actions is not considered.

Recent Historical Evidence for Presence of Coho

Locations that have been identified as supporting coho in the recent past (since the late 1980's) are more likely to provide suitable coho (and steelhead) habitat conditions today. We used a "Yes" or "No" designation in the screening process to indicate the recent historical status of coho presence in the watershed.

Suitability for In-channel Restoration Treatments

In-channel restoration treatments to improve the amount and quality of pool habitat are an important component of watershed-wide restoration efforts. We have considered the relative risks and benefits associated with implementing in-channel treatments for the various sub-basins and stream reaches of the watershed. We have identified a few locations (Anderson Creek, upper Rancheria Creek, Indian Creek) where channel stored sediments and on-going aggradation represent an impediment to in-channel restoration treatments and limit the likelihood of effective short-term restoration success. Therefore, these locations are not a high priority for restoration treatment. Also, segments of main trunk channels are likely to require more extensive efforts to stabilize in-channel structural treatments due to the higher shear stress forces during peak flows. We have designated higher priority status to those streams where opportunities exist for developing pools and providing cover through placement of LWD. Suitability for in-channel restoration treatments are ranked on a relative scale using "high", "moderate" and "low" designations.

Ability to Treat Sediment Production Sources

Basins that have a large percentage of sediment contribution from roads (these are the densely roaded areas: North Fork Navarro, Mainstem Navarro, and lower Rancheria Creek basins) are highly amenable to reducing sediment production through treatments such as floodproofing, road closure, etc. These locations provide good, cost-effective opportunities to reduce fine sediment accumulations in channels. Basins which derive more than 25% of total sediment production from roads were designated with a "high" feasibility for effectively treating sediment production sources. Bank erosion and shallow landslides in higher order channels and gullies have an intermediate level of technical difficulty and effectiveness associated with erosion control treatments. We designated basins with more than 25% sediment production from either gullies or bank erosion with a "moderate" feasibility for effectively treating sediment production sources. Deep-seated landslides, shallow landslides, and bank erosion to smaller (first & second order channels) are generally much more difficult to treat effectively. Where sediment production from these sources predominate, a "low" feasibility rating would apply. However, all of the major sub-basins fit either the high or moderate categories. Therefore, we did not designate a low feasibility rating in this screening process.

<u>Distribution & Abundance of Coho Salmon and Steelhead/Other Considerations in the Watershed</u>

The geographic distribution of fish in the watershed is another important consideration for developing a comprehensive, watershed-wide restoration strategy. As aquatic habitat has degraded, the areas where juvenile coho salmon are found in the watershed have shrunk in size and become disconnected. The isolation of the sub-populations is called *fragmentation*. Fragmentation is a major concern in the management of endangered species, because smaller population units are more prone to loss than a larger interconnected unit. Also, populations of low abundance are more prone to extinction compared to larger populations because the probability is greater that all individuals will be affected. Smaller populations also tend to be less resilient genetically to changes in the environment, diseases or predation. The priority for a restoration strategy is to maintain existing population levels and increase abundance in the short term. As abundance increases, the distribution of the organism to a wider areas of the watershed will typically occur.

Because there are differences in how coho salmon and steelhead are distributed in the watershed and differences in their habitat requirements, there is a different approach to recovery of the two species.[8] The primary area still supporting coho salmon in the Navarro River watershed is the North Fork Navarro. Abundance in this basin should be maintained and improved as a high priority restoration action. Furthermore, habitat improvements in other areas, such as the forested coastal belt terrane geology of the lower Rancheria Creek, lower Indian Creek, and Mill Creek, should be implemented and coho salmon planted into these sites. It is very unlikely that the National Marine Fisheries Service will allow transplanting of wild fish from the North Fork Navarro River so it will be necessary to use hatchery fish to restart these populations.[9] Simply maintaining or increasing the North Fork population may not provide enough effort in the short term to increase the distribution of coho salmon in the Navarro River soon enough. It is unlikely that adult coho salmon returning to spawn would enter other tributary streams or sub-basins of the watershed until the spawning population increases in abundance. Because the North Fork is located in the far western portion of the watershed, adult coho salmon would have to travel some distance past the north fork in order to find appropriate spawning sites in areas that would allow juvenile fish to move into suitable habitat in upstream tributaries.

Restoration actions for steelhead would be directed primarily at increasing abundance throughout the watershed and at reducing habitat fragmentation where it does occur. The Soda Creek, Con Creek, Yale Creek, and Adams Creek sub-basins are designated as important locations specifically for the restoration of steelhead habitat. There may be some conflicts wherein improving conditions for coho salmon may result in less

[8] Coho salmon are currently listed, but NMFS declined to list steelhead in March 1998.

[9] Juvenile coho salmon planted from stocks that are not thoroughly screened can result in the introduction of disease. Planted fish would also interbreed with the wild fish in the basin, thereby reducing the overall viability and genetic distinctiveness of the coho salmon population in the watershed.

favorable conditions for steelhead, but given the current population status and distribution of coho salmon in the Navarro River watershed, it is clear that coho salmon are in much more jeopardy than steelhead. In coastal streams supporting both species there are almost always more steelhead than coho salmon, and many streams support only steelhead. In streams that are excellent for coho, there are always some steelhead, while coho are often absent from steelhead streams. A higher restoration priority then, should be given to coho salmon over steelhead within the Navarro River basin.

We also considered other aspects of physical habitat conditions in the screening process, where the information was available or where we could confidently make an extrapolation from known locations. We considered streamflow regime, channel gradient, sub-basin size, stream length suitable for recovery actions which would support the target species, and position in the watershed with respect to upstream land-use and sediment supply conditions.

5.4.2 Sub-Basin Screening and Evaluation

In this section the screening criteria are applied to the five major basins of the Navarro watershed and priority locations are identified. For near-term field actions, sub-basins and stream reaches which currently provide the most suitable coho habitat conditions and which best meet the screening criteria were designated as high priority locations. Moderate priority status was designated for locations which met some, but not all of the screening criteria. A low-priority status was designated for locations that did not meet the temperature criteria, or for which other considerations (such as size of sub-basin, stream length suitable for the target species, streamflow regime, etc.) indicated that restoration actions might be unsuccessful or inefficient to implement.

Table 5-4 shows the application of the screening criteria to streams throughout the watershed. Based on the results of the screening, the following stream reaches and sub-basins should receive priority for restoration of the historical abundance and distribution of coho salmon and steelhead trout[10]:

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[10] Certain areas of the watershed are designated as priority restoration areas based on a limited amount of aerial photographic interpretation, review of other researchers' field observations (typically collected by CDFG), and inferences from nearby sub-basins that are believed to have similar habitat conditions. These areas are indicated in the sub-basin characterization at the beginning of this chapter, and in Table 5-4. A follow-up field survey should be conducted in these locations to confirm (or reject) the appropriateness of designation as priority restoration areas. In addition, for some stream reaches and sub-basins of the watershed there is insufficient information from which to make a preliminary prioritization designation. These areas, which are also noted in the sub-basin characterization, will require additional field surveys in order to identify their suitability for restoration.

North Fork Navarro Basin

a) North Fork Navarro River sub-basin

b) Flynn Creek, Dutch Henry Creek, and John Smith Creek sub-basins

Mainstem Navarro Basin

a) Marsh Gulch sub-basin (lower 1/4-mile reach only)

b) Mill Creek sub-basin

(Restoration priorities associated with the estuary are separately considered in the Navarro Estuary Study; see Appendix F)

Indian Creek Basin

a) Lower Mainstem Indian Creek (Parkinson Gulch to Navarro River)

Rancheria Creek Basin

a) Adams & Yale Creek sub-basins (for steelhead management only)

b) Dago Creek, Cold Springs Creek, Minnie Creek, Horse Creek, Camp Creek, and lower mainstem channel of Rancheria Creek

Anderson Creek Basin

a) Con Creek sub-basin (for steelhead management only)

b) Soda Creek sub-basin, lower reach (for steelhead management only)

Table 5-4. Restoration Priority Screening

Sub-basins & Stream Reaches	Temperatures Suitable for Coho/SH[1]	Recent Historical Evidence of Coho	Suitable for (n-Channel Restoration Treatments	Sediment Production: Source Treatability	Coho Distribution Importance and Other Considerations	Priority Status
North Fork Navarro Basin						
North Branch No. Fk.	S/S	Yes	High	High	Maintain existing coho population.	High
So. Branch North Fk.	M/S	Yes	Moderate	High	Maintain existing coho population. No recent evidence of coho above McGarvey Ck	Moderate
Flynn Ck, Dutch Henry; John Smith	S/S	Yes	High	High	No data for Dutch Henry Ck; assumed similar to other subbasins	High
Mainstem Navarro Basin						
Marsh Gulch	S/S	Yes	High	Moderate	Suitable habitat in lower 1/4-mile reach only	Low
Rays Gulch	S/S	Yes	Low	Moderate	no evidence of coho or Steelhead during 1996 survey; extensive fines	Low
Mill Creek	S/S	No	High	High	Mid-watershed coho population site	Moderate
Lazy Creek	S/S	No	High	High	Very low summer flows	Moderate
Mainstem Navarro *	U/M	Yes	Low	High	Important migration corridor, downstream location is recipient of sediment from all upstr. sources; high stream power requires stabilization of in-channel structures	Low

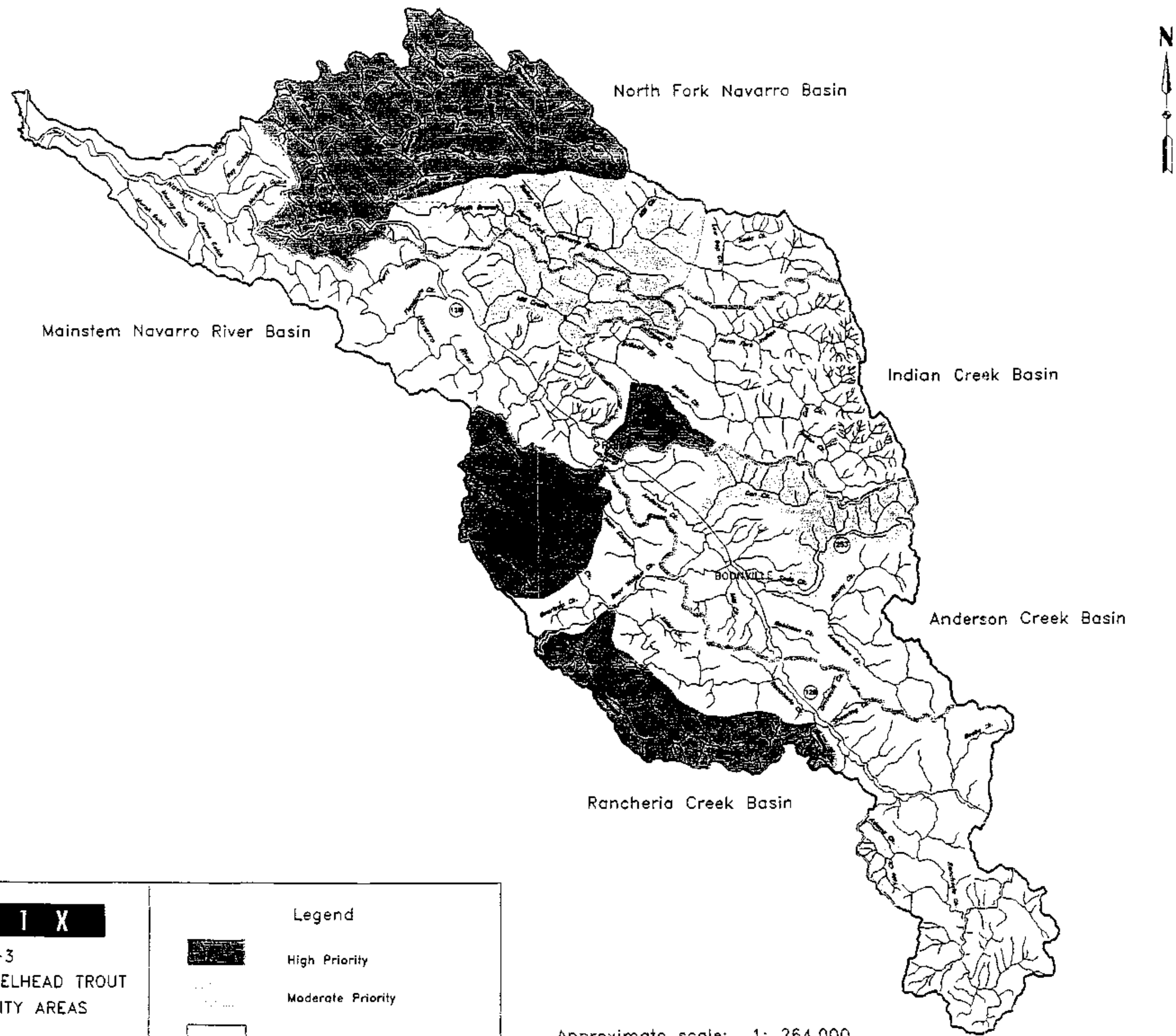
S = *Suitable, M = Marginal,* U = *Unsuitable*

Table 5-4. Restoration Screening (continued).

Sub-basins & Stream Reaches	Temperatures Suitable for Coho/SH[1]	Recent Historical Evidence of Coho	Suitable for In-Channel Restoration Treatments	Sediment Production: Source Treatability	Coho Distribution Importance and Other Considerations	Priority Status
Indian Creek Basin						
North Fork Indian Creek	U/M	Yes	Moderate	High	Evidence of aggradation with coarse sediments. NMFS found 1 coh salmon in 1997 survey	Low
Lower Mainstem Indian Ck (Parkinson Gulch to Navarro)	*SIS*	Yes	Moderate	High	Good baseflows	High
Rancheria Creek Basin						
Adams & Yale Creek	M/S	No	Moderate	Moderate	Upper watershed location to protect SH. Historical evidence of Steelhead only; restoration to target Steelhead	Moderate for SH only
Upper Mainstem Rancheria	U/M	No	Low	Moderate	historical aggradation is naturally recovering	Low
Dago, Cold Springs, Minnie Creek, Horse Ck, Camp Ck. Beasely Ck	*SIS*	Yes	High	High	Coho recruitment source to upper watershed. Cold Springs, Minnie, and Camp Ck not field surveyed, but likely to be very similar to Dago Ck. Temp, recorder on Camp Ck. Beasley Ck. has small watershed area and goes dry near confluence with Rancheria Ck	High
Maple, Shearing, Beebe Ck.	M/S	No	Moderate	Moderate	Sub-basins located in melange-grassland terrane, unlikely to support coho salmon. Generally steep & small drainages	Low

Table 5-4. Restoration Screening (concluded).

Sub-basins & Stream Reaches	Temperatures Suitable for Coho/SH[1]	Recent Historical Evidence of Coho	Suitable for In-Channel Restoration Treatments	Sediment Production: Source Treatability	Coho Distribution Importance and Other Considerations	Priority Status
Anderson Creek Basin						
Mainstem Anderson Ck	M/S	No	Low	Moderate	Actively aggrading; unsuitable for in-channel restoration. Water withdrawals impact habitat	Low
Con Creek	U/M	No	Moderate	Moderate	Upper watershed location for SH rearing	Moderate for SH only
Soda Creek	U/M	No	Moderate	Moderate	Upper watershed location for SH rearing. Low summer flows in upper half of basin limit habitat suitability	Moderate for SH only
Robinson Creek	U/M	No	Moderate	Moderate	Channel went dry in 1995.	Low



ENTRIX

Figure 5-3
COHO SALMON and STEELHEAD TROUT RESTORATION PRIORITY AREAS

Navarro Watershed Restoration Plan

6.0
RECOMMENDED LAND MANAGEMENT PRACTICES

Almost all land-uses ultimately have some effect on water quality and aquatic habitat conditions. There are, however, many opportunities through careful planning and specific land management practices to conserve existing habitat and water quality, and to minimize adverse impacts or to mitigate the effects of prior land disturbances. Regardless of the historical and present-day land-uses or land management practices, emphasis should be placed on preventing, rather than simply repairing damage. This is particularly true in those sub-basins of the Navarro watershed which have been designated as high priority locations for coho salmon protection and enhancement (see Section 5.0).

The recommended land management practices (RLMP's) presented here provide a useful guide for the voluntary implementation of land management practices to protect water quality and improve fish habitat. The purpose of the RLMP's is to assist landowners in identifying and addressing potential and actual problems associated with historic and present uses of their land. In many cases, landowners in the Navarro watershed are well aware of the potential impacts their activities may have on stream resources, and work diligently to prevent or minimize these impacts. For example, there are many people in the Anderson Valley engaged in forestry, agriculture, and residential or commercial development who strive to reduce erosion and to protect riparian areas and streams. Many have been able to balance their economic needs and their land use objectives with their desire to protect and enhance stream resources. Nevertheless, restoration of the watershed depends on the cumulative efforts of all landowners. Everyone can, and should, improve their land management practices to improve water quality and to benefit the fishery.

Many of the RLMP's provided in this section may be used in preventative planning as well as for remediation of existing problems which are related to water quality and aquatic habitat conditions. The RLMP's primarily address the two broad goals of the project: enhance water quality, and improve aquatic habitat conditions for coho salmon and steelhead trout. Therefore, the RLMP's are directed toward actions which will improve the three critical conditions that limit or impair water quality and fish habitat in the Navarro watershed: lack of pools, excess fine sediments, and high summer stream temperatures. There are likely other types of problems which may be of concern that affect different species or other aspects of the Navarro watershed ecosystem, such as the general loss of soil productivity due to erosion, amphibian habitat conditions, and riparian habitat for bird and mammal species. However, these issues were not part of the primary goals or objectives of the project, and therefore are not addressed directly by the studies or the RLMP's presented here. Nevertheless, many of the RLMP's are likely to have additional benefits to other aquatic habitat as well as riparian species, and the general biodiversity and health of the watershed.

The RLMP's cover a range of complexity and costs, although most are intended to be relatively straightforward and cost-effective, so that they can be implemented by private landowners without significant capital expenditures or specialized knowledge. However, landowners should also recognize that the RLMP's are not meant to be used in a cookbook approach. The effectiveness of RLMP's must be based on, and tailored to, existing site-specific conditions. Local topography, vegetation, soil type, hydrology, and the needs of the landowner, are some of the site-specific conditions which must be considered to ensure that a land management practice performs as expected. Therefore, whenever possible, the site-specific design and implementation of an RLMP should include the technical assistance of qualified professionals. Agencies such as the Natural Resources Conservation Service, U.C. Cooperative Extension, California Department of Forestry, and the Department of Fish & Game can often provide the guidance needed to tailor the design and implement the recommended land management practices successfully.

6.1 LAND-USE IMPACTS ON WATER QUALITY AND SALMONID HABITAT

In the Navarro watershed, land-use practices including forestry, grazing, agriculture, and urban development have substantially altered watershed processes over time, resulting in the degradation of water quality and loss of fish habitat. The following discussion describes the types of impacts associated with each of the major land uses in the Navarro watershed, and the mechanisms by which they occur. While impacts to water quality and fish habitat tend to occur slowly, but cumulatively over time, not all lands within a particular land use contribute equally to degradation of water quality and habitat. The geology, soil type, steepness, and vegetative cover type on a given parcel of land will influence its inherent stability and erodibility. The unique combination of these landscape factors and the particular land-uses imposed upon them, govern the extent to which water quality and aquatic habitat impacts may occur. Indeed, some landowners may experience little or no impacts as a result of the land-uses which take place on their properties. Landowners should take note of the condition of their properties and consider the potential for impacts due to their land-use activities. Where impacts are recognized, land-owners should address the problem by taking appropriate steps to minimize ongoing, or preventing potential future impacts. Potential impacts associated with various land-uses in the Navarro watershed are summarized in Table 6-1, and discussed below. The table lists the *principle potential* impacts associated with each land-use.

Many of the human-induced impacts which adversely influence water quality and fish habitat also occur by natural processes. For example, streambank erosion is a natural process by which gravels which are needed to supply and maintain fish spawning habitat are introduced to the channel. Likewise, large woody debris in the form of trees and root wads, which are important for the creation of pools and to provide fish cover, are in part recruited to the stream by bank erosion. Other "perturbations" in the watershed such as large landslides, or droughts, are part of the natural ecology of the region. Coho and steelhead have evolved under these natural conditions, and their distribution and

Table 6-1. Potential Land-use Impacts on Water Quality and Salmonid Habitat.

	Loss of Large Woody Debris	Increased Bank Erosion	Increased Summer Stream Temperatures	Decreased Summer Streamflows	Loss of Pools and Simplified Aquatic Habitat	Increased Sediment Production
Forestry	X	X	X		X	X
Agriculture: grazing		X	X			X
Agriculture: orchards, row crops, vineyards		X	X	X		X
Residential and Commercial Development		X		X		X

population typically fluctuate in response to environmental conditions. However, when the frequency and magnitude of perturbations, such as sediment inputs from streambank erosion, are accelerated beyond natural conditions over extended periods of time, then fish habitat conditions may be permanently degraded and populations may be severely reduced, unless active intervention takes place.

6.1.1 FORESTRY

Forest practices result in removal and disturbance of natural vegetation, compaction of soils, construction of roads and skid trails, installation of culverts, and alteration of drainage patterns. Removal of vegetation, particularly the riparian canopy, reduces shading and increases the amount of solar radiation reaching streams, resulting in higher average summer stream temperatures and increased daily temperature fluctuations. Increases in maximum water temperature after logging depend upon the size and morphology of the stream, the type and density of canopy removed, and the amount of topographic shading provided by adjacent hillslopes. In many streams draining the North Fork Navarro basin, loss of riparian shading and resulting increased stream temperatures are somewhat moderated by deep, relatively narrow valleys and their proximity to the relatively cooler influences of coastal temperatures and fog. Where logging has occurred in riparian areas, delivery of large woody debris to streams is reduced, significantly altering channel morphology and fish habitat. Loss of large woody debris reduces the complexity of fish habitat, causes the loss of pools, and reduces the retention of gravels used by salmonids for spawning. Most streams, particularly those in the forested regions of the Navarro watershed, are severely lacking in large woody debris. Land disturbance, particularly due to road and landing construction, have increased sediment production to streams. Fill slope failures, diversion of runoff at stream crossings due to undersized, improperly designed, or poorly maintained culverts, landing failures, and shallow debris slides initiated by changes in drainage patterns from road construction and removal of vegetation, are significant contributors of sediment to streams in the Navarro watershed. Construction of commercial forest roads may also cause drainage onto inherently unstable slopes within the inner gorge, triggering deep-seated landslides. However, large landslides initiated by road construction and alteration of drainage are a much less significant source of sediment production to streams in the Navarro basin on a watershed-wide basis, compared with streambank and gully erosion processes.

Impacts of forest practices can be reduced by using longer rotation periods, selective harvesting instead of clear-cutting, retention of riparian buffer zones along streams, identification of no-cut zones in areas which are most susceptible to shallow landsliding and other mass-wasting failures (such as in the inner gorge), and the careful design, placement and maintenance of roads and landings. In many parts of the watershed, it is necessary to address continuing impacts initiated by historic logging, particularly related to logging roads and disturbance of riparian vegetation.

The following RLMP's address prevention and remediation of land-use impacts due to timber harvest practices:

6.4.2 Preserving Large Woody Debris

6.5.3 Riparian Corridor Protection and Restoration
6.6.1 Inventory Existing and Future Road-related Sediment Sources
6.6.2 Decommissioning Abandoned Roads
6.6.3 Decommissioning High Risk Roads
6.6.4 Road Upgrading Practices
6.6.5 Excavating Unstable Road and Landing Sidecast and Fill Material
6.6.7 Eliminating Diversion Potential at Stream Crossings
6.7.2 Timber Harvesting Practices

6.1.2 AGRICULTURE: GRAZING

Grazing can result in the removal of natural vegetation and modification of soil characteristics which affects hydrologic and erosional processes. Grazing impacts are most critical in the riparian zone, where livestock tend to congregate for water, shade, and forage. In upslope areas, over-grazing may denude vegetation, leaving soils exposed to splash and sheet erosion. However, observations in the Navarro watershed indicate that sheet and splash erosion are probably a relatively minor source of sediment production to streams. Trampling can compact soils, reduce infiltration, and increasing runoff. This has the potential to cause channel incision and gullying in response to increased peak flows. Grasslands in the melange and coastal-belt terrane are most susceptible to gullying. Over-grazing can devegetate riparian corridors, reducing shading and increasing summer stream temperatures. Elimination of riparian vegetation may cause streambank instability, resulting in increased sediment production, and wider and shallower channels. Livestock can also break down streambanks by trampling, introducing sediments to channels. Anderson Creek in the Anderson Valley and portions of upper Rancheria Creek have widened channels with unstable streambanks, which are likely due in part to grazing practices in these basins.

Grazing impacts can be reduced by controlling livestock access to riparian zones using fencing, providing watering for stock at sites outside of the riparian corridor, and by controlling the numbers and season of livestock use in riparian areas.

The following RLMP's address prevention and remediation of land-use impacts due to grazing:

6.4.1 Stream Protection and Stabilization Planning
6.5.1 Exclusionary Fencing
6.5.2 Invasive Plant Species
6.5.3 Riparian Corridor Protection and Restoration
6.5.4 Riparian Revegetation
6.5.5 Grazing/Range Management
6.6.1 Inventory Existing and Future Road-related Sediment Sources
6.6.11 Road Maintenance Practices
6.7.3 Gully Prevention and Control Practices

6.1.3 AGRICULTURE: ROW CROPS, ORCHARDS, VINEYARDS

Agriculture, including row crops, orchards, and vineyards can increase sediment production to streams. Sediment production is generally most significant where agricultural activities take place on hillslopes. Where riparian vegetation is removed for conversion to agricultural uses, shading is reduced and stream temperatures may increase. Similar to other land-use activities which remove riparian vegetation, even along ephemeral streams, can result in streambank instability, widened channels, and increased sedimentation. Agricultural activities which divert water during summer low-flow periods reduce the available pool habitat, increase stream temperatures, and may completely dry the channel. Streamflow monitoring performed by the Mendocino County Water Agency and the State Water Resources Control Board indicate that segments of Anderson Creek can go dry for brief periods due to pumping. Groundwater, particularly in the flat alluvial areas such as Anderson Valley, usually contributes to the baseflow of streams during the summer months. Groundwater extraction for irrigation can lower water tables and reduce baseflow contributions. Not only does this result in less water for aquatic habitat, but it may also cause stream temperatures to increase because groundwater inputs to streams are generally cooler in temperature than surface runoff.

Agricultural practices that establish a buffer zone in the riparian corridor allow for protection or regeneration of riparian vegetation, providing greater shade and cooler summer stream temperatures, and increased streambank stability. Riparian buffer zones between agricultural lands and streams also provide an enhanced capacity to filter sediments, particularly during flood flows. The use of cover crops during the wet winter season provides a vegetative cover, reducing sheet erosion, rilling, and the loss of fertile soils. Ditch lining with rip-rap or grass covers also reduces erosion and transport of sediment to fish bearing streams. Contour planting on hillslopes reduces the potential for gullying from surface runoff. Water conservation practices such as the capture and storage of runoff during peak winter flows, reduces reliance on direct diversions from streams during the critical summer low-flow period.

The following RLMP's address prevention and remediation of land-use impacts associated with agricultural practices for row-crops, vineyards, and orchards:

6.4.1 Stream Protection and Stabilization Planning
6.4.9 Water Conservation and Storage
6.5.2 Invasive Plant Species
6.5.3 Riparian Corridor Protection and Restoration
6.5.4 Riparian Revegetation
6.6.1 Inventory Existing and Future Road-related Sediment Sources
6.6.11 Road Maintenance Practices
6.7.3 Gully Prevention and Control Practices
6.7.4 Agricultural Erosion Control Practices for Uplands and Riparian Corridors

6.1.4 Residential and Commercial Development

Although most of the land area in the Navarro basin is used for timber harvest, grazing, and agricultural purposes, rural residential and commercial development alters hydrology and sediment production rates. Residential development has increased significantly over the last 20 years. Often residential development is accompanied by small-scale agricultural development and road building. As the percentage of land covered by impervious or compacted surfaces (such as homes, roads, and driveways), increases, the area available for infiltration is reduced and surface runoff is increased. Buildings, parking lots, drainage ditches, roads, and storm drains increase the rate and volume of runoff to streams. This tends to increase the magnitude and frequency of peak flows, and increases erosion rates along streambanks. As vegetation is replaced by impervious surfaces, and surface runoff is increased, summer baseflows decrease. The problem may be compounded by extraction of drinking water from wells and springs, which similar to pumping for agricultural irrigation, can reduce the groundwater table and thus the baseflow contribution to streams. Sediment delivery also typically increases during construction activities, particularly during the wet winter months. Residential and commercial development also increases the likelihood of water quality pollution due to runoff of substances such as oil, grease, and heavy metals.

The following RLMP's address prevention and remediation of land-use impacts associated with residential and commercial development:

6.4.1 Stream Protection and Stabilization Planning
6.4.9 Water Conservation and Storage
6.5.2 Invasive Plant Species
6.5.3 Riparian Corridor Protection and Restoration
6.6.1 Inventory Existing and Future Road-related Sediment Sources
6.6.11 Road Maintenance Practices
6.7.1 Grading and Erosion Control Practices for Construction Sites

6.2 Regulatory Framework

Many of the RLMP's addressing streambank stability, aquatic habitat enhancement measures, and hillslope and road-related erosion control generally include some combination of re-vegetation and earth-moving work, either on hillslopes, streambanks, or within the channel itself. A variety of federal, state, and local permits apply to these projects, depending upon the specific nature and extent of the work to be performed. Projects which include only a re-vegetation component, with no grading or construction work, do not require any permits or authorization from federal, state, or local agencies. Often, a simple description of the project, its purpose, location, and principal features is all that is required in order to obtain a permit. Typically, this information is developed by the landowner as part of the planning process. However, more detailed information, such as design specifications, site maps, and an evaluation of natural resources at the project site, can also be requested. It is recommended that landowners contact and consult with the relevant agencies to determine if a permit is in fact required, and to expedite permit approval. Provided below is an overview of the types of permits which may be needed. A more detailed discussion regarding permitting and project implementation is provided in Section 9.0, *Recommendations for Future of Watershed Coordination.*

6.2.1 Permits from Local Agencies

A Floodplain Development Permit from the Mendocino County Planning Department is needed for any project which occurs within the channel or floodplain. The county engineer will review projects in order to determine if there is an increase in the potential for flooding. Mitigations are required if the project affects flooding. A Grading Permit is also required from the Building Department, depending upon the amount of earthwork to be performed. A Use Permit must be obtained, and a Reclamation Plan filed with the county for extraction of gravel from streams or from the floodplain.

6.2.2 Permits from State Agencies

At the state level, a streambed alteration agreement with CDFG pursuant to CDFG Code sections 1601-1603, must be in place prior to activity in the streambed, channel or bank. The Department reviews the project plans, and may condition the project by recommending alternative procedures, techniques, etc. It is recommended that CDFG be contacted and consulted before proceeding with any project within a stream channel. CDF requires landowners engaged in timber harvest activities to prepare Timber Harvest Plans (THP), or Nonindustrial Timber Management Plans (NTMP). Commercial timber harvesters must file a Sustained Yield Plan (SYP) for larger land areas (greater than 50,000 acres). Landowners may wish to consider the RLMP's associated with riparian buffer strips (RLMP 6.5.3), roads (RLMP 6.6.1 to 6.6.5), and timber harvest practices (6.7.2) when preparing these plans.

6.2.3 Permits from Federal Agencies

There are several federal agencies with jurisdiction over aquatic resources. The statutory requirements are established through the Endangered Species Act (ESA), California Endangered Species Act (CESA), and the Federal Clean Water Act. The federal agencies responsible for the protection of native fish in the Navarro River are the National Marine Fisheries Service (NMFS) and the US Fish and Wildlife Service (USFWS). Coho salmon are currently listed as threatened in the Navarro watershed by the NMFS.

Technically, any activity which potentially results in the mortality or harming (known as a "taking") of species currently listed as threatened or endangered, may require an Incidental Take Permit. A taking occurs when individuals of a listed species are inadvertently harmed, harassed, or collected, or their habitat suffers significant modification. Projects which result in a taking of coho salmon are in violation of the ESA. NMFS should be consulted for activities and projects which may affect listed anadromous fishes.

Also at the federal level, the Army Corps of Engineers may have jurisdiction under Section 404 of the Clean Water Act and Section 10 of the Harbor and Rivers Act (Section 10 would probably apply only to projects in the Navarro Estuary as a navigable section of the river). The Corps would have jurisdiction for projects that may affect wetlands (for example, seeps or springs) or for activities which occur below "ordinary high water" (there is no specific criteria for identifying ordinary high water, however it generally includes any section of the channel below the top of streambank). A Nationwide Permit is usually issued for projects which are considered restoration activities. If a permit is required from the Corps of Engineers, the National Marine Fisheries Service may also be asked to review the project. Projects affecting less than one-third acre may be exempt from permit requirements. It is recommended that landowners who seek to implement a streambank stabilization project consult with the Corps of Engineers to determine if a permit will be necessary.

Under Section 303 D of the Clean Water Act the US EPA has listed the Navarro River and its tributaries as "impaired" due to excessive sediments and high stream temperatures. The North Coast Regional Water Quality Control Board (NCRWQCB) is responsible for setting target goals for the total maximum daily load (commonly referred to as TMDL) of sediment and temperature which will assure protection of fish and wildlife in the Navarro watershed, as well as several other watersheds which drain the northern California coast. As part of the TMDL process, the NCRWQCB will establish quantifiable and verifiable standards for water quality related to sediment and temperature.

These standards are likely to include goals for establishing land-management practices (commonly referred to as "best management practices", or BMP's) which will reduce sediment production to streams and lower summer stream temperatures. There are also likely to be quantitative standards related to in-stream conditions and processes, for example, a maximum allowable amount of fine sediment on the streambed. Studies identifying TMDL's for the neighboring Garcia River watershed will be similarly performed and established for the Navarro River watershed by the year 2000. Land owners are encouraged to document how they will manage their properties in a way which supports attainment of the TMDL standards. As part of the TMDL process, funding is available to assist landowners with implementing projects that are directed toward achieving the water quality goals. Many of the RLMP's presented in this section are likely to be identified by the NCRWQCB as the type of land management practices which will achieve TMDL goals.

6.3 Organization and Preparation of RLMP Chapter

The remainder of this section is devoted to a description of the recommended land management practices. The RLMP's provide a diversity of techniques and actions, over a wide range of costs and design complexity, which can be used by private landowners. The RLMP's are organized according to the type of resource: (a) streambank and aquatic habitat, (b) riparian corridor, (c) hillslopes, and (d) roads, which are included as a distinct section since they have an influence on all three resource areas. In addition to the RLMP's associated with these four resource areas, the use of conservation easements is discussed as a distinct land "management" approach to support the goals of conservation and restoration of fish habitat and water quality. As described above, the various land-uses in the Navarro watershed may affect any one, or all, of the resource types. Each resource area contains a reference and bibliography section, including agency contacts, for land-owners who wish to gather information on additional RLMP's or who seek more detailed descriptions of design and implementation methods.

The RLMP's presented here are based, in part, on a compilation of various existing sources of information, most of which have been published in scientific reports, technical papers, texts, or county, state, and federal agency publications. We also relied on information gathered from discussions with various local, state, and federal agency personnel familiar with the Navarro watershed. The information provided in each RLMP is unique, having been selected and tailored to address the types of land-use activities, and water quality and fish habitat issues, which are of particular concern in the Navarro watershed. Some portions of many of the RLMP's were also prepared based on the professional experience and knowledge of the Navarro study team members. All of the RLMP's are based on generally accepted practices within the scientific community.

The sources of information used to prepare the RLMP's (as well as suggestions for obtaining additional information) are listed with complete citations under the Bibliography/References section provided at the conclusion of each of the four resource topic areas. Some of the more heavily relied upon sources of information include:

Streambank Stability and Aquatic Habitat Protection - USDA Soil Conservation Service (now NRCS), Engineering Field Handbook; Donald Gray and Robin Sotir, Biotechnical and Soil Bioengineering Slope Stabilization; California Department of Fish and Game, California Salmonid Stream Habitat Restoration Manual.

Riparian Corridor Integrity - Scientific journals including Bioscience, Ecology, Restoration Ecology, Conservation Biology, Oecologica; conference proceedings including Proceedings of the California Riparian Systems Conference: Protection, Management and Restoration for the 1990's; technical publications including Circuit Rider Productions, Acorn to Oak, USFS Pacific Southwest Range Experiment Station, Collecting, Processing, and Germinating Seeds of Wildland Plants; and discussions with agency personnel including Mr. John Harper, Livestock and Natural Resources Advisor, UC Cooperative Extension.

Roads – Pacific Watershed Associates, Handbook for Forest and Ranch Roads; California Dept. of Forestry, A Basic Guide on How to Plan, Construct, and Maintain Small Private Forest Roads.

Hillslope Erosion Control Practices - Napa County Resource Conservation District, Napa River Watershed Owner's Manual; S. J. Goldman, Erosion and Sediment Control Handbook.

Conservation Easements - Anderson Valley Land Trust.

The Navarro study team members preparing RLMP sections are as follows:

Streambank Stability and Aquatic Habitat Protection - Mitchell Katzel, ENTRIX, Inc.

Water Conservation – Dan Sicular, Project Coordinator

Riparian Corridor Integrity - Karen Gaffney, Circuit Rider Productions, Inc.

Roads - Bill Weaver, Pacific Watershed Associates.

Hillslope Erosion Control Practices - Bill Weaver, Pacific Watershed Assoc., and Mitchell Katzel, ENTRIX Inc.

Conservation Easements - Connie Best, Anderson Valley Land Trust.

6.4 STREAMBANK STABILITY AND AQUATIC HABITAT PROTECTION

This section offers RLMP's for preventing and restoring unstable, eroding streambanks. Streambank erosion is the single largest source of sediment production in the Navarro watershed (see Section 3.0, Figure 3-2). Prevention and control of streambank erosion begins with appropriate planning and design considerations which are discussed in RLMP 6.5.1, *Stream Protection and Stabilization Planning.* An overview of the various types of approaches to streambank erosion control is also provided in this RLMP. Recognizing, preserving, and understanding the importance of large woody debris as a critical element in fish habitat protection is discussed in RLMP 6.5.2, *Preserving Large Woody Debris*. Several detailed examples of bio-engineering methods which can be used to control erosion are provided in the following RLMP's:

6.4.3 *Brush Mattress*
6.4.4 *Live Willow Fascine*
6.4.5 *Live Staking*
6.4.6 *Vegetative Geogrid*

RLMP 6.4.7, *Streambank Protection Using Hard Armoring Techniques*, describes measures which use inert construction materials, but do not rely on vegetation as a primary means for controlling erosion. RLMP 6.4.8, *Gravel Extraction*, discusses how gravel mining can affect aquatic habitat, and provides a general approach to the management of gravel extraction in the Navarro River watershed. RLMP 6.4.9, *Water Conservation and Storage*, describes methods to improve summer streamflow needed to support riparian habitat and aquatic life during low-flow periods.

6.4.1 STREAM PROTECTION AND STABILIZATION PLANNING

Description & Purpose

Stabilization of streambanks is an effective treatment to reduce sediment loading to streams, and to prevent the loss of land or structures. Advanced planning and design, particularly in consultation with knowledgeable professionals and resource agencies, will enhance the likelihood of project success. There are many different types of methods which can be used to protect and stabilize streambanks from erosion (Table 6-2). Different methods may be suited to different types of problems. Technical guidelines and a comparison of the suitability of selected structural and vegetative treatments to stabilize stream channels and streambanks are provided in this RLMP.

Planning Criteria & Applicability

Streambank erosion is the largest single source of sediment production to streams in the Navarro watershed. Methods for reducing streambank erosion will improve water quality, as well as pool and spawning habitat for coho salmon and steelhead trout.

Each stream is unique, so streambank protection and erosion control measures must be installed according to a plan which is adapted to the specific site. The following methods describe a general approach to planning a streambank erosion control and protection project.

1. Establish the project objectives. Objectives may include multi-purposes, incorporating elements of fish habitat restoration by providing shade, cover, or scouring pools, as part of the project. Select alternative methods of streambank erosion control which best meet the objectives of the project. Table 6-3 provides a comparative evaluation of the relative benefits from various streambank protection measures.

2. Identify the initiating causes of streambank instability. There may be various, or even multiple causes for streambank instability. A common cause of erosion and instability in the Navarro watershed is the removal of riparian vegetation. Has riparian vegetation been removed from the project site? Reviewing aerial photography (available at the Anderson Valley library, and at the County Assessors office and NRCS) over a 10, 20, or even longer time period, can often answer this question. Another cause of streambank instability and erosion is channel incision (downcutting into the channel bed). This type of problem is evident on Robinson Creek. Channel incision undermines the toe of bank slopes causing streambank collapse. Channel aggradation (gradual filling of the streambed with sediment), can also cause unstable banks, as in Anderson Creek. Aggradation tends to cause the stream channel to laterally migrate against channel banks which causes erosion.

Table 6-2. Classification and Examples of Streambank Protection and Erosion Control Measures

Category	Examples
Live Construction	
Conventional Planting	Grass seeding Sodding Transplants Willow sprigging
Mixed Construction (Bioengineering methods)	
Woody Plants used as reinforcements and barriers to soil movement	Live staking* Live fascines* Brushmattress* Branchpacking
Plant/Structure Associations	Revetments with slope face plantings Breast walls with slope face plantings Tiered structure with bench plantings
Woody Plants grown in the frontal openings or interstices of retaining structures	Live crib walls Vegetated rock gabions Vegetated geogrid*
Woody plants grown in the frontal openings or interstices of porous revetments and ground covers	Joint plantings Staked gabion mattresses Vegetated concrete block revetments Vegetated cellular grids
Inert Construction (structural engineering methods)	
Retaining structures	Gravity walls (gabions, crib walls) Articulated block walls Reinforced earth structures (geogrids, geotextiles) Cellular confinement systems
Revetment Systems	Riprap Gabion mattress Concrete facings (gunnite, concrete mattress) Cellular confinement systems (3-dimensional webs that cover the surface)

Table 6-2. Classification and Examples of Streambank Protection and Erosion Control Measures (continued).

Category	Examples
Inert Construction (structural engineering methods) - continued	
Flow deflectors	Anchored tree revetment Boulder or log wing deflectors* (may also include gabions, rip-rap, and others)
Ground Covers	Mulches Blankets, mats, netting (slope coverings to protect the surface and promote vegetation growth)

*Detailed RLMP descriptions are provided in Section 6.4. See Section 6.10, Bibliography/References for a list of various information sources that describe the streambank protection and erosion control measures listed in Table 6-2.

Table 6-3. Relative Benefits of Streambank Protection Measures

Method	Aquatic Habitat	Riparian Habitat	Water Quality[1]	Flood Conveyance Concerns[2]
Live staking	fair	good	negligible, except on small streams	negligible, except on small streams
Live fascines	good	good	fair to good on small streams	negligible, except on small streams
Brushmattress	good	very good to excellent	fair to good	negligible, except on small streams
Live cribwall	good to fair very good	fair		negligible, up to high flows; depends on stream size
Vegetated geogrid	good to very good	good to good very good	on small and medium streams	negligible, up to high flows; depends on stream size
Conventional vegetation	negligible	fair	negligible	negligible, except on small streams
Rip-rap	negligible to fair	negligible	negligible	can be significant impairment on small streams; depends on design

[1]Water quality factors considered include temperature and sediment.

[2]Flood conveyance concerns relate to reduction of channel capacity to hold floods, typically due to vegetative encroachment or loss of channel cross-sectional area.

In some cases, streambank erosion is a natural process which should not be controlled. Lateral channel migration occurs when a stream builds point bars on the inside, and cuts the outside of a meander. This is a natural channel building processes. Often, this is how streams are replenished with new gravels and how large woody debris (such as whole trees) are introduced to the channel where they provide important spawning habitat and cover elements for anadromous fish. Consideration should be given to the initiating causes of streambank instability, and to determine if bank erosion rates at specific sites have been accelerated beyond typical rates by land-management activities before remedial actions are implemented. Consultation with hydrologists, geomorphologists, or the Department of Fish & Game, can be an invaluable aid in assessing the causes and determining the suitability of sites for streambank erosion control .

3. Consider the potential for upstream or downstream impacts as a result of the project design. Any action which affects the stream channel, including relatively simple revegetation projects on streambanks, will cause some reaction and channel adjustment. For instance, a project may direct flow towards the opposite bank downstream initiating new erosion. Establishing vegetation can cause higher water surface elevations and over-bank flooding for a given streamflow. Increased flooding is not necessarily a problem per se, unless roads, buildings, or other structures are affected. The potential for such channel adjustments should be investigated as part of the project design.

4. Select a method that is suited to the site conditions. Site conditions to consider include slope gradient, bank height, soil depth and erodibility, and whether surface erosion or mass movement (for example, protection against large scale bank collapse or shallow landsliding) is the dominant type of erosion. Table 6-4 provides a comparative guide to the use of different soil bioengineering methods for erosion control based on these conditions. It is also important to remember that the erosion control method to be employed will be subject to very high flow conditions on occasion, and must be able to withstand the stream velocities which are generated. The US Army Corps of Engineers provides a guide to sizing rip-rap which will remain stable under a range of flow velocities (US Army Corps of Engineers 1991). However, there is no comparable guide for vegetation or soil bio-engineering methods.

5. When possible, streambank protection should start and end at stabilized or controlled areas (such as at a bedrock outcrop) within the stream.

6. Channel and/or bank clearing to remove debris, stumps, and fallen trees is often an initial step for implementation of streambank stabilization treatments. This is so that spaces are cleared for planting vegetation or to provide for the appropriate installation of engineering structures which are in firm contact with the streambank and are stable. Where possible, only loose debris should be cleared, and debris which is keyed into place should be left. Large woody debris which is

Table 6-4. Suitability of Different Soil Bioengineering Methods Based on Site Conditions.

Site Factor	Type of Condition	*Soil Bioengineering Method* Live Staking	Live Fascine	Brush-Mattress	Live Crib Wall	Vegetated Geogrid
Slope gradient	*Steep*		X	X	X	X
	Moderate		X	X	X	X
	Gentle	X	X		X	
Slope height	*High*	X	X	X	X	X
	Low	X	X	X	X	X
Soil depth	*Deep*	X	X	X	na	X
	Shallow	X	X		na	
Soil erodibility	*High*		X		na	X
	Moderate		X	X	na	X
	Low	X	X	X	na	X
Surficial erosion		X	X			
Mass movement	*Shallow*	X	X	X	X	
	Moderate			X		

na=not applicable

found within the channel or partially covered by the streambank may be providing fish habitat. Preservation of fisheries and associated habitat should be considered a priority.

7. Bank grading and shaping is sometimes needed to reduce the slope and provide suitable conditions for the installation of structures and plants. Before bank sloping is initiated, potential impacts to fisheries and habitat should be considered. Consultation with the Department of Fish & Game is recommended to reduce the risk to aquatic and riparian habitat. A 1603 Streambed Alteration Agreement is required from the Department for all projects which affect the streambed or banks.

8. Adequate erosion control measures during the construction process (such as the use of filter fabrics, straw bales, sediment detention basins, etc.) should be implemented.

9. The channel grade should be stabilized before permanent bank protection can be successfully installed. Bank protection measures will be undermined in streams which are actively incising, and may be ineffective in streams which are actively aggrading. In the Navarro watershed, some streams have been historically aggrading, including segments of Anderson Creek and upper Rancheria Creek. Source control of sediment production, particularly gully erosion control and reducing road-related erosion, is recommended as the best means of reducing channel aggradation and stabilizing the channel grade on these streams. Because gully and other forms of erosion are not specific to one landowner's property, a cooperative, basin-wide approach is important for upper watershed control of sediment production to reduce lower watershed aggradation of these streams.

10. Minimize the amount of cross-sectional area (channel width) which is filled with inert construction materials, particularly when using rip-rap to armor streambanks. This also applies to placing rip-rap at the toe of bank slopes (usually trenched into bank toe), when used in conjunction with bio-engineering methods. As cross-sectional area is filled by hard-armoring materials, stream velocities will increase for flows of a given discharge. This increases the likelihood that new erosion will be initiated on the opposite streambank or that channel incision may occur.

11. Minimize access routes required to implement streambank erosion control measures to create the least disturbance and protect existing vegetation. Revegetate areas which are disturbed or where it is lacking. Natural revegetation may be possible depending upon the specific conditions at the site.

12. When using revegetation or bioengineering techniques, appropriate vegetation can often, and should preferably be obtained from local stands of species such as willow, alder, and others. This stock is already well-suited to the climate, soil conditions, and available moisture of the area.

Methods & Materials

There are many methods and materials which may be utilized to stabilize and protect streambanks (see Table 6-2). In general there are three categories of bank slope protection and erosion control measures: (1) live construction (traditional use of grass and other live plants for erosion control); (2) mixed construction (bioengineering or biotechnical methods), and (3) inert construction (use of inert materials, usually structural or mechanical systems).

Live construction uses conventional plantings, primarily for control of surface erosion. Live construction methods include grass seeding, sodding, transplants, and willow sprigging. Although these methods may be effective for surface erosion control, they are sometimes difficult to establish on slopes because of adverse conditions such as steepness, lack of moisture, and high velocity runoff. Plantings of woody vegetation may not suffice where slopes are very steep and where mass stability (for example, shallow landslides) is a problem, or where site conditions make vegetative establishment very difficult. Under these conditions it is necessary to use a mixed construction (biotechnical approach), or use inert construction methods.

Biotechnical stabilization describes the integrated or combined use of living vegetation and inert structural or mechanical components. The inert components include the use of concrete, wood, stone, and geofabrics (woven or non-woven geotextiles and geogrids made from synthetic polymers or natural materials such as jute and coir). Biotechnical stabilization may be inadequate or inappropriate in some instances, particularly in sites that are unsuitable to support vegetative growth (poor moisture and/or soil conditions, lack of sunlight), or where bank slopes are subject to very high water velocities in well-confined and steep channels. Bioengineering methods range from relatively simple techniques such as live staking (RLMP 6.4.5) to more complex and costly methods such as vegetated geogrids (RLMP 6.4.6). Other selected bioengineering techniques which are discussed in this section include brushmattress (RLMP 6.4.3), and live fascines (RLMP 6.4.4).

Biotechnical measures tend to be labor and skill-intensive as opposed to capital intensive. Generally hand labor is required, and often some mechanized equipment is utilized for installation, such as a backhoe. In spite of the heavy reliance on hand labor, biotechnical measures are often more cost-effective than conventional vegetative treatments or structural engineering solutions alone (Gray 1996). Unlike inert systems, bioengineering techniques tend to become stronger over time as the vegetation roots and becomes well established. In addition, vegetation is often self-repairing, having the ability to regenerate after being subjected to stress that does not cause mortality of all plants. When structural engineering systems fail or require maintenance, costs are typically significantly higher than for bioengineering systems. Bioengineering techniques tend to be much better suited to meeting habitat restoration objectives than conventional inert methods. Typically, bioengineering can provide not only bank stability and protection, but also shade to help reduce stream temperatures, provide wildlife habitat, and achieve improvement of water quality by filtering suspended sediments. Bioengineered structures are aesthetically more suited to most sites than engineering structures alone, since with time they blend into the naturally vegetated landscape.

Bioengineering methods must take into account site and soil conditions. Selection guidelines for several bioengineering techniques are presented in Table 6-4. The guidelines should always be augmented by good judgment and experience. Table 6-5 provides a general guide to the relative costs for the different soil bioengineering methods.

Table 6-5. Relative Costs for Bioengineering Streambank Protection Measures.

Method	Construction costs per sq. ft. of bank protection	Maintenance costs per sq. ft. of bank protection
Live staking	very low ($1.50-3.50/stake)	low
Live fascine	low ($5-12/lineal ft.)	low
Brushmattress	low/moderate ($10-20/lineal ft.)	low
Live cribwall	moderate/high ($14-25/sq. ft.)	moderate
Vegetated geogrid	moderate/high ($12-30/lineal ft.)	low
Conventional vegetation	moderate/high	moderate

Inert construction methods (often known as hard armoring techniques), use materials such as boulders, logs, concrete, gabions, and other non-living materials to protect streambanks from erosion. Inert construction methods are best suited to situations where vegetative growth needed for bioengineering techniques are not possible due to site-specific conditions such as the lack of a perennial water source. Mulches, which are considered an inert construction method, may be used for the control of surface erosion, although they are frequently used in conjunction with live construction and bioengineering techniques to assist with vegetation establishment. The other types of inert construction methods are similar in that they either directly protect the streambank from the erosive force of high velocity water (revetment systems), support and prevent the undermining of the streambank slopes (retaining structures), or direct flow away from the streambank (flow deflectors). These categories (shown in Table 6-2) are closely related in how they function and are often interchangeable. For example, revetment systems such as gabions or rip-rap which are usually constructed flush against and into the streambank, also function as flow deflectors when they are designed to extend into the channel in a manner which re-directs the flowline away from the bank. Hard-armoring techniques are discussed in RLMP 6.4.7, and the methods and materials associated with the construction of a log wing deflector are specifically described.

Many of the streambank protection and erosion control measures listed in Table 6-2 are described in detail in the references provided in section 6.4.10, *Bibliography/References for Streambank Stability and Aquatic Habitat Protection/Enhancement*

Maintenance

Methods using vegetation are often self-repairing, having the ability to regenerate after being subjected to stress that does not cause mortality of all plants. On drier sites, irrigation may be required to establish root systems initially. Replanting and infill planting are often used to repair damaged areas. Generally, projects using bioengineering methods should be regularly inspected for at least the first two to three years after installation to ensure that vegetation has become well established. Thereafter, little or no maintenance may be required. Methods using structural engineering systems also require regular inspection after high flow events, and should be repaired as soon as possible if they have been subject to undermining or other erosive forces causing damage. Engineered structures can have ongoing high maintenance costs if failures are due to improper design or incorrect installation.

Effectiveness

Stabilization of streambanks is an effective treatment to reduce sediment loading to streams, and to prevent the loss of land or structures. When developing bank stabilization projects, particularly using engineered structures, consideration must be given to the potential for aggravating bank stability problems up and down-stream of the project site. In some settings, particularly lower-gradient channels in wide alluvial valleys, or channels with very high sediment loads, streams naturally meander, inducing bank erosion in the process. Attempts to protect against lateral channel migration and bank erosion in such instances could be ineffective.

6.4.2 PRESERVING LARGE WOODY DEBRIS

Description & Purpose

Large Woody Debris (LWD) is a critical habitat element for coho salmon and steelhead trout in forested stream channels of the Navarro watershed (Bisson *et al.* 1987, Sedell 1984). Recruitment of trees, root wads, and other woody materials to streams is a natural process which must be protected to ensure that habitat conditions will provide for the survival, growth, and distribution of salmonids. Removal of debris jams, salvage logging from streambeds, and removal of riparian forests, should be avoided because of their potential impacts on fish habitat and water quality. The following RLMP provides a description of how to identify large woody debris, where it is important, how it effects stream processes, how it functions to provide fish habitat, and how it should be managed.

Planning Criteria & Applicability

Although various researchers have applied different criteria, generally, LWD is defined as any piece of wood at least 12" in diameter and 6 feet in length (Flosi and Reynolds 1994). LWD can be whole trees with tops and root wads, large branches, snags, or detached tree boles. LWD is not slash, which is the residue of timber harvest activities composed of small trees and branches. Slash tends to be unstable and contributes little to in-stream fish habitat. The larger the piece (in both diameter and length), the more likely it is to influence stream channel morphology. In the Navarro watershed, redwood, Douglas fir, big-leaf maple, and alder are the main contributors of LWD.

Large woody debris (LWD) in streams once was considered undesirable because it was thought that it could block migration of fish, cause adverse channel erosion, and in some instances increase the likelihood of flooding such as when debris is trapped at bridges. In some site-specific instances this is true, but on a stream basin and watershed-wide scale, LWD is necessary for a healthy aquatic environment. LWD in the streams of redwood forests can profoundly affect channel form and fluvial processes, particularly in small (first and second order) to intermediate sized (third to fifth order) streams. Redwood trees in particular are resistant to rapid decay and may remain in the stream channel for hundreds of years. Larger streams, such as the Navarro River, are capable of transporting even the largest woody debris material to the sea, although they may be stored for periods of time in bars or on streambanks. Thus, the influence of LWD on stream processes and channel form is more significant in the small-to-intermediate sized and steeper streams, than in larger, low gradient streams. However, LWD will still influence development of pools and may help stabilize channel banks in larger streams.

LWD produces diverse hydraulic conditions that create a variety of stream habitats necessary for the survival of fish. Pool formation, provision of complex cover, and moderating the effects of sediment input on fish habitat, are all critical functions of LWD (Abbe and Montgomery 1996). Removal of LWD typically results in loss of pool habitat and complexity, lower fish numbers, smaller average size, and a reduced total biomass (Tschaplinski and Hartman 1986).

In the Navarro watershed, many of the stream channels, particularly those streams in the forested Coastal belt geologic terrane (for example, the North Fork Navarro basin, mainstem Navarro and tributaries, and lower Rancheria Creek and tributaries) lack LWD (see Table 3-5 and Section 3.0). This lack of LWD is attributable to land-use activities which remove or impair regeneration of riparian forests, including timber-harvest, grazing, viticulture, orchards, and urbanizing land-uses. Other land-use activities such as salvage logging operations, debris-jam removal, or general stream clearing for flood-protection, may remove valuable LWD. Past activities by CDFG to clear debris jams, believed to block fish migration, resulted in the loss of LWD. Our field surveys indicate that pool frequencies have been reduced by about one-quarter to one-half due to the loss of LWD in Navarro watershed streams.

LWD in stream channels of the Navarro watershed provide the following important functions:

1. Routing and storage of sediment. LWD often acts as a buffer, particularly in small streams where mass wasting (such as landslides) and other erosion processes introduce large volumes of sediment to channels. Large organic debris provides temporary storage sites for sediment in smaller channels, moderating the potential impact of sediment transport to larger, downstream channels. Without the temporary storage sites, sediment is transported quickly to larger channels where it may have an adverse impact on channel morphology and fish habitat, including shallowing of pools and sedimentation of spawning beds (Lisle 1986, Montgomery 1995, Pitlick 1981).

2. Root mats and downed trees may armor streambanks, reducing erosion and sediment delivery to channels. In smaller streams, a single downed tree may defend a length of bank for a distance of several channel widths. The rootmats and LWD can improve channel stability by restricting the lateral migration of stream channels. However, not all LWD necessarily increases channel stability. Debris that blocks or diverts the stream may cause local bank and bed erosion.

3. LWD reduces the potential energy available for erosion and increases the variability in channel depth. Where LWD is present in sufficient quantities, debris jams may be formed. Sediment is ponded above debris dams, and a pool is scoured immediately below. The result of this "organic stepping" is to produce a stream profile characterized by long sections of stored sediment with low gradients, alternating with short steep cascades or falls that terminate in a scour pool. The stepped profile is significant in that the loss of potential energy takes place at the cascades or falls, thus reducing the energy available to erode the stream bed and stream banks. Furthermore, the steps and pools provide a diversity of flow conditions and aquatic habitats (Abbe and Montgomery 1996).

4. The distribution and development of pools and riffles is in part controlled by the scour which occurs around LWD obstructions during high flow. Up to 50% of the pools in coastal redwood forests may be developed because of the presence and position of LWD (Keller and Tally 1979). Pools are particularly important for fish habitat, because they provide cover, rearing space, low-flow and high-flow refuge (Baltz and Moyle 1984). Deep pools with cooler waters at depth also provide thermal refuge during warm summer months (Nielsen *et al.* 1992).

5. LWD can provide complex cover for fish, particularly when it is associated with deep pools. Some pools may have undercut banks that extend below root mats. Fish find shelter from high streamflows by moving into the low-velocity areas found behind LWD accumulations and rootwads (Baltz and Moyle 1984).

Methods & Materials

1. Stream "clean-up" operations should carefully assess the role and function of large woody materials in the channel before removing or altering the position of LWD. Removal or repositioning of LWD should be restricted to those sites where LWD is likely to clog bridges or culverts and thereby increase flooding. In some instances LWD may direct flow against a streambank, causing erosion. Unless a road, structure, or agricultural land is in direct danger of loss from the erosion, LWD should not be disturbed.

2. LWD should not be removed from the stream channel for salvage logging operations. Removal represents an immediate loss of fish habitat. LWD which is resting on bars above low-water or on banks is a potential source of material that may be recruited to the stream during the next flood and should be left in a position where it can influence channel hydraulics to enhance fish habitat.

3. Riparian forests should be protected and conserved. The best opportunity for providing LWD in stream channels is to allow the development of mature riparian forests that will be a source of LWD recruitment. Buffer strips can be established in the riparian zone from which late-successional trees will be recruited. Most LWD enters streams from a relatively narrow band on either bank. Over 70% of the LWD in streams flowing through mature and old-growth riparian zones in western Washington and Oregon originated within 60 ft. of the streambank (McDade *et al.* 1990). The effective width of buffer strips or streamside management zones should be based on objective criteria including the probability of LWD recruitment (see RLMP 6.5.3 for discussion of buffer widths).

4. LWD can be introduced to stream channels directly to provide for fish habitat enhancement. This is difficult to accomplish on a watershed wide or even reach-level scale so that it is effective and meaningful as a restoration action for the recovery of anadromous fish. However, at local sites, fish habitat can be improved. Generally, simply placing LWD in the stream channel will not necessarily provide the type of hydraulics needed to scour pools or provide cover. LWD should be keyed into the streambank so that it is stable. It must also be placed at an appropriate elevation above the streambed and at an angle to flow lines in order to be effective for pool scour and to provide cover. Consultation with a fisheries biologist or the Department of Fish & Game is recommended before LWD is introduced to the channel. The Department actively works with individual landowners to assess the condition of streams and to design and implement projects which enhance fish habitat (see contacts in the Reference Section 6.4.10).

5. Where it is feasible, streambanks and floodplains can be revegetated with coniferous trees. Trees planted near the outside bend of channels that are actively eroding are most likely to become a source of LWD which is eventually recruited by the stream.

Maintenance

No maintenance is required for protection of established buffer zones and conservation of seral-stage old-growth forests. LWD which is actively introduced to the stream channel generally does not require maintenance, unless bank erosion has de-stabilized the anchoring site. In this case the LWD may need to be re-excavated and placed in a more stable position. Occasionally, cable can be discretely used to assist in anchoring and stabilizing LWD.

Effectiveness

Natural regeneration and protection of existing riparian forests is the best and most effective means for recruiting LWD to stream channels. However, this is a long process taking 100-500 years, or more, before mature trees can develop and recruitment to the stream channel occurs. On a basin-wide scale, even longer time periods may be necessary before LWD loading has reached a level which will functionally effect stream-riparian processes so as to provide fish habitat within all of the forested regions of the Navarro watershed.

Sketch Drawings

Drawings from the California Stream Habitat Restoration Manual (see references section), illustrate some of the types of pools which are formed by LWD (Figure 6-1).

6.4.3 Brush Mattress

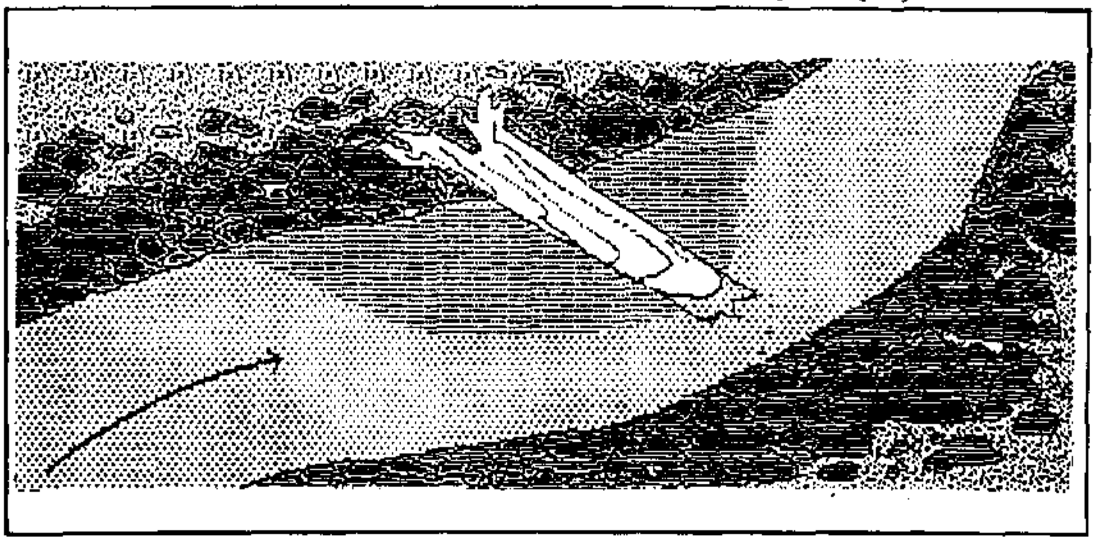
Description & Purpose

A brushmattress is a combination of a thick layer (mattress) of interlaced live willow switches or branches, live stakes, and wattling (live fascine). The live branches, stakes, and wattling (see RLMP 6.4.4, Live Fascine) root and grow to form an immediate protective surface cover and to stabilize the bank soil. Brush mattresses are used as a streambank protection and erosion control measure, and are often used in conjunction with other erosion control measures such as rock rip-rap or bank reconstruction. The brushmattress can be a fairly complex system to design and install. Assistance from geomorphologists, hydrologists, and plant ecologists may provide the guidance necessary for a successful project.

Planning Criteria & Applicability

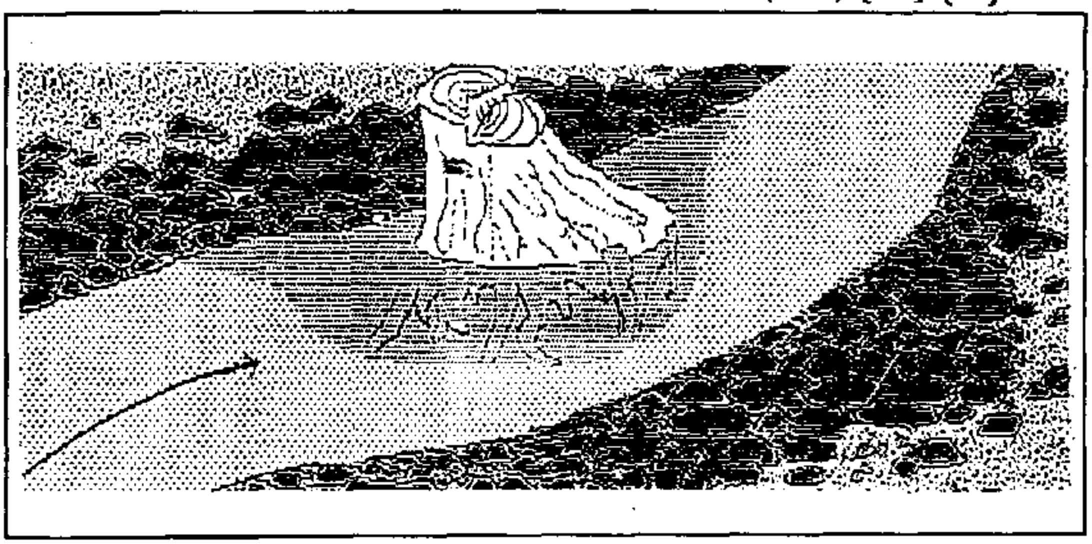
Brushmattresses are usually installed above the toe of the bank slope, between normal high water, and normal low-water surface elevations (defined as the "splash zone" by the US Army Corps of Engineers). The toe of the bank may be riprapped and the mats placed above. Seasonal water will promote rooting and sprouting of the mats, however, if the mats are submerged, they will not usually sprout. The brushmattress installation may be used effectively for surface protection against floods on a range of stream types, from

LATERAL SCOUR POOL - LOG ENHANCED (LSL) [5.2] {10}



Formed by flow impinging against a partial channel obstruction consisting of large woody debris. The associated scour is generally confined to < 60% of the wetted channel width.

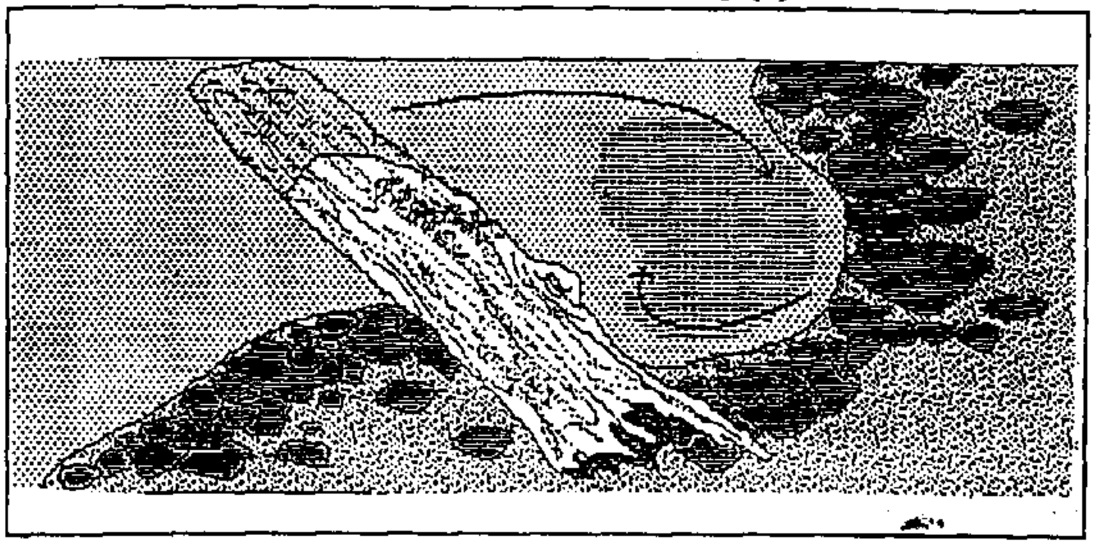
LATERAL SCOUR POOL ROOT WAD ENHANCED (LSR) [5.3] {11}



Formed by flow impinging against a partial channel obstruction consisting of a root wad. The associated scour is generally confined to < 60% of the wetted channel width.

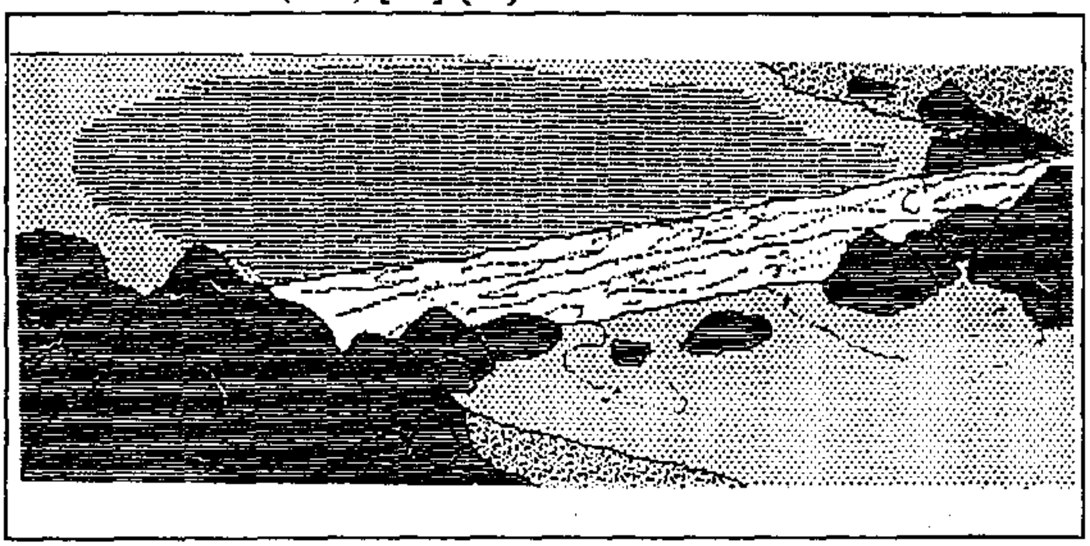
Figure 6-1. LWD Pool Types.

BACKWATERPOOL - LOG FORMED (BPL) [6.4] {7}



Found along channel margins and caused by eddies around a large woody debris obstruction. These pools are usually shallow and are dominated by fine-grained substrate. Current velocities are quite low.

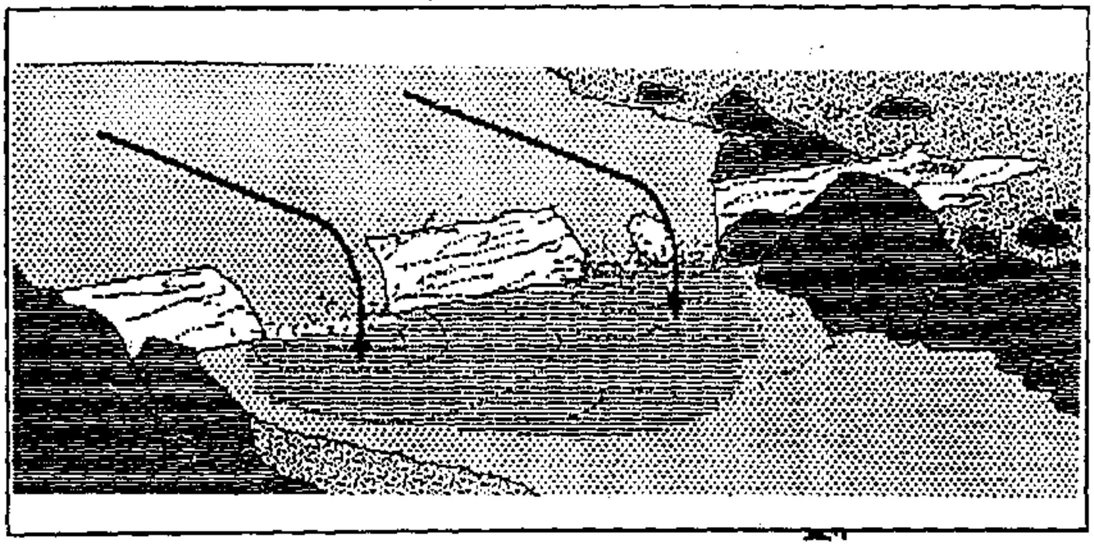
DAMMED POOLS (DPL) [6.5] {13}



Water impounded from a complete or nearly complete channel blockage (debris jams, rock landslides or beaver dams). Substrate tends to be dominated by smaller gravel and sand.

Figure 6-1. LWD Pool Types (continued).

PLUNGE POOL (PLP) [5.6] {9}



Found where the stream passes over a complete or nearly complete channel obstruction and drops steeply into the streambed below, scouring out a depression; often large and deep. Substrate size is highly variable.

Figure 6-1. LWD Pool Types (concluded).

wide and incised, low-gradient streams, to high velocity, steep-gradient streams. The brushmattress system is generally restricted to slopes flatter than 1.5:1 (H:V, 67% grade). Examples of stream locations where brushmattresses are likely to be effective in the Navarro watershed include the mainstem of Anderson Creek and tributaries to Anderson Creek where there is adequate sunlight, the mainstem of the Navarro River, and tributaries to the mainstem Navarro in locations where there is an opportunity for overbank flow onto the floodplain.

Methods & Materials

1. Plant collection and installation should take place during the dormant period, either in the late fall after bud set, or in the early spring before bud break. Branches are collected locally, cut from live willow plants, and kept moist until planting. Other woody plant species which can sprout roots and branches from the stem, include cottonwood. The species of alder and maple found in the Navarro watershed will not root from dormant cuttings and should therefore not be used. Dogwood may be a suitable species for dormant rooting.

2. On vertical or oversteepened streambanks, grading and shaping may be required to reduce the slope gradient to a stable angle and provide a smooth surface for installation of the brushmattress system. This can be done by hand-labor or with the assistance of a backhoe.

3. A trench is cut at the toe of the slope below the stream grade for the installation of rip-rap to provide protection against bank undercutting and washout of the slope. The trench should be cut at least as deep as the diameter of the largest rip-rap material which is used.

4. Willow branches are usually about 2 to 3 years old, and 5 ft. to 11 ft. long. Basal (rooting) ends are at least 1-inch diameter, but no more than 3.0 inches thick. They are placed perpendicular to the channel margin with the basal ends inserted into the trench cut at the bottom of the slope, generally above any toe protection such as rip-rap. Branches will sprout along the entire length of willow after planting.

5. A compacted layer of branches 4-inches to 18-inches thick is held in place with live construction stakes, and may also use woven live willow branches, wire, twine, or netting. Thickness of the mat to be created depends upon the stream discharge. The brush is trimmed, if necessary, to lie flat on the bank forming a tight mat.

6. The brushmattress is covered immediately with soil about 1 to 2-inches thick, and tamped. A light straw mulch and protective netting such as jute may be used to hold the soil and mulch in place.

   The brush mattress is labor intensive, requiring approximately 1 to 5 man-hours per square meter (includes harvesting of brush, cutting branches to appropriate lengths, and constructing the mattress). However, brush mattresses are likely more cost-effective over the long-term than traditional engineering applications.

Maintenance

Regular inspection and maintenance of brush matting should be conducted during at least the first two years following installation and after major runoff events. Areas where scouring or bank undercutting have occurred must be repaired immediately. Brushmattresses are susceptible to gullying due to their orientation perpendicular to the streambank contour. The bank should be smoothly graded before installation, and no concentrated drainage over the top-of-bank towards the stream channel should occur.

Effectiveness

Brush mattresses can be an extremely effective streambank erosion control measure if properly installed. The mats will sprout and send an extensive root system into the streambank, binding soil, filtering sediment from the streamflow, and protecting the soil surface. Willows tend to establish in areas where there is adequate sunlight, but do not do well in shady locations.

Sketch Drawing

Note that the brushmattress sketch drawing (Figure 6-2) includes a live willow fascine which is not discussed in this RLMP, but is discussed under the following RLMP.

6.4.4 Live Willow Fascine

Description & Purpose

Live willow fascine (also known as willow wattling) is a revegetation technique consisting of placing bundles of willow cuttings in shallow trenches, on the contour of bank slopes. The live fascine bundles are typically installed with live stakes and dead stout stakes, and are often used in conjunction with jute mesh, coir, or other erosion control fabrics. The live willow fascine is used to stabilize streambanks, stabilize soil surfaces on moist cut and fill slopes, reduce the velocity of surface runoff, trap sediments, and to establish vegetation.

Planning Criteria & Applicability

The live willow fascine may be used as an integral component of the brushmattress (see preceding RLMP 6.4.3, Brushmattress). It may also be used independent of the brush mattress along the streambank contour. The live willow fascine is used to break up the slope length into a series of shorter slopes separated by benches. Willow fascines are also applicable to surface disturbances involving cut and fill slopes, and in control of erosion at shallow gully sites. The live willow fascine is not applicable to excessively steep slopes, and is generally restricted to slopes flatter than 1.5H:1V (67% grade). As a type

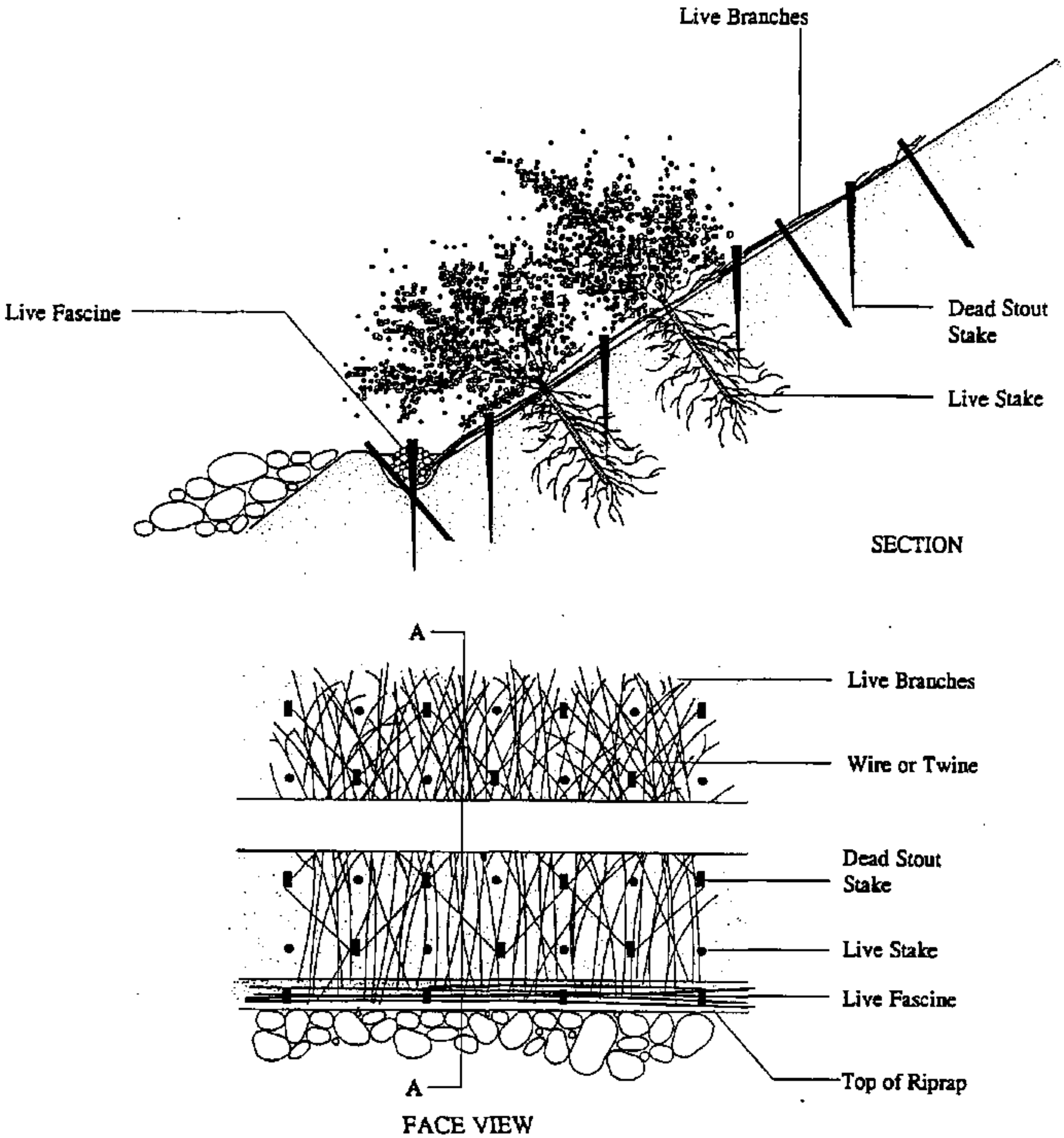


Figure 6-2. Brushmattress.

of revegetation, live fascines may be used on moist sites or seeped areas. In the Navarro watershed, a live willow fascine could be used at sites similar to those used for a brushmattress.

Methods & Materials

Willow bundles are buried across the slope, approximately parallel to the stream course, and supported on the downhill side by stakes. They also have stakes driven through the bundle, and can be either living or constructed from wood. The sprouting attributes of the brush species used, such as willow, combined with the supportive attributes of the structure itself, provide an integrated system of stems, roots, wire, and stakes that hold soil in place. Rows of live fascines act as small sediment traps and increase the amount of infiltration on site.

1. The willow fascine is prepared from living branches of willow, preferably collected near the project area. Willow material is cut with lopping shears, chain saws, or power brush cutting saws.

2. Willow bundles can vary in length, depending upon the material available. Bundles up to 5 feet long are relatively easy to work with. Bundles taper at both ends by alternately placing each stem so that about one-half of the basal ends are at each end of the bundle. The butts of individual stems in the bundle should not vary more than one-half inch in diameter.

3. The bundle is compressed firmly and tied, so that each bundle is approximately eight inches in diameter.

4. Bundles should be tied on about 15-inch centers with two wraps of binder twine or heavier tying material with a non-slipping knot.

5. Bundles can be prepared up to seven days in advance of placement, but must be kept covered and wet.

6. Trenches are excavated into the streambank along the (horizontal) slope contour, with about four feet vertical spacing between rows for 1.5:1 slopes (larger spacing may be specified for less steep slopes). Trenches are excavated to a depth of approximately one-half the diameter of the bundles.

7. Bundles are laid in trenches with ends of bundles overlapping at least 12 inches. Willow bundles are anchored firmly in place with vertical stakes on the down-hill side of the bundles. Vertical stakes are spaced not more than 18 inches on center. Also, stakes should be installed through the bundles on about 20 inch centers. Where bundles overlap, an additional pair of stakes should be used at the mid-point of the overlap. Stakes may be made of live wattling material greater than 1 1/2 inches in diameter, or they may be construction stakes (1”x2”x36”). Live willow stakes will root and sprout.

8. The live willow fascine is covered with soil and packed firmly behind and on the uphill side of the wattling by tamping or by walking. About 75% of the willow should be covered, leaving some branches exposed to facilitate sprouting of stems rather than roots. Long straw or similar mulching material should be used between rows on 2.5:1 or flatter slopes, while slopes steeper than 2.5:1 should have a jute mesh or similar material placed in addition to the mulch.

   About 6 linear feet of live willow fascine per person-hour can be prepared and installed on streambanks.

Maintenance

Regular inspection and maintenance should be conducted during the first two years after installation, and after major storm events. Stakes or bundles which have worked out of the ground should be immediately repaired. The live fascine is susceptible to gullying, which will prevent rooting. The fascine should therefore be well secured in the ground.

Effectiveness

Live fascines are very effective, particularly when rooting is well established, to protect the streambank from erosion. The wattle bundles sprout and root, binding and stabilizing soil. Wattling is a labor intensive technique, similar to brushmattresses, however they are usually cost-effective over the long-term.

Sketch Drawing

Figure 6-3, illustrates a live willow fascine.

6.4.5 LIVE STAKING

Description & Purpose

Live staking (also known as dormant post method) is a revegetation technique which consists of placing dormant but living stems of woody species that sprout, such as willow or cottonwood, along streambanks. A system of live stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture through evapotranspiration. Dormant posts can be an effective and relatively inexpensive means to stabilize streambanks, armor active headcuts, and protect eroding gully banks.

Planning Criteria & Applicability

The live staking technique is suitable for small and relatively uncomplicated erosion problems when construction time is limited and an inexpensive method is necessary. Live stakes can be used to repair small earth slips and slumps that are usually very wet. When placed in rows across a slope, they can used to help control shallow mass movement. Live staking is also an effective method for securing natural geotextiles such

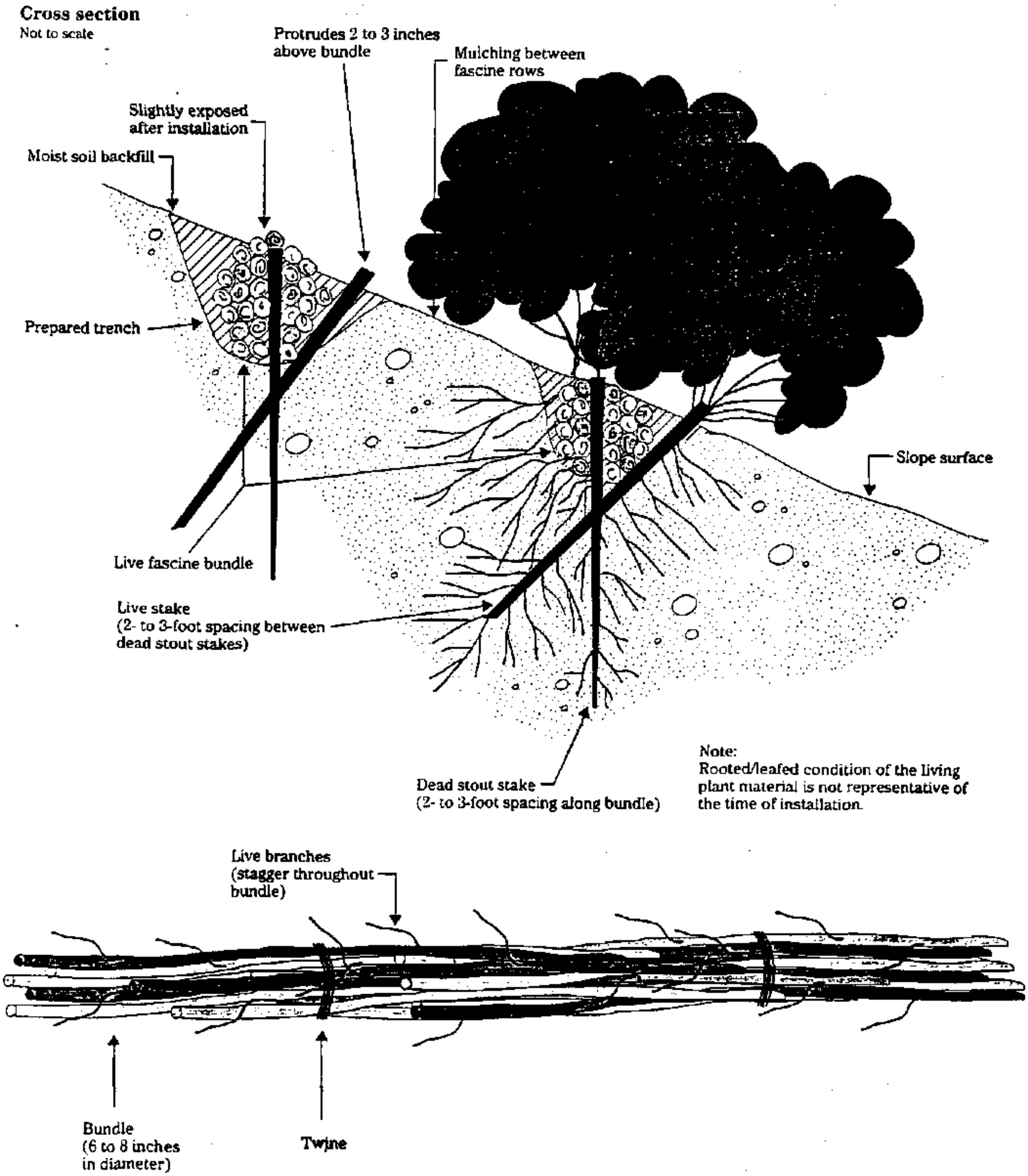


Figure 6-3. Live Willow Fascine.

as jute mesh, coir, or other blanket surface treatments. When first installed, the live staking system does not offer immediate surface or soil mantle stabilization to an area.

There are several constraints which should be addressed before selecting dormant post techniques:

1. Partial to full sunlight must be available for growth.

2. Soil should be at least 4 feet deep. Bedrock near the surface will prevent rooting and growth.

3. Does soil piping (usually occurs through lenses of fine sand) contribute to bank erosion? If so, other methods such as the brushmattress technique in combination with a geotextile fabric may be more suitable to control site erosion.

4. Willow posts require considerable water while the roots are establishing. Therefore, the posts should be long enough and placed deep enough to reach into the mid-summer groundwater table. If soil moisture cannot be reached, then deep and regular irrigation will be a requirement following installation, until roots develop and penetrate the groundwater table. Willows must have a year round moisture source to survive.

Methods & Materials

1. Willow are typically used, and are cut when the leaves have fallen and the tree is dormant. Cuttings are usually 1/2 to 1 1/2 inches in diameter and 2 to 3-ft. long, although longer posts may be used. Plant materials should be installed the same day that they are prepared.

2. Side branches are cleanly removed and the bark left intact. The basal ends are cut at an angle for insertion into the soil, the top is cut square.

3. The live stakes are tamped into the ground to about four-fifths of the length of the live stake, at right angles to the slope. An iron bar can be used to make a pilot hole, and the stake driven into the ground with a hammer. For extensive plantings, or plantings that require considerable depth, a tractor that is fitted with an auger may be used to create the pilot hole. The soil is firmly packed around the stake after installation.

4. Live stakes are installed 2 to 3-ft apart using a triangular spacing pattern.

Maintenance

Regular inspection and maintenance should be conducted during the first two years after installation, and after major storm events. Stakes which have been undermined or worked out of the ground should be immediately repaired. Under normal conditions, maintenance requirements should be minor after the living system has established. In general, maintenance consists of light pruning and removal of undesirable vegetation.

Effectiveness

When first installed, the live staking system offers no immediate surface or soil mantle stabilization to an area. Live stakes may be used in conjunction with live fascines or other bio-engineering methods to increase their effectiveness.

Sketch Drawing

A cross-section view of live staking is shown (Figure 6-4). The sketch is from the USDA, Soil Conservation Service, Engineering Field Handbook.

6.4.6 VEGETATIVE GEOGRID

Description & Purpose

Vegetative geogrid is a bio-engineering system which can be used above the toe of streambanks to reduce erosion, stabilize streambanks, and establish vegetation. The system is sometimes referred to as "fabric encapsulated soil". It generally consists of successive walls of several lifts of fabric reinforcement (usually a coconut fiber blanket held together by synthetic mesh netting, with vegetative plantings such as willows, between the lift layers. Other, stronger and more durable geo-synthetic materials may be used.

Planning Criteria & Applicability

The vegetated geogrid is a fairly complex method that requires some geotechnical and hydrologic understanding of site conditions and methods of installation. The method involves the cutting and placement of live rooted plants or branch cuttings in regular arrays on the face of a reconstructed bank slope. The plants and geogrid are used to solve more complex, deeper instability problems than vegetative techniques can offer alone. Vegetated geogrid structures can be used to stabilize very steep slopes in addition to providing surface erosion protection. The vegetated geogrid may be constructed on very steep bank slopes and therefore provides an alternative to vertical retaining structures.

Methods & Materials

A vegetated geogrid installation begins at the base of the slope and proceeds upward. The system should be supported on a rock toe or base and be inclined at an angle of at least 10 to 20 degrees to minimize lateral earth forces. The live plant materials consist of long branches cut from willow that are 1/2 to 2 inches in diameter. The length of the branches will vary with the type of application and desired depth of reinforcement. The inert construction material consists of either fabric reinforced geogrid or a synthetic,

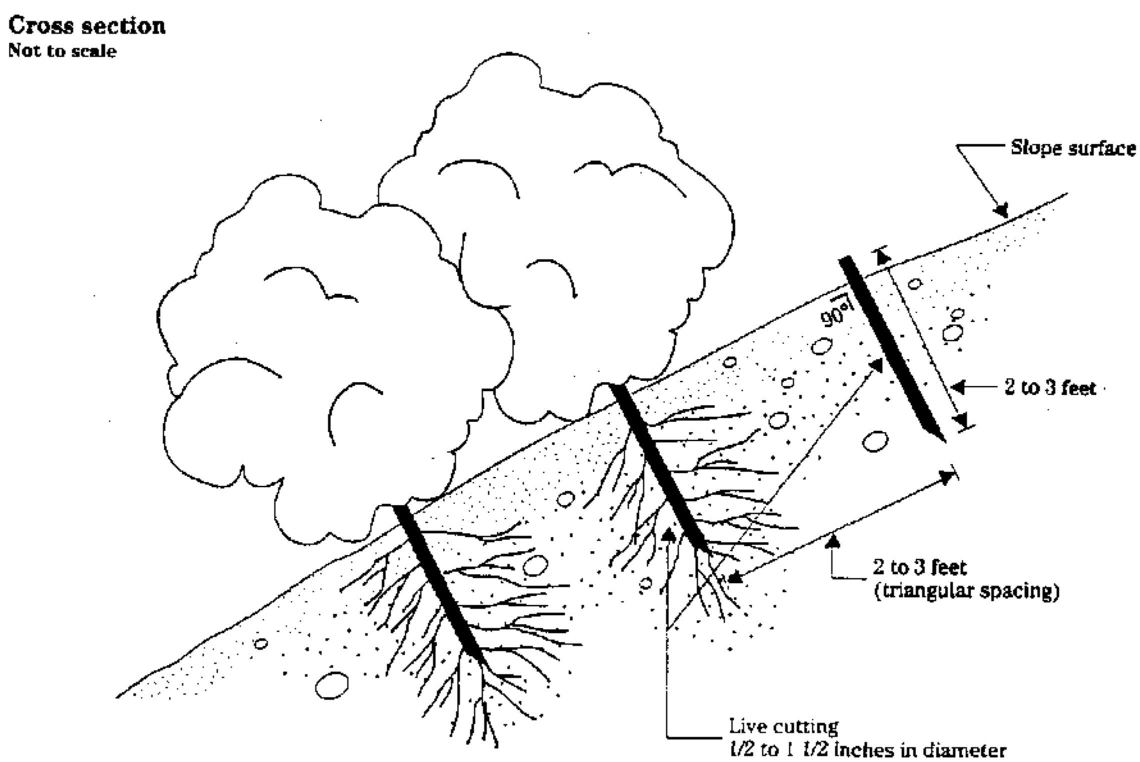


Figure 6-4. Live Staking.

polymeric geogrid. The geogrids can be selected according to their allowable unit tensile strength.

1. A trench is excavated, usually with a backhoe, below the depth of channel scour, and backfilled with rock to provide a base.

2. An earthen structure reinforced with synthetic geogrids and live brush is constructed on top of the rock base. A geogrid strip is gathered near the front edge of the fill and staked down over the underlying lift with a minimum overlap of 3 feet. Wood construction stakes spaced every 3 feet along the length of the overlap are used.

3. Fill material is placed on the geogrid and compacted in 3-inch lifts to a nominal thickness ranging from 12 to 30 inches. Thinner lifts are used at the base of the structure where shear stresses are higher. A backhoe or tracked excavator is to excavate the lifts and move the fill material.

4. The exposed sections of geogrids are pulled up and over the faces of the fill layers and staked in place. The geogrids should be pulled as uniformly as possible, using equipment such as a tractor or winch, and supplemented with hand labor.

5. One to two inches of fill material is placed on top of each wrapped geogrid layer. Three layers of live cut branches are then placed with two to four feet of fill material between each layer. This process is repeated with succeeding layers of fill, live brush, and geogrids until the specified height is reached. The recommended fill lift thickness between geogrid layers depends on soil and site variables, properties of the reinforcements, and desired safety factor.

   There are many commercial suppliers of synthetic geogrid materials as well as other erosion control materials such as nettings, fabrics, etc. A good source of information on where to purchase these erosion control materials, and how they compare in terms of cost, performance, and applications, is the professional journal, Erosion Control, which is sponsored by the International Erosion Control Association (see section 6.4.10, References/Bibliography).

Maintenance

Regular inspection and maintenance should be conducted during the first two years after installation, and after major storm events. The structure must be placed on competent materials.

Effectiveness

Vegetated geogrid installations produce immediately reinforced slopes. The protecting branches assist in retarding runoff and surface erosion, as well as reducing velocities from flowing water. The installed branches will produce roots which become entangled with the grids and bind the entire structure together, making it stronger over time. Construction costs for a vegetated geogrid is typically greater than for other bio-engineering methods such as live staking, live fascine, and brushmattress (see Table 6-5, RLMP 6.4.1). Installed unit costs have been reported to range between $12 to $30 per lineal foot (these are approximations only, and will vary greatly depending upon the actual site conditions and materials used).

Sketch Drawing

Figure 6-5 shows a vegetated geogrid.

6.4.7 Streambank Protection Using Hard Armoring Techniques

Description & Purpose

Hard armoring techniques use materials such as boulders, logs, and trees, to protect and stabilize eroding streambanks. Hard armoring techniques have the advantage of providing immediate protection to eroding streambanks which is not afforded by either revegetation or many bio-engineering methods. Hard armoring methods include boulder rip-rap, gabion structures, log cribbing, log and boulder wing deflectors, and anchored tree revetments. This RLMP describes the use, advantages and disadvantages of hard armoring methods to improve bank stability. An example of hard armoring using a log-wing deflector is provided.

Planning Criteria and Applicability

Streambank stabilization methods which do not depend on a vegetation component for improving streambank stability should be considered for use under the following applications:

1. Where vegetation cannot be effectively established such as in locations which have limited soil depths, lack a year round water supply, or where shading from overstory trees or topography limits the amount of sunlight needed for adequate growth.

2. Where steep bank slopes cannot be effectively graded back to provide a soil surface suitable for planting

3. Where immediate bank stabilization and protection is required

Hard-armoring methods have the disadvantage of providing little or no improvement in riparian habitat, and often provide little in the way of improving fish habitat conditions, except by reducing erosion and sediment production to streams. However, a few hard-armoring methods can provide additional improvements to fish habitat beyond control of bank erosion. If site conditions allow, hard armoring can be combined with vegetative

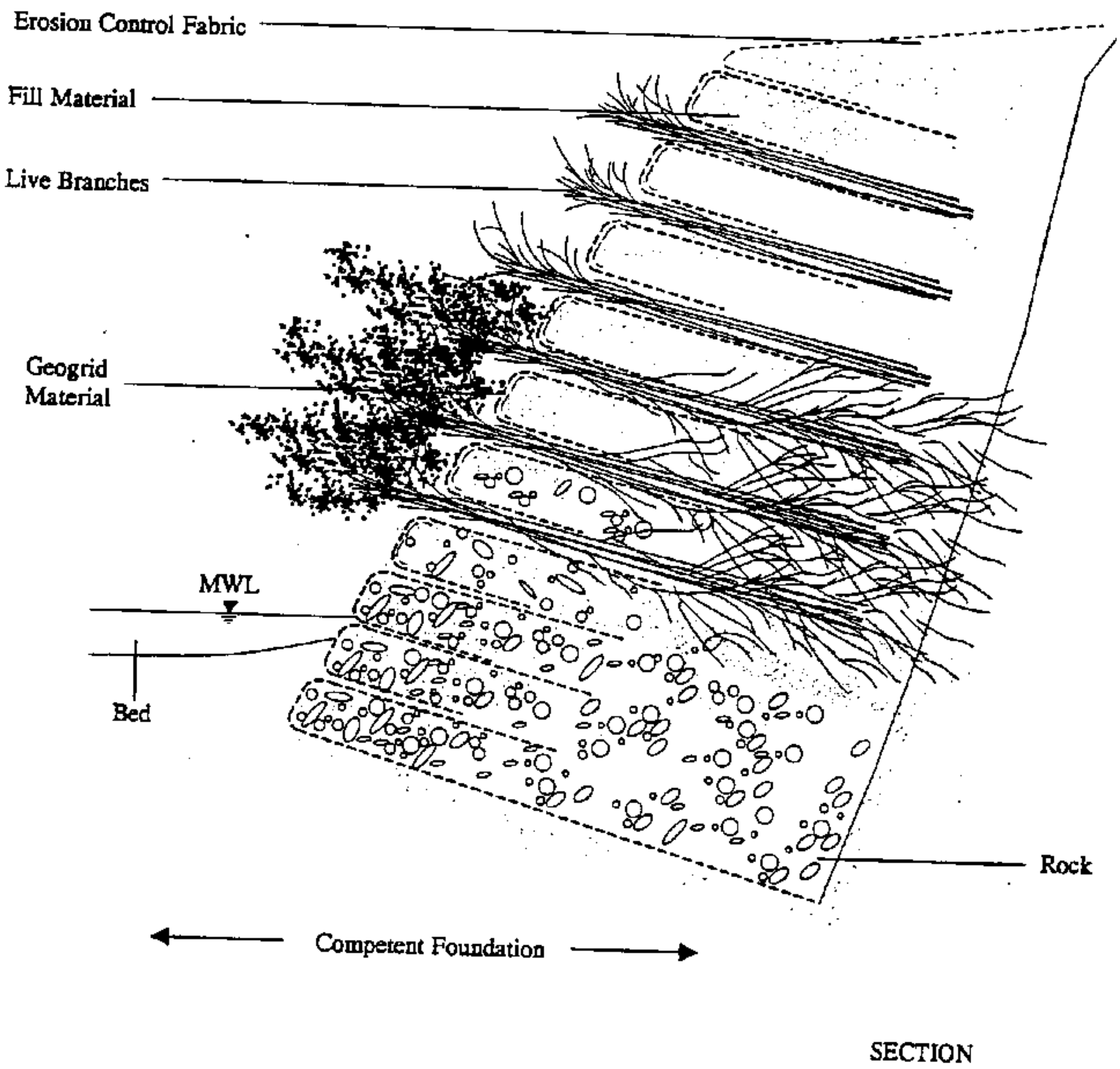


Figure 6-5. Vegetative Geogrid

plantings to improve their riparian and fish habitat value, and this often improves their aesthetic quality as well.

Methods and Materials

Hard armor protection methods fall into two groups; treatments which simply armor the streambank and treatments which deflect flow away from the site of bank erosion. Streambank armor protection include the use of boulder rip-rap, gabions, cribbing, and tree revetments. Flow deflectors include log or boulder wing-deflectors. The wing-deflectors direct flow away from an unstable streambank and armor the toe of the bank slope to protect against undermining and erosion. A log-wing deflector is described below.

1. Log wing deflectors are constructed from logs and small boulders or cobble to create a triangular shaped structure which functions as a unit and extends into the channel.

2. A trench is excavated into the streambank just below the streambed elevation, for the placement of logs. The deflector logs are placed into the trench and are notched, overlapped, and secured together with threaded rebar to form a stable, triangular unit. Large boulders are placed over the logs which extend into the streambank to anchor the log structure. The portion of the trench excavated into the streambank is backfilled to key the logs securely into the bank.

3. Small boulders are placed on top of the logs and within the interior of the triangular structure. The rock should be placed to a height about equal to the bankfull flow elevation to assure adequate protection during high flows. The boulders slope upwards to the streambank. The largest boulders should be placed on the upstream edge of the structure. The wing-deflector should not extend more than one-third of the bankfull width into the channel. For example, if the bankfull channel width is 100 ft., then the wing-deflector should extend no more than 33 ft into the channel.

   Care should be taken that the opposite streambank does not erode in response to the higher water velocities which occur due to the narrowing of the stream channel around the flow deflector. Generally, use of wing deflectors is not advised on very small streams due to the greater likelihood of scour on the opposite streambank. The increased flow velocities may scour a pool near the apex of the wing-deflector, providing improved summer rearing habitat for fish.

Maintenance

Maintenance may be required for hard-armored structures. Erosion can occur near the intersection of the streambank and the structure, or excessive bed-scour which can undermine the bank toe, causing instability. Structures should be monitored after high flow events to determine if repairs are necessary.

Effectiveness

Hard armored structures can provide very good protection against streambank instability and erosion when properly installed. Because many hard armoring methods constrict the channel flow, they are not generally recommended for smaller channels where accelerated erosion on the opposite bank may occur, or in channels where there is a potential for increased flooding.

Sketch Drawing

The log wing-deflector sketch (Figure 6-6) is selected from the Department of Fish and Game's *California Salmonid Stream Habitat Restoration Manual*.

6.4.8 GRAVEL EXTRACTION

Description & Purpose

Gravel is extracted from the floodplain, bars, and the low-water channel of many rivers, usually to obtain a supply of aggregate for industrial use. Gravel is also removed for the purpose of restoring or maintaining flood capacity. Gravel extraction is not an appropriate technique for the restoration of fish habitat conditions. Harvesting gravel from streams in north coastal California has often been documented to affect patterns of bank erosion, and to change the elevation and morphology of the river bed (Sandecki 1989, Mount 1995). These changes can in turn affect fish and wildlife habitat, flooding, and engineering structures.

Prior to initiating gravel extraction activities, it is important to assess the gravel supply of a stream reach in order to predict, and to potentially avoid, adverse effects to aquatic resources. After gravel extraction has been initiated, it is important to monitor on an annual basis changes in channel morphology and aquatic habitat to identify how aquatic resources are responding to gravel mining.

Planning Criteria & Applicability

The Navarro River and its major tributaries, carry large supplies of sand and gravel. It is part of the normal function of rivers to erode streambanks, transport, and deposit their sediment loads. Bars of sand and gravel are natural geomorphic features which comprise an important part of the channel's form and function. All streams are continuously and dynamically adjusting to changes in sediment supply and streamflow conditions. Extraction of sand and gravel can alter this relationship between sediment supply and streamflow. The response to altering the dynamic balance of sediment and streamflow can produce changes in river morphology and behavior over a significantly greater area than the extraction site itself.

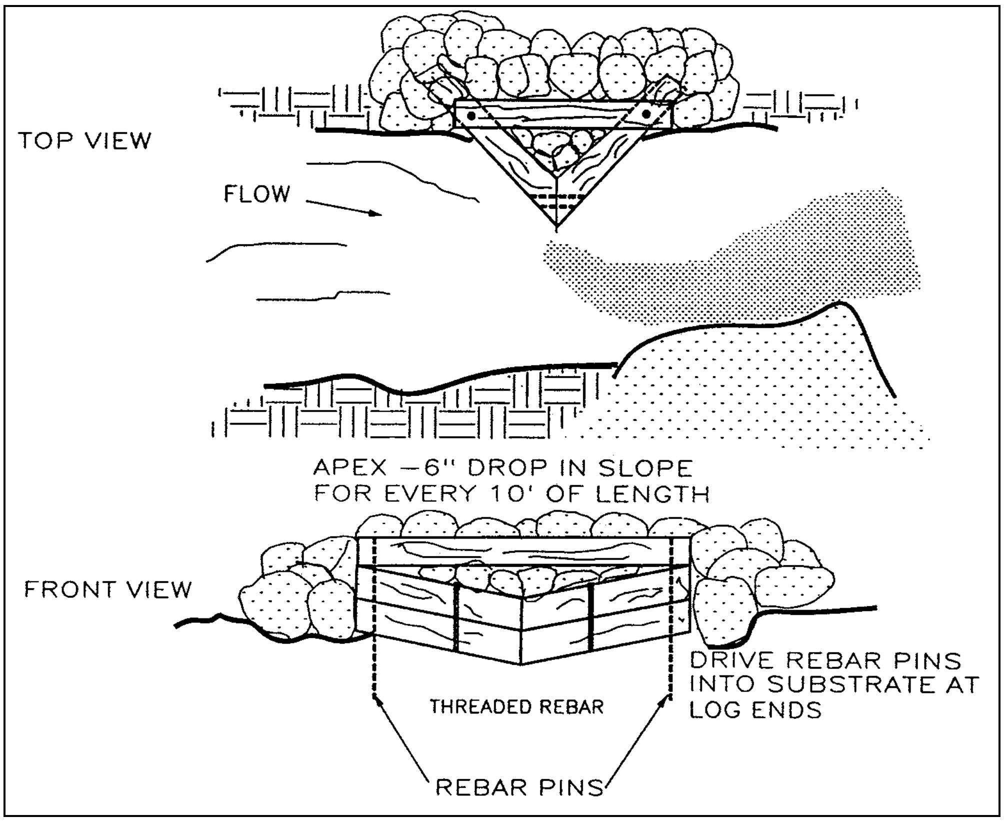


Figure 6-6. Log-wing Deflector.

Gravel extraction may affect river morphology and fish habitat in various ways (Collins and Dunne 1989):

1. Extraction of bed material in excess of replenishment by transport from upstream causes the bed to lower (degrade, or "incise") upstream and downstream of the site of removal.

2. Bed degradation can undermine bridge supports, pipelines, or other structures.

3. Degradation may change the morphology of the river bed, which can adversely influence aquatic habitat and salmonid spawning sites.

4. Degradation can deplete the entire depth of gravely bed material, exposing other substrates that may underlie the gravel.

5. If a floodplain aquifer drains to the stream, groundwater levels can be lowered as a result of bed degradation.

6. Lowering of the water table can cause mortality of riparian vegetation. Direct mortality of riparian vegetation can also occur due to river access by heavy equipment and to the processing of aggregate resources adjacent to stream channels.

7. Flooding is reduced as bed elevations are lowered, reducing the hazard for human occupancy of floodplains.

8. The supply of overbank sediment deposition on floodplains is reduced as the bed is degraded.

9. Rapid bed degradation may cause oversteepening of banks and eventual collapse and erosion.

10. Removal of gravel from bars may cause downstream bars to erode if they subsequently receive less bed material than is carried downstream to them by fluvial transport.

11. The reduction in size or height of bars can cause adjacent banks to erode more rapidly or to stabilize, depending on how much gravel is removed, the distribution of the removal, and on the geometry of the meander bend.

12. Mining gravel on the floodplain creates large pits which can be captured by rivers during floods or by their natural lateral migration over time. Pit capture can permanently alter the course of a river, and can initiate channel incision (headward erosion) beginning at the upstream end of the pit. The local groundwater table may also be lowered by drainage to deep mining pits.

13. The processing of aggregate material (crushing, sieving, and washing) adjacent to stream channels can increase turbidity in the mined river, impacting water quality.

14. For rivers in which sediments are accumulating on the bed (aggrading), gravel extraction can slow or stop aggradation, thereby maintaining the channel's capacity to convey floodwaters. In the Navarro watershed, stream reaches which appear to be actively aggrading include Anderson Creek in the Anderson Valley, and segments of upper Rancheria Creek. Careful extraction of gravel resources, *in quantities which do not exceed the approximate annual replenishment rate*, can be used to reduce the rate of channel aggradation.

15. Small-scale gravel extraction intended to provide pool habitat for salmonids are unlikely to be successful. This is due to the high sediment loads and high sediment transport rates in most north coastal California streams. In addition, the appropriate channel hydraulics needed to scour sediments and thereby maintain pool capacity is very difficult to re-create. Pools constructed by gravel extraction during the summer low-flow period can be filled-in after a single high-flow event.

16. Gravel extraction as a component of a larger restoration program for Anderson Creek may have some merit. Although gravel extraction itself is not a means for restoring Anderson Creek, it may provide a tool for assisting with a more integrated plan of restoration. Such an integrated plan should consider:

    a) source control of sediment inputs from gullying and other erosion processes in the basin;

    b) re-vegetation, bio-engineering and other methods to reduce streambank erosion; and

    c) appropriate rates, locations, and patterns of gravel extraction needed to reduce the rate of channel aggradation and lateral channel migration and thus, the likelihood of erosion along streambanks.

If gravel extraction is to occur, it should be performed in a manner which assists in defining a stable, single-thread channel in Anderson Creek. This will likely involve identifying an appropriate design for channel width, depth, sinuosity, and other geomorphic characteristics in relation to the hydrologic regime of Anderson Creek.

Any gravel mining operation would be required to conform with all county, state, and federal regulations, and would need to demonstrate that riparian and aquatic habitat will not be significantly impacted, before a county Use Permit is issued.

Material & Methods

There are four general types of aggregate mining operations; (1) wet pit, active channel mining, in which draglines or hydraulic excavators remove material from below the water table or directly from a perennial stream channel; (2) dry pit, active channel mining, in which bulldozers, scrapers, and loaders excavate pits on ephemeral streambeds; (3) bar skimming, in which the tops of gravel bars are removed without excavating below the summer water table level; and (4) floodplain gravel extraction, in which hydraulic excavators and bulldozers remove material which has been deposited and stored over long-periods of time above the streambank in floodplains and terraces.

There is no standard or objective procedure for determining which of these gravel mining methods are least likely to alter channel morphology, and thus to impact aquatic and riparian habitat. All of the gravel extraction methods have the potential to significantly impact habitat conditions. However, as a general rule-of-thumb, floodplain gravel extraction is least likely to have an immediate impact on aquatic habitat, since mining activities occur outside of the active channel. Bar skimming is the next least intrusive mining approach, since excavation does not occur so as to alter the depth and gradient of the deepest portion of the channel (termed thalweg). Dry pit and wet pit active channel mining excavate deeply into the streambed, altering the local gradient and channel depth. The river's response to such extensive modifications may be to cause channel incision, leading to other impacts which have been described above.

Probably the most significant factor to consider when developing a plan for gravel extraction is the total volume of sand and gravel which can be removed. The amount of gravel extracted should be in balance with the annual replenishment rate. The greatest potential for impacts to channel and aquatic habitat conditions are likely to occur when extraction rates exceed replenishment rates. Other site-specific conditions, such as ease of access, presence of riparian vegetation, proximity to fish spawning and rearing habitat, and local channel hydraulics, are also factors which will have an influence on the nature and extent of impacts to natural resources.

In order to characterize the supply of gravel to downstream reaches, and to assess or predict the effects of gravel removal, it is necessary to understand how sediment is produced and transported, and its interaction with river-channel morphology. The location and manner in which sediment is contributed to rivers influences the amount and durability of gravel supplied to downstream reaches. A combination of observation and measurement in the field, and on aerial photographs, may be used to identify, locate, and quantify, sediment sources and to define how they change through time, and as a result of changes in land use (see Section 3.0).

A general approach for management of gravel extraction from rivers should include:

1. Appropriate rates and locations of gravel extraction should be determined before gravel extraction begins, based on:

   a) the rate of upstream replenishment

   b) whether the river bed elevation under undisturbed conditions remains the same over periods of decades, or if not, a determination of the aggradation or degradation rates

   c) historical patterns of sediment transport, bar growth, and bank erosion, in particular stream bends (historical aerial photography can be used to assess patterns and trends)

d) projection of anticipated effects on the river bed and banks, including when feasible, analysis of present or past effects of gravel extraction at various rates

e) an analysis of the desirability or acceptability of the anticipated effects of extraction at different rates

It is strongly recommended that a geomorphologist or hydraulic engineer provide assistance in estimating the replenishment rates and therefore the gravel extraction rates which are likely to reasonable for a given stream reach.

2. Records of extraction quantities should be maintained.

3. Monitoring subsequent to implementation of a regulated harvesting rate should document effects to the river bed, banks, and bars, using cross-sections and aerial photographs. The data should be analyzed immediately after collection. The monitoring program may be simple and relatively inexpensive if carefully designed. It is necessary to monitor upstream and downstream of the immediate vicinity of a bar skimming operation, because effects can extend upstream and downstream. At a minimum, cross-sections should be located at riffles immediately upstream and downstream of a mined bar. Aerial photographs can be a powerful tool for evaluating the rates of lateral migration.

4. Permitted extraction rates should be reviewed periodically in light of information generated by the monitoring programs. Use Permits for gravel mining are issued by the Mendocino County Planning Department.

Maintenance

There is no active maintenance of the channel, per se, associated with this RLMP. However, as detailed in the methods & materials section, monitoring the effects of gravel harvest operations and documenting the locations and amount of gravel material extracted, should be accepted as part of an annual program. Typical monitoring conditions required by the County include permanently monumented pre- and post-extraction cross-sections (5-7 per site) performed by a registered engineer or surveyor, and extending into the 10-year floodplain. Also usually required is a longitudinal profile, replenishment calculations, extraction quantities, and aerial and ground elevation photographs.

Effectiveness

The combined approach of up-front planning to predict how much gravel can be removed from a river reach without initiating adverse effects on the stream channel or aquatic habitat, and an annual monitoring program to document actual changes after extraction, is an extremely effective tool in preventing long-term negative impacts to aquatic resources.

6.4.9 WATER CONSERVATION AND STORAGE

Description & Purpose

Streamflows in the Navarro River watershed vary widely from year-to-year, and season-to-season, with higher flows occurring between December through April, and lower flows occurring in the summer and fall months. Fish habitat during the low-flow period may be restricted to small, and in some stream reaches, isolated pools. Surface water diversions for residential and agricultural uses during this critical period can adversely impact fish habitat by drying-up pools. In addition, groundwater contributions to surface streamflows help to maintain cooler water temperatures, an important factor supporting aquatic life. Therefore, it is important to consider various methods whereby in-stream flows for the fishery can be maintained or increased during the low-flow period. The following recommendations are intended to contribute to maximizing in-stream flows, and minimizing withdrawals of surface flows, to protect aquatic life.

Planning Criteria & Applicability

Many of the streams draining the Navarro watershed have low streamflows during the summer months. Monitoring by the Mendocino County Water Agency and the State Water Resources Control Board indicate that Soda Creek and Robinson Creek dried-up early in the summer of 1995. Most other streams which were monitored had flows less than 0.5 cubic feet per second (cfs). Flow in the Navarro River (near Hendy Woods) is usually less than 3.0 cfs by late summer. The mainstem has been known to have no surface flow in some reaches during drought years. Flows tend to decrease rapidly between June and August. By late August the rapid reduction in streamflow levels off, and does not appreciably decrease during the months of September or October. By November, streamflow usually increases dramatically with the onset of winter rains (in average years, unless drought conditions prevail).

During the dry season, groundwater is the source of flow to streams draining the Navarro watershed. The portion of the total discharge within a river that is due to groundwater is termed baseflow. The amount of baseflow discharge that a river receives is dependent on four factors: (1) the total amount of groundwater recharge in the region; (2) the porosity of the aquifer (total amount of water that the rock and sediment can hold); (3) the hydraulic conductivity of the aquifer (rate at which the water can move through the subsurface; and (4) the steepness or gradient of the water table. As the gradient of the water table declines, the rate of discharge progressively slows. If the water table lies below the elevation of flow in the stream, seepage downward through the riverbed into the groundwater table may occur. The loss of surface flow in channels can occur where pumping has lowered the groundwater table adjacent to streams.

Streamflow monitoring in 1995 and 1996 indicates that portions of lower Anderson Creek are subject to periods when pumping of surface water has caused pools to go dry. Where pools persist, higher stream temperatures occur. The Anderson Creek drainage, lower reaches of Indian Creek, and the mainstem Navarro River are probably the most important locations in the Navarro watershed where recommendations for improving streamflow apply, due to the larger population and to the presence of agricultural activities. However, practices to improve streamflows in all basins of the watershed will benefit aquatic life. The remainder of this RLMP includes specific recommendations for reducing water use and for reducing the impact of water diversions on stream flow. The recommendations are divided into two parts: water conservation, and water storage.

Material & Methods

Water Conservation

The major water-consuming land uses in the Navarro Watershed are agriculture, especially wine grapes, orchards, and grazing; and residential and commercial uses, including domestic uses, landscaping, and gardening. The following recommendations detail means of reducing water consumption for people engaged in these land uses.

Orchards

Water is used in apple orchards for irrigation, for spring frost protection, and for heat protection. The goal of orchard owners should be to select a water delivery system that uses the least water necessary to satisfy all three needs.

Not all orchards require application of water. Some apple rootstocks, such as standard rootstock and MM111, a semi-dwarf rootstock, are able to withstand drought, and may not require irrigation once the trees are established. Mulching trees, especially out to the drip line where the majority of the tree's feeder roots grow, helps reduce evaporative loss from the soil. Watering drought-tolerant trees will, however, increase yield, fruit size, and year-to-year consistency of production.

In the higher elevations of the hills above Anderson Valley, frosts are not as frequent or as severe, and frost protection will not be necessary in most years. In the Valley itself, late-blooming varieties, such as Northern Spy, Golden Delicious, Red Delicious, and Fuji, are less likely to require frost protection. Maintaining a closely-cut cover crop during the spring will result in higher temperatures on the orchard floor and will reduce frost, when compared to high cover crops. On bare orchard floors, rolled soil is warmer and less prone to frost than cultivated or freshly disced soil.

The need for heat protection can be minimized by pruning to establish a closed canopy to provide shade for the fruit, and by tolerating some loss of fruit during unusually hot spells.

Water delivery systems for apples include, in order of least efficient water use to most efficient, flood irrigation, overhead sprinklers, under-tree sprinklers, and localized systems. Flood irrigation uses large quantities of water and is inappropriate in Anderson Valley. Overhead sprinklers provide excellent frost and heat protection, but consume water less efficiently than other systems. Low-volume under-tree sprinklers are available, but may not provide even distribution in hedgerow and espalier orchards.

Localized irrigation, which includes drip and low-volume sprinklers (including micro, mini, mister, and fogger sprinklers) provide irrigation water, and the sprinkler systems also provide heat protection. These methods are not, however, sufficient for frost protection. With localized irrigation, soil moisture used by the tree is replaced by applying water to a relatively small percentage of the orchard floor on a frequent basis. Trees irrigated by this method may have a reduced root zone compared with trees irrigated by other methods. Placement or burying of sprinklers or emitters in a circle at the drip line of the tree, and moved outward as the tree grows, will help increase the root zone, but may interfere with cultural operations. Localized irrigation works well on soils with low infiltration rates and is suited to automatic operation with time clocks.

The disadvantages of localized irrigation are, besides not providing frost protection, high installation costs, emitter clogging, risk of damage during cultural operations, and lack of reserve moisture in the soil. Clogging is a major difficulty, but can be reduced by using self-cleaning emitters, and by filtering of the water supply. Drip irrigation systems must be engineered to meet the maximum summer water demand for the whole orchard, or trees will become stressed during hot spells and production may decline more rapidly than with other irrigation methods.

Whatever type of irrigation system is used, applications should be scheduled to use the least water necessary to maintain tree health and vigor. Application during the early morning or evening significantly reduces losses to evaporation and increases infiltration. Coordinating applications with neighbors sharing a common source of water helps avoid sharp declines in stream flow. A number of orchard and vineyard owners are already cooperatively scheduling pumping from the Navarro River. Using winter diversion ponds for water supply is preferable to pumping from wells or streams in the summer. Depending on spring rains, onset of irrigation can be delayed, sometimes until as late as mid to late June. In dryer springs, soil moisture testing or establishment of a water budget may be used to determine when irrigation is necessary. University of California, Cooperative Extension and the RCD/NRCS should be consulted regarding selection of irrigation technologies and scheduling of applications.

Vineyards

Vineyards use water both for spring frost protection and for irrigation. Like apple orchards, vineyards' water requirements can be reduced through various means, and vineyards located in higher elevations generally do not require frost protection.

Wine grape growers can reduce water consumption through diversion of winter run-off, rather than pumping ground or surface water in the summer; using drip or underground irrigation instead of overhead sprinklers; growing and maintaining early dormancy cover crops; selection of rootstock that is drought tolerant and suited to the growing site; and decreasing water use through using new instrument technologies to measure the water needs of the vines. Wine growers who must use groundwater or water from streams in the summer should be particularly careful to implement water conservation methods. These landowners should consider development of ponds for storage of winter runoff to meet some or all of their summer water needs, and should coordinate pumping schedules with neighbors.

Grazing

Ranchers use water for irrigating pasture and for watering livestock. In general, ranchers prefer to minimize water use to keep down expenses. Water conservation on irrigated pastures includes use of pasture crops that are relatively drought-tolerant and use less water (consult with the NRCS for types of drought resistant cover crops suitable for the Navarro watershed), watering in the evening or early morning to reduce evaporative loss and to increase infiltration; rotating pasture crops with green manure crops to increase soil organic matter content and therefore water holding capacity; use of winter diversion ponds, rather than direct summer pumping of streams or groundwater; cooperative scheduling of pumping for neighbors who share a common water source; and use of soil moisture testing or water budgeting to minimize irrigation.

Stock ponds and troughs should be used for watering stock where possible, as opposed to allowing stock access to streams. Troughs should be sized only as large as necessary for providing adequate access for the planned number of animals.

Residential and Commercial Water Conservation

Substantial water savings can be achieved in residences and businesses using simple, effective methods. Indoors, water conservation includes:

- low-flow showerheads;
- aerators on kitchen and bathroom faucets;
- low-flush toilets, or retrofitted high-flush toilets. Retrofitting includes use of "dual flush" systems that allow for either partial or full flush; use of bricks or other water displacement devices in toilet tanks; and adjusting float valves to lower the water level in the tank.
- use of front-loading clothes washing machines, rather than top-loaders.
- changes in water consuming behavior, such as not letting the water run while shaving or brushing teeth; taking shorter showers or navy showers (wet-down, shut off water; soap-up, rinse-off); and using running water during dishwashing only for final rinse;
- in restaurants, only serve water when requested.

Outdoors, water conservation includes use of methods for reducing water consumption in landscapes and gardens. These include:

- drip irrigation;
- xeriscaping (use of drought-tolerant plants in landscaping);

- mulching to reduce evaporative loss;
- watering in the early morning or evening;
- use of compost and other organic soil amendments to increase water holding capacity of soil;
- collection and use of graywater for irrigation (not for vegetables).

Water Storage and Water Diversion

1. The Navarro Watershed Advisory Group has adopted a policy to promote the construction of agricultural water storage ponds (Appendix D), in accordance with sound environmental practices, to achieve reduced diversion of summer stream flows. The AG encourages agricultural water users to divert and impound high winter flows, where feasible, for use in summer in order to help decrease reliance on diverted summer stream flows. The AG encourages interested landowners, including those who already hold rights or permits allowing diversion of summer flows, to develop such ponds.

   Storage reservoirs are constructed to capture and conserve water for later beneficial use such as irrigation, frost control, heat control, and stock watering. The reservoir is made by constructing a dam or embankment. These should be located off-stream, or on ephemeral, non-fish bearing streams. The reservoir captures runoff during winter storm events, and the stored water is used during the low-flow summer period in lieu of pumping water from perennial, fish bearing streams.

   The feasibility and cost-effectiveness of storage reservoirs must consider the intended uses and suitability of available sites. Site suitability typically includes understanding the range of flows available for water supply from the catchment, as well as geologic and soil conditions required for construction. The State Water Resources Control Board, Division of Water Rights, issues permits for all appropriative water rights. Water rights may be necessary depending upon the size and location of the impoundment. Small domestic use appropriations are registered with the State Water Board, and do not require a water right permit. Small domestic use includes normal domestic use, plus incidental stock watering and irrigation of one-half acre or less, not exceeding storage of water up to 10 acre-ft per annum. Any other water use which involves storage in a reservoir for later use on either riparian or non riparian land must apply for a water right. In addition, Department of Fish and Game may require permit issuance for impoundments. Also, dams higher than 25 feet must be approved by the California Department of Dam Safety.

   The State Water Resources Control Board (SWRCB), Division of Water Rights, sets conditions for appropriate permits that define a diversion "season". Currently, permits are being issued with the condition that water may only be diverted from the mainstem Navarro River and stored between December 15 and March 31, and then only when the discharge at the USGS Navarro River gage is above 300 cubic feet per second. Ponds must be fitted with a controllable by-pass that allows for release of water when the flow conditions specified above are not met. The SWRCB is currently considering setting more restrictive conditions on the diversion season. All landowners with ponds on their property should consider adopting these conditions as guidelines for the management of their ponds, whether or not they are required to do so.

2. Agricultural landowners who are currently able to divert summer flows under riparian rights or older appropriative permits should consider development of winter diversion ponds to fulfill some or all of their water needs.

3. Wherever possible, use groundwater resources in the drier months rather than direct in-stream diversions from surface waters. During wet winter months, utilization of surface water sources will have the least impact on aquatic life.

4. When feasible, allow sheetflow and surface water runoff to naturally disperse over floodplains. Reduce reliance on drainage ditches to concentrate runoff directly into tributary stream channels. This maximizes opportunities for infiltration and groundwater recharge, and can result in higher baseflows in streams.

5. Several agricultural landowners have an ongoing grassroots effort to coordinate and schedule surface water diversions. By reducing the chances for simultaneous pumping from nearby stream reaches, and distributing water extractions more evenly in a given stream reach, the risk of drying up pools will be reduced. This effort should be supported and expanded to include other agricultural water users who divert summer flows.

Maintenance

There is no maintenance required for either water conservation practices or obtaining appropriate water rights. Maintenance programs are recommended for water storage reservoirs. Regular inspections of the dam or earthen embankment are necessary. Sealing of impoundments with clay liners, plastic sheeting, compaction, or other means may need to be renewed and maintained.

Groundwater monitoring has not been conducted in the Navarro watershed, so that the potential for groundwater pumping to affect streamflow in locations such as Anderson Valley are unknown. A program of surface flow and water table monitoring should be developed as a good first step towards implementing a groundwater management strategy. Voluntary local monitoring of wells in conjunction with continued streamflow monitoring, will provide much of the information needed to determine how groundwater withdrawals might affect baseflow conditions, and how best to manage both water resources to protect in-stream flows. The Mendocino County Water Agency can become the central repository for groundwater monitoring data, and can coordinate surface flow monitoring in critical stream reaches.

Effectiveness

The most effective means of reducing reliance on surface flows during the summer period are to use water captured during the high flow winter runoff, and to practice water conservation measures.

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University of California
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6.5 RIPARIAN CORRIDOR INTEGRITY AND PROTECTION

The riparian corridor is the portion of the watershed which borders streams and rivers, generally including the channel banks and floodplain area. Riparian corridors cover only a relatively small portion of the watershed, but their functions are critically important to the maintenance of water quality and to the protection of fish habitat. Land-use activities which remove riparian vegetation or otherwise disturb their integrity can lead to increases in water temperature, reduction in terrestrial as well as aquatic habitat diversity, and promotes bank instability leading to erosion and stream sedimentation.

RLMP 6.5.1, *Exclusionary Fencing*, describes the need for, types, and various management practices associated with fencing, to protect and restore riparian corridors. RLMP 6.5.2, *Invasive Plant Species*, provides information describing non-native species which have invaded the Navarro watershed and how they can be removed to maintain the integrity and function of riparian corridors. Protecting riparian corridors and minimizing the loss of habitat diversity is discussed in RLMP 6.5.3, *Riparian Corridor Protection and Restoration*. RLMP 6.5.4, *Riparian Revegetation*, provides technical guidelines, typical costs, and additional resource information needed to ensure successful revegetation of degraded riparian corridors. RLMP 6.5.5**,** *Grazing/Range Management* provides recommendations for developing a grazing management program which reduces sediment production and protects the riparian corridor.

6.5.1 EXCLUSIONARY FENCING

Description and Purpose

Temporary fencing of riparian zones to exclude livestock and wildlife allows for natural regeneration or active revegetation of riparian habitat. Exclusionary fencing is only recommended in areas which have little native vegetation due to grazing pressure, and where there is minimal natural regeneration.

Fencing is usually a short term option to allow for a rest and recovery period so that the riparian zone can re-establish a dense stand of native riparian trees. After this objective has been met, and canopy over the stream has been established, fences can often be removed. In some cases it may then be appropriate to reintroduce managed grazing in riparian pastures.

Re-establishment of riparian vegetation alongside streams provides for cooler water temperatures, recruitment of woody debris, contribution of insects and leaf litter to the aquatic zone, reduction in streambank erosion, and a reduction in sediment delivery to the stream from upslope sources. Additionally, re-establishment of riparian vegetation can reduce land loss associated with streambank erosion.

Planning Criteria and Applicability

Exclusionary fencing should be used only where appropriate. Streamside areas which are characterized by high quality riparian habitat and good canopy may not require fencing. Fencing long sections of a stream on a permanent basis may not be the most cost-effective method of meeting the objectives for riparian corridor integrity in the Navarro basin. The stream corridor should be evaluated for problem areas where there is little native vegetation, low canopy cover, and minimal natural regeneration in evidence. These areas should be prioritized for fencing. Types of fencing will depend upon landowner preference and site-specific considerations.

Viability of the livestock operation is a critical factor in developing riparian fencing plans. Exclusionary fencing designs need to incorporate opportunities for off-stream water development, shelter and shade, and seasonal usage of riparian pastures.

Methods and Materials

Width of Exclusionary Fencing Zone

In determining the width of the fenced riparian area, landowners may wish to take into account adjacent land use practices, flood frequency and extent, and physical processes within the stream corridor. Riparian habitat tends to develop in areas that are subject to regular inundation - with different species adapted to different inundation levels. Ideally, the livestock exclusion zone should be wide enough to accommodate the historic meander corridor of the stream, and a variety of riparian habitat vegetation types (e.g., willows in the active channel, large bay and maple trees on the floodplain). This will allow for the greatest degree of riparian corridor integrity and biological diversity within the zone. Landowners may also wish to consider establishing an exclusionary fencing zone equivalent in width to a riparian buffer strip. See discussion under RLMP 6.5.3, *Riparian Corridor Protection and Restoration,* for recommendations on buffer strip considerations. A sustainable riparian corridor will provide shade, woody debris, and pool structure to the stream over the long term - with minimal management from humans.

In watersheds which have been modified by various land use practices, it may be a challenge to determine the extent of the meander corridor. Historic aerial photographs, as well as consultation with a qualified hydrologist/geomorphologist, can help to determine an adequate width for the exclusionary zone. In the long run, a wide enough exclusion zone will reduce the amount of maintenance required by the landowner - fences further away from the channel are less subject to flood damage.

Types of Fencing

Fencing is a site-specific decision which depends upon the grazing operation in place, flood frequency and extent, potential for livestock and wildlife injury, cost and landowner preference.

Following are types of fencing which can be used to exclude livestock from riparian corridors:

1. four or five strand barbed wire;

2. field fence;

3. high tensile fence/New Zealand fence;

4. electric fence: temporary or permanent.

Costs for exclusionary fencing vary widely depending upon the type of fencing selected and the number of corners, posts, etc. Most public agencies which fund exclusionary fencing on private lands specify a range from $4.00 to $6.00 per linear foot, although actual costs may be higher.

Funding

The following agencies have programs which fund exclusionary fencing on private lands:

- California State Coastal Conservancy
- California Department of Fish and Game
- California Department of Forestry - Forest Stewardship Incentive Program
- California Wildlife Conservation Board - Riparian Program
- California State Water Resources Control Board - Non-point source Program
- United States Environmental Protection Agency - Wetlands Program
- United States Fish and Wildlife Service - Partners for Wildlife Program

Natural Regeneration or Active Revegetation?

Stream corridors which are devoid of riparian habitat in selected locations, but which have a good source of native seeds upstream, may not require active revegetation. Riparian species tend to regenerate quickly when wildlife or livestock grazing pressure is removed. Often, only a few years are required to re-establish a dense riparian forest which can be seasonally grazed. Natural regeneration is a simple, low-cost alternative to active revegetation, and is usually most effective for areas within the active channel or zones which are subject to regular flooding. Floodplain areas are generally not as quick to re-establish native riparian habitat.

To “jump start” the natural regeneration process, or for areas which do not have a good upstream seed source, active revegetation is often warranted. See RLMP 6.5.4, *Riparian Revegetation*, for more information.

<u>Riparian Pastures</u>

Understory species in the riparian zone are adapted to grazing and browsing by various wildlife species. Appropriate, limited livestock grazing can replicate this natural condition. Livestock grazing of riparian areas (riparian pasture) may be appropriate for short periods during the spring, and may be effective for controlling certain exotic species. Livestock should not be allowed to enter the riparian pasture until banks have solidified (i.e., no longer saturated), due to the potential for excessive trampling and stream sedimentation. Herbaceous plants may still be available for grazing in the spring, and willows will have the opportunity to recover from short duration grazing during the remaining summer months. An off-stream water source should be available to the stock at all times so that animals do not rely on accessing the stream for drinking water. Salt and other nutrient supplements should be placed away from the stream to discourage livestock access to the riparian zone.

If riparian species such as willow and alder are below six feet tall (browse height), stock should be excluded from the riparian pasture in summer. If however, riparian tree species have formed a canopy layer and are above browse height, it may be appropriate to allow limited grazing during the summer months.

<u>Maintenance</u>

Areas where fencing crosses the stream need to be routinely examined for debris accumulation, damage to flood gates, or excessive build-up of young vegetation which impedes flood gate movement. Removal of debris from fences and flood gates, and careful removal of vegetation around flood gates may be performed several times per year as needed.

<u>Effectiveness</u>

Exclusionary fencing can be a highly effective, limited duration method for restoration or enhancement of riparian corridor integrity - including shading of the stream channel, increased woody debris and pool formation, as well as reduction in siltation.

6.5.2 INVASIVE PLANT SPECIES

Description and Purpose

Exotic plant species are capable of invading riparian zones and replacing native habitats. Highly invasive species may negatively affect riparian corridor integrity in the following ways:

1. increased water temperatures due to displacement of native canopy tree species;
2. changes in water quality and pH;
3. do not provide woody debris or structure to the stream;
4. do not provide appropriate nutrients/litter to the stream;
5. less effective than native vegetation as a buffer for sediments;
6. ineffective for bank stabilization and erosion control due to shallow roots;
7. suppression of biological diversity, destruction of native wildlife habitat.

This RLMP identifies some of the common invasive plant species found in north coast riparian areas, and recommends general guidelines for monitoring and control.

Planning Criteria and Applicability

Only species which threaten the integrity of the riparian zone are addressed here. There are numerous exotic plant species in California - many of which are not invasive. Numerous invasive plants - such as Yellow Star Thistle (*Centaurea solstitialis*) invade upland habitats, but are not successful invaders in the riparian zone.

Following is a list of invasive species which are known to occur in riparian zones within the Navarro watershed:

Salt Cedar	*Tamarix sp.*
Chinese Tree of Heaven	*Ailanthus altissima*
Himalayan Blackberry	*Rubus discolor*
Periwinkle	*Vinca major*
Harding Grass	*Phalaris aquatica*
(floodplain wetland invader)	

Salt Cedar is found in few locations, but should be carefully monitored as it uses significantly more water than native riparian species, and may spread very quickly and replace riparian habitat. Chinese Tree of Heaven is not widespread, and although less invasive than Salt Cedar, should be monitored. Himalayan blackberry is widespread throughout streams in the basin, and may be successfully competing with the native blackberry.

Giant Reed (*Arundo donax*) is not known to occur in the Navarro watershed at this time. However, its presence should be monitored, as it poses a serious threat to fish and wildlife habitat, and is found in large numbers in the Russian river and nearby watersheds, including the Dry Creek basin (near Yorkville). In many river systems in

California, Giant Reed and Salt Cedar have entirely replaced the native riparian habitat - virtually eliminating riparian canopy, structure, and woody debris contributions.

Methods and Materials

Invasive plant species should not be planted as ornamentals because they may escape from landscaped areas. Landowners should use native plant species or non-invasive exotics for landscaping.

Invasive plants species can be removed in a variety of ways, including manual removal, herbicide, grazing, and in some cases, burning. Before making a decision on the most effective means of eradication and control, it is important to understand the life history and physiology of the particular species. For example, Giant Reed is fire adapted, and responds positively to burning. Species such as Himalaya Berry, which spread primarily by vegetative reproduction as opposed to sexual reproduction (i.e., seeds), are difficult to control manually, and may require herbicide application.

Application of herbicide in the riparian zone requires surgical spraying to avoid impact to native vegetation, and should only be undertaken if other methods of control are deemed ineffective. It is important to evaluate the proximity to aquatic habitats, and the potential for leaching of herbicide into the stream environment, where it may be toxic to aquatic organisms. A licensed pesticide applicator and a riparian ecologist familiar with the control of invasive species should be consulted prior to herbicide application. The University of California Cooperative Extension has information and staff expertise in the area of invasive exotic species. There are also numerous websites on the internet devoted to identification and control of noxious weeds (see references/ bibliography).

Certain widespread species such as Himalaya Berry may not be candidates for complete eradication. In areas of heavy infestation, complete removal of these species may require such large amounts of herbicide that only partial suppression is warranted.

Maintenance

Monitoring of invasive plants is critical to suppression and control. After treatment of the invaded site with any of the above-mentioned techniques, the site should be monitored for several years to ensure that eradication has been successful. Early implementation of a suppression program and follow-up monitoring are key to successful control, and will save time and money in the long term.

Effectiveness

Early detection and elimination of invasive plant species will help to preserve native habitats and retain the values of the riparian zone, including shading of the stream channel, recruitment of woody debris, and reduction in sedimentation.

Sketch Drawings

Photos of the principal invasive species are provided (Figure 6-7 to Figure 6-10).

6.5.3 RIPARIAN CORRIDOR PROTECTION AND RESTORATION

Description and Purpose

Healthy riparian corridors are critical to the survival of salmonids and to the protection of water quality. In addition, numerous other species, including 3/4 of California's amphibians and 1/2 of the State's reptiles, birds, and terrestrial wildlife, depend on the habitat provided by healthy riparian corridors (Anderson *et al.* 1984, Bloom *et al.* 1984, Gray *et al.* 1984, Itallberg *et al.* 1984, Hunter 1996, Williams *et al.* 1989, Trapp *et al.* 1984). Riparian corridors are often the connection between distinctly different habitat types - such as oak woodland or mixed evergreen forest - and act as important transportation routes for terrestrial and aquatic species. Degradation, destruction, or isolation of one section of the riparian corridor may result in broadly felt negative impacts.

Planning Criteria & Applicability

Land use activities that degrade riparian vegetation usually have adverse impacts on water quality and on aquatic and riparian habitat, and should be avoided. Salmonid habitat and water quality are particularly sensitive to the cumulative effects of numerous, isolated sites of riparian destruction or degradation. Timber harvest, grazing, agriculture, and residential development may affect terrestrial species, aquatic habitat, and water quality in the following ways:

1. Removal of riparian vegetation reduces shading, increases solar input, and results in higher summer stream temperatures which may be unsuitable for salmonids. It is particularly important to recognize that warmer water temperatures do not affect just the immediate site where riparian vegetation has been removed, but affect downstream reaches as well.

2. Removal of riparian vegetation can de-stabilize stream banks, causing an increase in erosion and sediment delivery to stream channels. Increased sediment delivery may cause a shallowing of pool depths, and degradation of spawning habitat. De-stabilized streambanks can result in channel widening which also reduces shading and increases summer water temperatures.

Figure 6-1.   Salt Cedar.

Figure 6-2. Chinese Tree of Heaven.

Figure 6-3. Himalayan Blackberry.

Figure 6-4. Giant Reed. (Not available for this edition of this document)

3. In coniferous forested regions of the watershed, loss of riparian forests, particularly large trees, reduces the load of large woody debris recruited to stream channels. Large woody debris provides several critical habitat elements for coho salmon and steelhead trout (see RLMP 6.4.2, *Large Woody Debris*).

4. The riparian corridor functions as a filter for sediments which are carried in over-bank flows. Vegetation provides "roughness elements" along streambanks and on the floodplain, which reduces water velocities during high flows. As water velocities are reduced, sediments may be deposited, assisting in the maintenance and building of streambanks.

5. Riparian vegetation provides habitat for insects which in turn are an important food base for salmonids.

6. Seasonal damming, culverting or blocking of tributary streams -- affecting only a small section of the riparian corridor -- may restrict access to significant areas of upstream or downstream habitat for aquatic and terrestrial organisms.

Methods & Materials

The most effective means of reducing habitat fragmentation and preserving riparian corridor integrity is to avoid or minimize land-use activities which remove or degrade riparian habitats. Landowners should avoid all activities that disturb the riparian corridor or which damage or remove riparian vegetation, including timber harvest, land clearing for agriculture, residential, or commercial development, earth moving, grading, grazing (see Exclusionary Fencing RLMP), and recreation. Landowners should take particular care not to damage or remove stream canopy trees.

In already degraded riparian habitats, revegetation should be used to restore riparian corridors (see RLMP 6.5.4, *Native Plant Revegetation*). Focused revegetation of denuded or degraded riparian areas will help restore stream canopy, thus reducing stream temperatures; will help improve the filtering and stream bank stabilizing functions of the riparian corridor; will help ensure the long-term supply of large woody debris; and may restore the connection to adjacent upland habitats.

The following recommendations are directed to riparian landowners who wish to protect riparian corridor integrity, reduce habitat fragmentation, and improve the functioning of degraded riparian corridors.

1. Riparian landowners should establish and maintain streamside buffer strips, both at individual sites and, in cooperation with neighbors, along streams through contiguous properties. These buffer strips may be established formally, as for example as a part of a Resource Conservation Plan, Conservation Easement, Habitat Conservation Plan, Nonindustrial Timber Management Plan, or Sustained Yield Plan; or informally. Landowners should define buffer strip width and allowable land uses that are commensurate with the goals of protecting water quality and enhancing stream habitat. Economic feasibility is often a

consideration in determining buffer strip width and allowable uses. Buffer strips should be established for year-round and ephemeral (Class III) streams. Once buffer strips are established, land-use activities such as timber harvest, grazing, building, viticulture, and orchards should not be allowed to encroach on the protected area to the extent that it is degraded.

2. Landowners should protect tree cover along streams to provide shade, reduce stream sedimentation, reduce summer water temperatures, decrease algal blooms, and increase aesthetic values. Except under extraordinary circumstances, trees that form stream canopy should not be disturbed or removed. Within buffer strips on fish-bearing streams (Class I waterways), there should be no disturbance of canopy trees (100% canopy retention). Within buffer strips on Class II and Class III waterways (non-fish bearing streams and ephemeral stream channels), there should be minimal disturbance of canopy trees. At minimum, timber harvest and other disturbances should not remove more than 20% of the canopy on Class II and Class III streams (80% canopy retention), and trees growing within or on the banks of these streams should not be disturbed. Long-term management of all buffer strips should ensure sufficient permanent retention of conifers to establish and protect a diversity of habitats, and to ensure a long-term supply of high-quality large woody debris (See discussion of LWD in RLMP 6.4.2).

3. The practice of maintaining riparian buffer strips along stream channels is widely applied to various land-uses, and is considered one of the most important aspects of protecting stream habitats. Establishing appropriate buffer widths has been the subject of much debate, and many alternative approaches for determining adequate buffer widths have been proposed. The most important considerations in establishing buffer zones are: purpose of the buffer zone, width of buffer zone, and level of activity allowed within the riparian zone. Landowners may also need to consider if buffer zones should be actively restored or allowed to recovery naturally.

   As a general rule-of-thumb, streambank stability and litter inputs to streams are provided by trees within one-half of their potential mature heights of the channel. Shading and large woody debris are provided by trees farther from the channel, generally up to 1.0 tree height distance. Some level of disturbance within the riparian zone may be acceptable if there are minimal, cumulative downstream effects on salmonid habitat. Since steelhead are found in almost every drainage of the Navarro watershed, some type of buffer zone should be established around all streams to protect aquatic habitat conditions.

   A recommended criteria for buffer zone width to ensure long-term recruitment of LWD is to establish a streamside management zone wide enough so that if a tree within the designated zone falls perpendicular to the channel, the portion of the tree that intersects the channel has the minimum diameter and length necessary to qualify as LWD. If the buffer zone is too narrow, then trees outside the perimeter of the designated zone which could potentially be a source of LWD to the channel, would not be protected. If the buffer zone is too wide, the same trees within the designated zone will be protected but are highly unlikely to be a source of LWD to the stream channel.

As an example of the calculation to determine buffer zone width, if the trees in the riparian corridor are about 50 feet tall, and at 10 feet from the top of the tree (40 feet up), the trees have a diameter which qualifies as large woody debris (i.e., is at least 12" in diameter), then the designated buffer zone should be 35 feet in width from each streambank (for a total buffer width of 70 feet wide, plus the width of the channel). Thus, a 50' tree at the margin of the 35 foot buffer zone which falls perpendicular to the channel will intersect the channel at 15 feet from its top. At 10 feet from the tree top the diameter qualifies as large woody debris. The additional 5 feet intersecting the channel satisfies the length requirement.

The following table provides examples of buffer zone widths using the above criteria for recruitment of LWD for typical maximum heights of mature trees in the Navarro watershed. The buffer zone widths are calculated based on the assumption that the top 20% of the total tree height is smaller than the diameter requirement (12") needed to qualify as LWD. The total buffer zone width is the last column of the table x2, plus the width of the channel.

Tree	Maximum Typical Height (ft)	Buffer Zone Width (ft from one streambank)
Redwood	300	245
Douglas Fir	200	155
Alder and Oak	100	75
Bay	75	55
Willow	30	19

A simple general rule-of-thumb landowners may wish to follow for establishing buffer strips to provide LWD recruitment and shading to help maintain cool water temperatures is to allow a minimum buffer width of 100-ft from the top of each streambank. This would result in a buffer zone width of 200-ft plus the width of the channel. Note, however, that a 100-ft buffer strip will not necessarily satisfy the LWD rule described above for all forest types.

4. Use native plants to revegetate riparian buffer strips (see RLMP 6.5.4 *Riparian Revegetation*).

5. To the extent possible, landowners should designate stream side areas for uses that do not disturb riparian vegetation, and which are not affected by periodic flooding.

   Over-bank flow onto floodplains is a natural process which provides sediments and nutrients which maintain healthy riparian corridors. Activities that disturb streambanks should be avoided or limited to the minimum amount necessary. Where such activities do occur. Landowners should plan and implement remedial revegetation and soil stabilization.

6. Landowners should control or eliminate grazing access to streamside areas (RLMP 6.5.1).

7. Aerial photos and planview assessment of proposed or existing projects can be helpful in determining areas of potential habitat fragmentation, and areas in need of restoration. Landowners, neighbors, and watershed groups can use aerial photos as a tool in formulating riparian management strategies, and for monitoring the results of riparian restoration efforts. The USDA Natural Resources Conservation Service can assist in interpretation of aerial photos and development of planviews. The Navarro Watershed Restoration Project has complete aerial photo coverage of the Watershed for 1952, 1965, 1981, and 1992 (see Section 8.0). The Mendocino County Assessor has 1996 aerial photos for the entire County.

8. Landowners should conduct field surveys of streams on their property to identify fish passage barriers such as culverts and dams. Such barriers may result in aquatic habitat fragmentation. The California Department of Fish and Game may be consulted regarding potential fish passage barriers and means of alleviating them. Landowners may also wish to refer to the *California Salmonid Stream Habitat Restoration Manual* for stream survey and restoration methods (see references).

Effectiveness

Protection and enhancement of riparian areas is crucial to the long-term recovery of the fishery and improvement of water quality, and without widespread conservation and restoration of riparian areas there is little hope for the success of this plan. The best treatment is prevention in areas where there is still relatively intact riparian habitat. However, riparian areas are remarkably dynamic and resilient, and, given the opportunity, are capable of relatively quick recovery from past disturbances.

Maintenance

Large scale aerial monitoring of riparian corridors can be a useful tool for identifying problems which are not visible from the ground, such as devegetation. Often, minor corrective action such as modification of a barrier, or revegetation, can resolve the problem and improve a significant section of the stream.

Using aerial photos and ground reconnaissance, riparian corridors can be evaluated on a yearly basis for habitat fragmentation and corrective actions taken.

Sketch Drawing

The attached drawing (Figure 6-11) depicts a schematic view of a hypothetical river. An intact riparian corridor is surrounded by adjacent land uses (north side of the river), and a fragmented riparian corridor is seen on the south side of the river. Land use changes -

such as devegetation, damming, culverting - which contribute to habitat fragmentation are shown.

6.5.4 RIPARIAN REVEGETATION

Description and Purpose

Revegetation using native plants is effective for enhancing habitat for numerous fish and wildlife species, as well as reducing upslope erosion and sedimentation to streams. Native plant revegetation can be an important tool in restoring structural and biological diversity to degraded riparian areas. The objectives of revegetation are to re-establish plant communities which provide habitat for fish and wildlife, and to facilitate the development of riparian forests which are self-sustaining. Provided that the physical features of the site remain intact (i.e., adequate hydrologic width in the stream corridor/diversity of landforms), revegetation can accelerate the establishment of diverse late successional plant communities and a dense canopy over the stream. Revegetation may include broadcast seeding of native grass or forbs on hillslopes, in-stream sprigging of dormant willow cuttings to increase cover and reduce bank erosion, installation of plants propagated in a native plants nursery, transplanting of emergent species such as rush, tule or sedge, or direct seeding of native species such as oaks or buckeyes.

Planning Criteria and Applicability

Revegetation is an important method for enhancing and restoring native habitats, and in many cases can be used to reduce surface erosion and sedimentation to streams. Although riparian vegetation can be very effective as a means to reduce bank erosion, it is normally not effective for the control of large scale land movements or erosion due to fluvial processes (e.g., lateral stream migration). Vegetation is adapted to respond to these physical processes, and the plant palette is determined by these processes.

A successful revegetation project needs to include the following considerations:

1. Revegetation should attempt to replicate the natural system. In the riparian zone, different species are adapted to distinct “microsites”, often based on elevation and proximity to the stream. Planning of a riparian revegetation project should take into account where each species occurs in a natural system. The attached conceptual cross sections of riparian vegetation depict appropriate planting sites based on elevation above the low flow channel.
2. Seeds or propagules (e.g., willow sprigs, emergent clumps, transplants) should be collected from as close as possible to the project site. This ensures that only

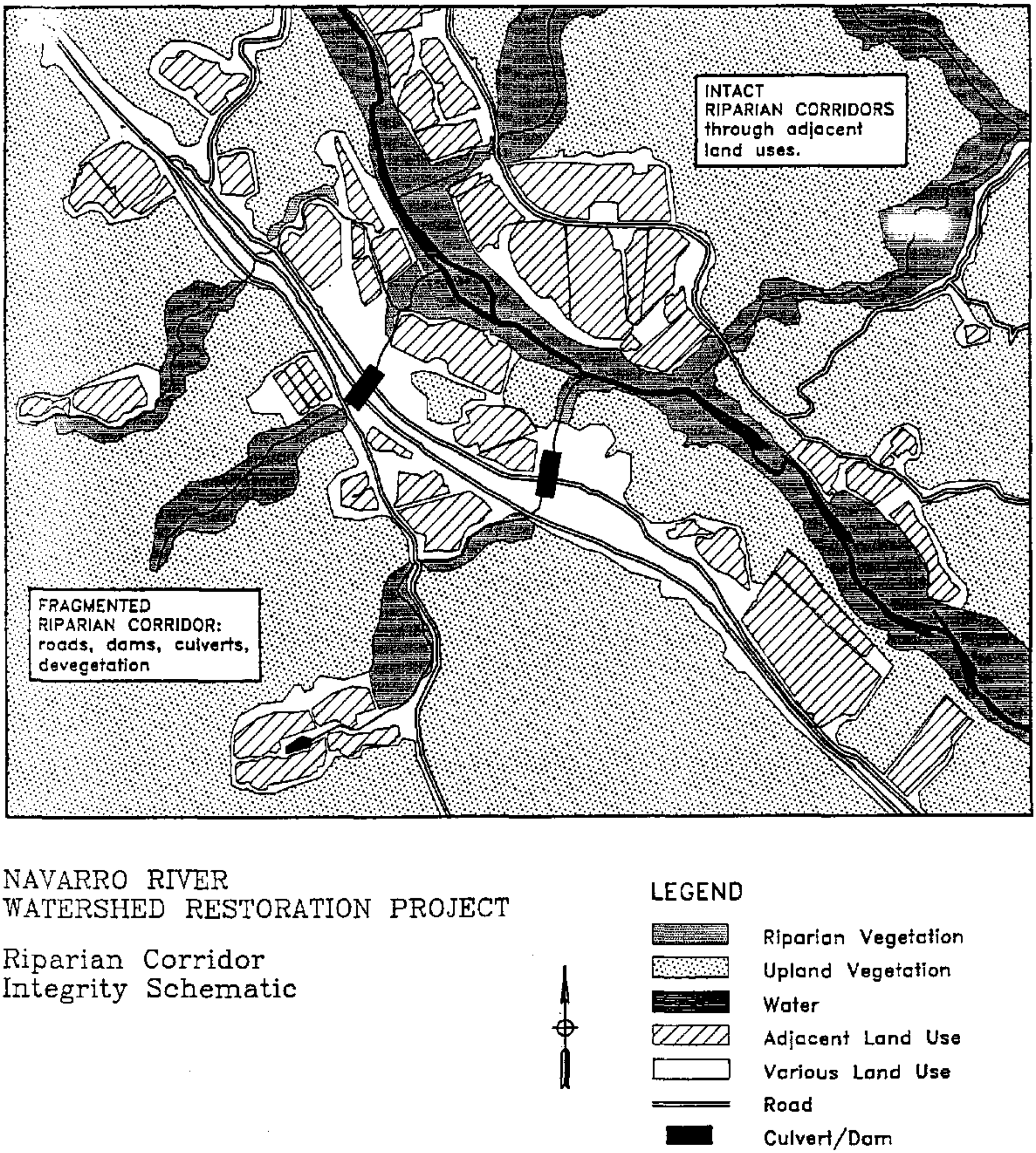


Figure 6-11. Riparian Corridor Fragmentation.

genetically appropriate plants (i.e., those that are adapted to local conditions) will be used on site. Introduction of plant material from outside of the Navarro watershed should be avoided.

3. Propagation of plant material in containers needs to begin up to 18 months prior to planned installation. For example, a particular species may have seed which ripens in June. After treatment of the seed and propagation in the nursery, the plant may not be ready for outplanting until the following Fall/Winter.

4. Installation of containerized and direct seeded plants should take place in the Fall/Winter, after several significant rainstorms have resulted in high soil moisture levels.

5. Broadcast seeding of native grasses and forbs should take place prior to October 30 of each year to ensure adequate time for seed germination prior to heavy rain and cold weather.

6. In general, planting in the active channel is not recommended. If there is a severe bank erosion problem, or the system has lost all upstream sources of seeds and propagules, some active channel revegetation may be warranted. Because the active channel is subject to regular flooding, installed plants are subject to removal. Willow sprigs, which are adapted to this floodway environment, are an effective, relatively inexpensive way to stabilize a streambank or introduce cover to the stream. Plants installed in the active channel should not have protective hardware as they may be subject to regular scour, and the plant will be more susceptible to wash-out. In addition, the hardware deposited downstream is a form of litter, and may pose a hazard to aquatic organisms.

Methods and Materials

Sources of Native Plants and Seeds:

Native and Erosion Control Seed

Anderson Valley Farm Supply
7050 Highway 128
Philo, CA 95466
(707) 895-3655

Harmony Farm Supply
3244 Gravenstein Highway North
Sebastopol, CA 95472
(707) 823-9125

LeBallisters
1250 Sebastopol Road
Santa Rosa, CA 95401

(707) 526-6733

Pacific Coast Seed
6144 A Industrial
Livermore, CA 94550
510-373-4417

S & S Seeds
P. O. Box 1275
Carpinteria, CA 93014
(805) 684-0436

Native Plant Nurseries (plants for revegetation)

Anderson Valley Nursery
18151 Mountain View Road
Boonville, CA 95415
(707) 895-3853

California Conservation Corps Nursery
P.O. Box 7199
Napa, CA 94558
(707) 253-7783

Circuit Rider Productions, Inc.
9619 Old Redwood Highway
Windsor, CA 95492
(707) 838-6641

Cornflower Farms
P. O. Box 896
Elk Grove, CA 95759
916-689-1015

Costs

Costs for revegetation vary widely depending upon the approach. Following are some representative prices for projects implemented by landowners or community groups:

erosion control seed:	$2.00-10.00 per pound Typical application rate is 50-60 pounds per acre

native seed:	$10.00-120.00 per pound Typical application rate is 10-20 pounds per acre
native plants	
liner:	$1.65 each
deepot:	$2.50 each
one gallon treepot:	$4.00 each
tree shelters:	$1.30 each
fertilizer tablets:	$0.10 each
consulting restoration ecologist:	$35-50 per hour

Sketch Drawing

1. Typical riparian vegetation cross sections:

    Anderson Creek and Flynn Creek (Figure 6-12)
    Robinson Creek and Mainstem Navarro (Figure 6-13)

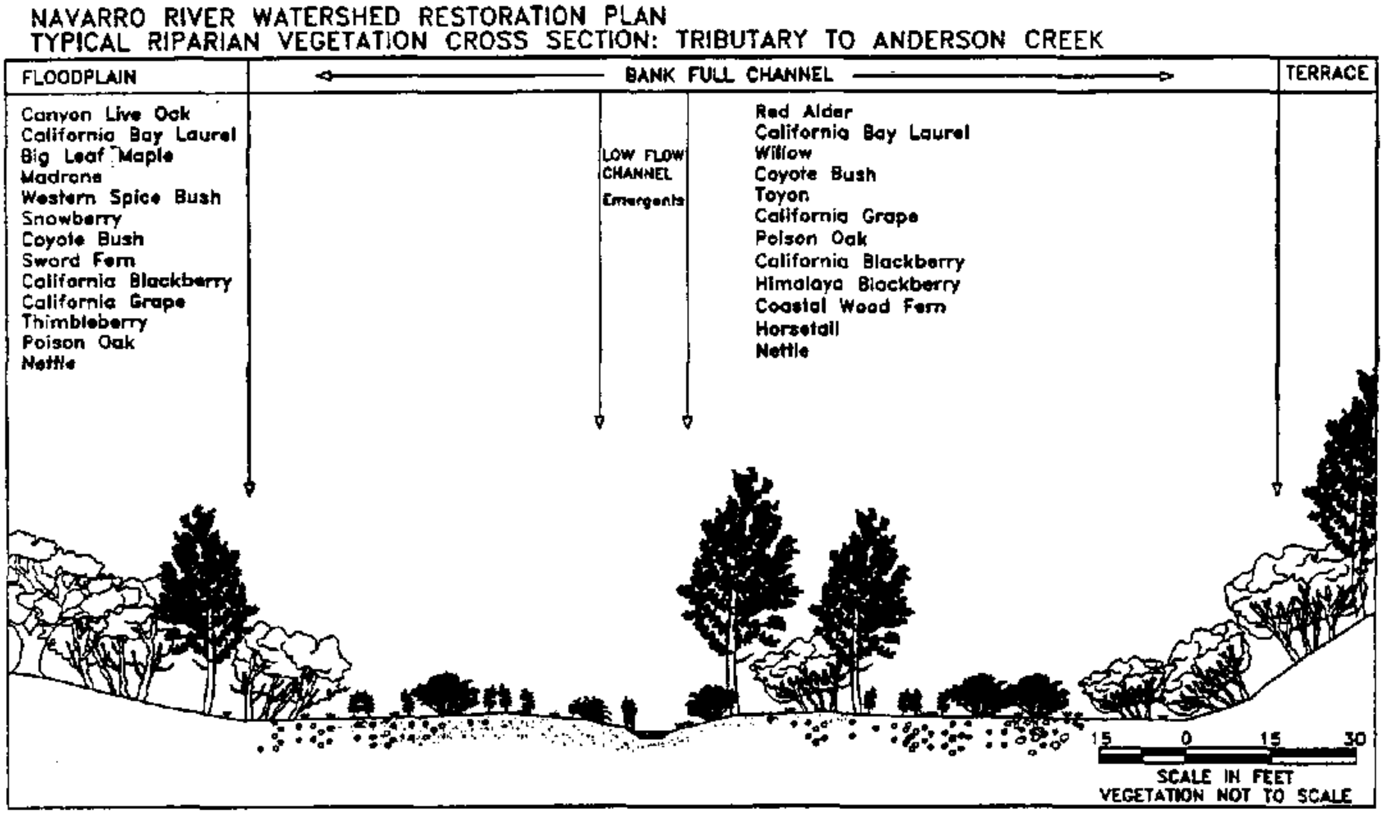
The attached drawings represent cross sections for four stream systems in the Navarro watershed, including a year round coastal tributary (Flynn Creek), an intermittent stream which runs through a dry upland environment (South Fk. Robinson Creek), the mainstem Navarro River, and an alluvial tributary with a wide floodplain (Anderson Creek).

The cross sections are based on field surveys, with representative vegetation shown at various elevations. Note the differences in plant species depending upon the diverse physical site characteristics. This type of cross section can be developed by landowners and community groups at several locations throughout the stream reach as a method for developing a revegetation plan. If survey equipment is not available, a simple version of this method can be accomplished using a hand level (available at hardware stores for under $5) and a 30 foot measuring tape.

2. Revegetation Specifications:

    Dormant Willow or Cottonwood Sprig Installation (Figure 6-14
    Direct Spot Seeding (Figure 6-15)
    Supertube Planting Detail (Figure 6-16)
    Liner Planting Detail (Figure 6-17)
    Planting Installation Detail (Figure 6-18)
    Emergent Vegetation Installation (Figure 6-19)

There are often significant differences in riparian plant communities depending upon climate, slope, soils, topography, and watershed size of a given stream. Revegetation project design should include an understanding of the plant community found in the particular stream section being restored. Even within the corridor of a particular stream reach, different plants are adapted to different elevations and levels of flood inundation.



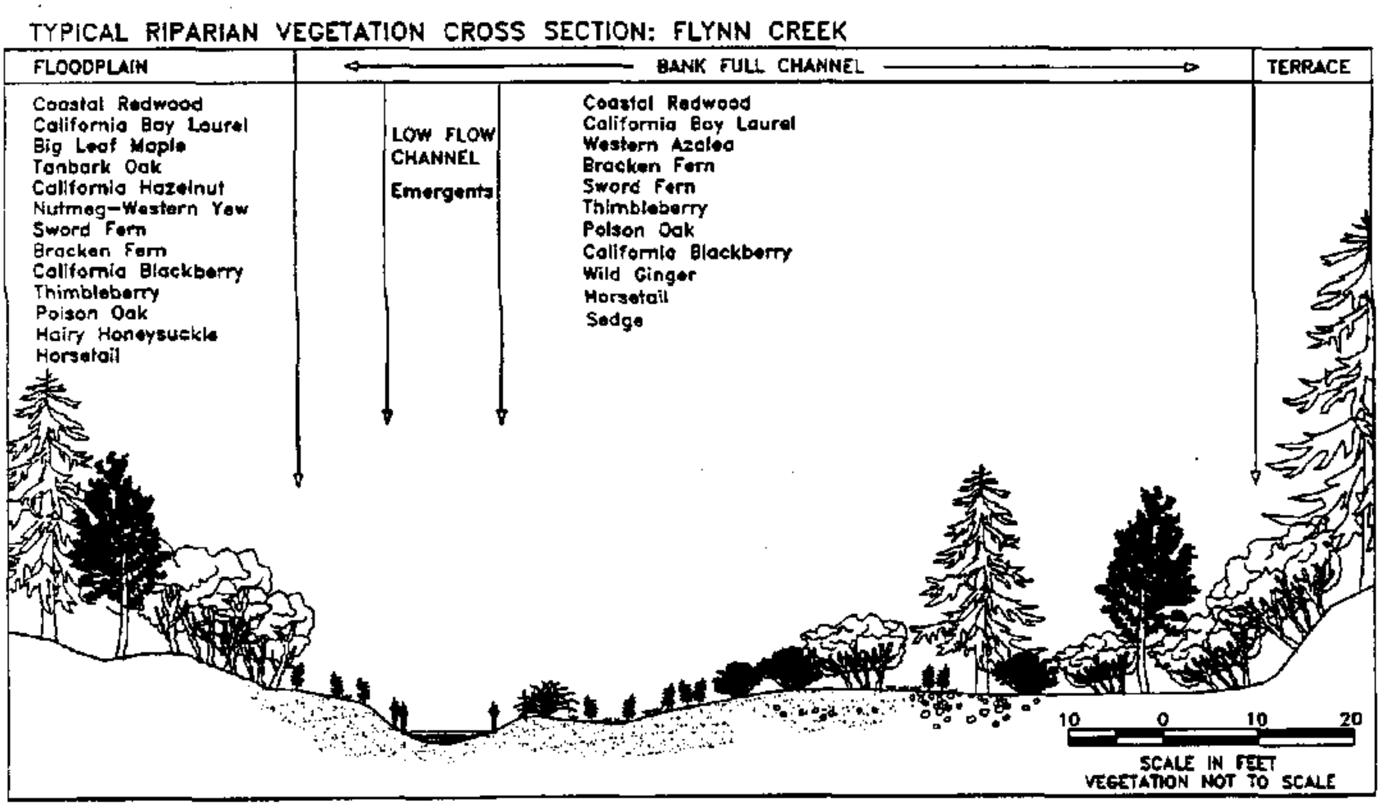
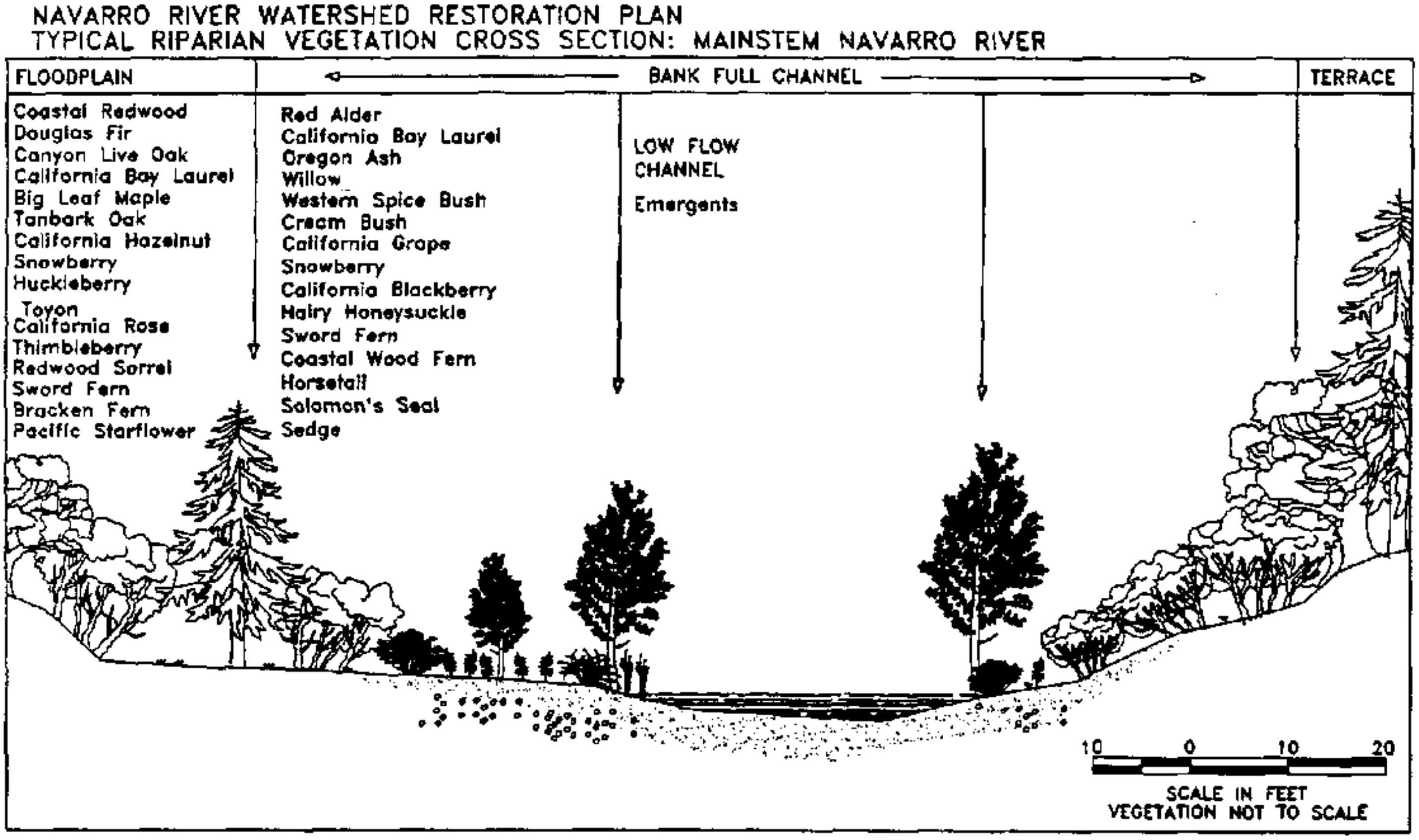


Figure 6-12. Cross-section Anderson Creek and Flynn Creek.



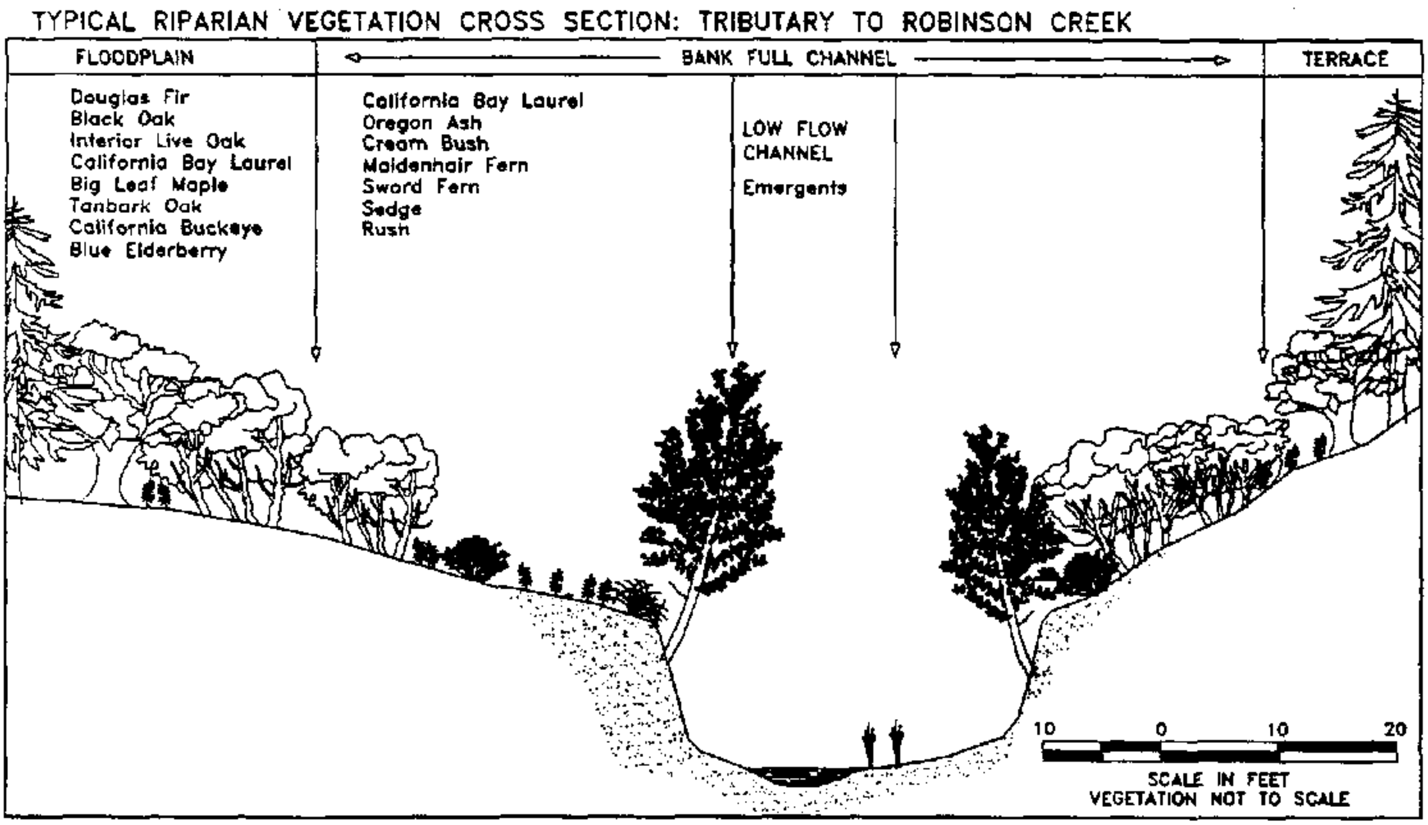


Figure 6-13. Cross-section Mainstem Navarro and Robinson Creek.

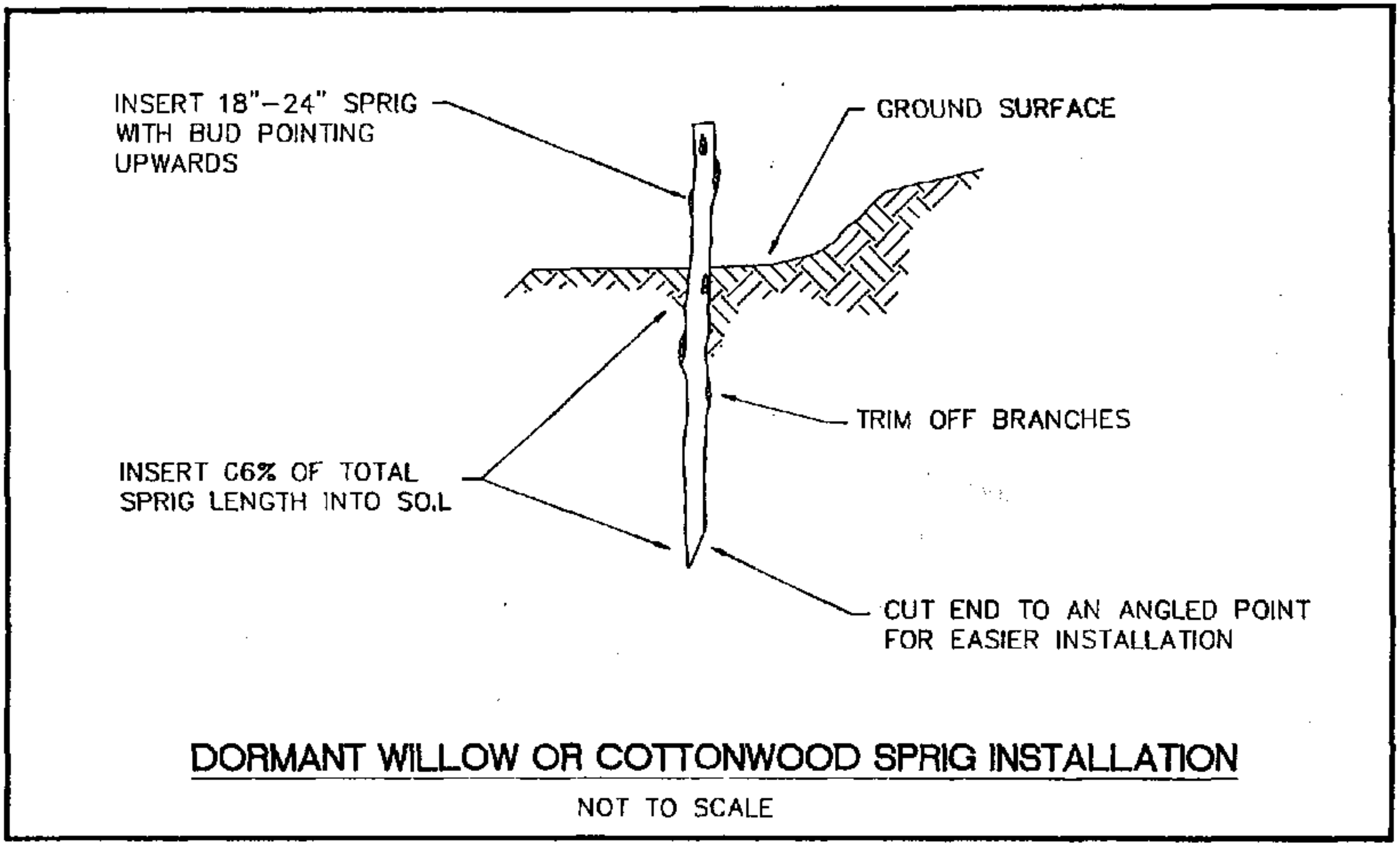


Figure 6-14. Dormant Willow or Cottonwood Sprig Installation.

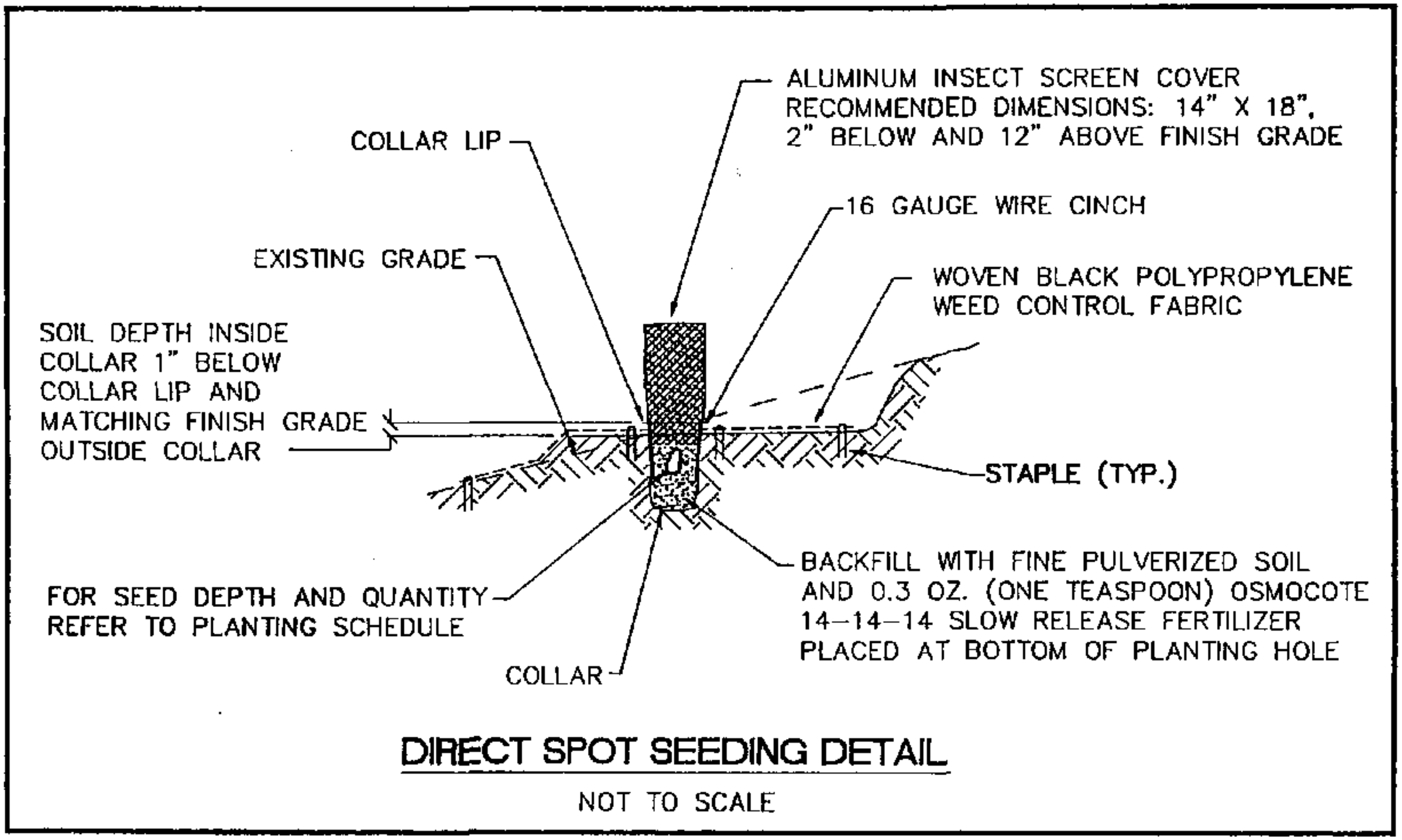


Figure 6-15. Direct Spot Seeding Detail.

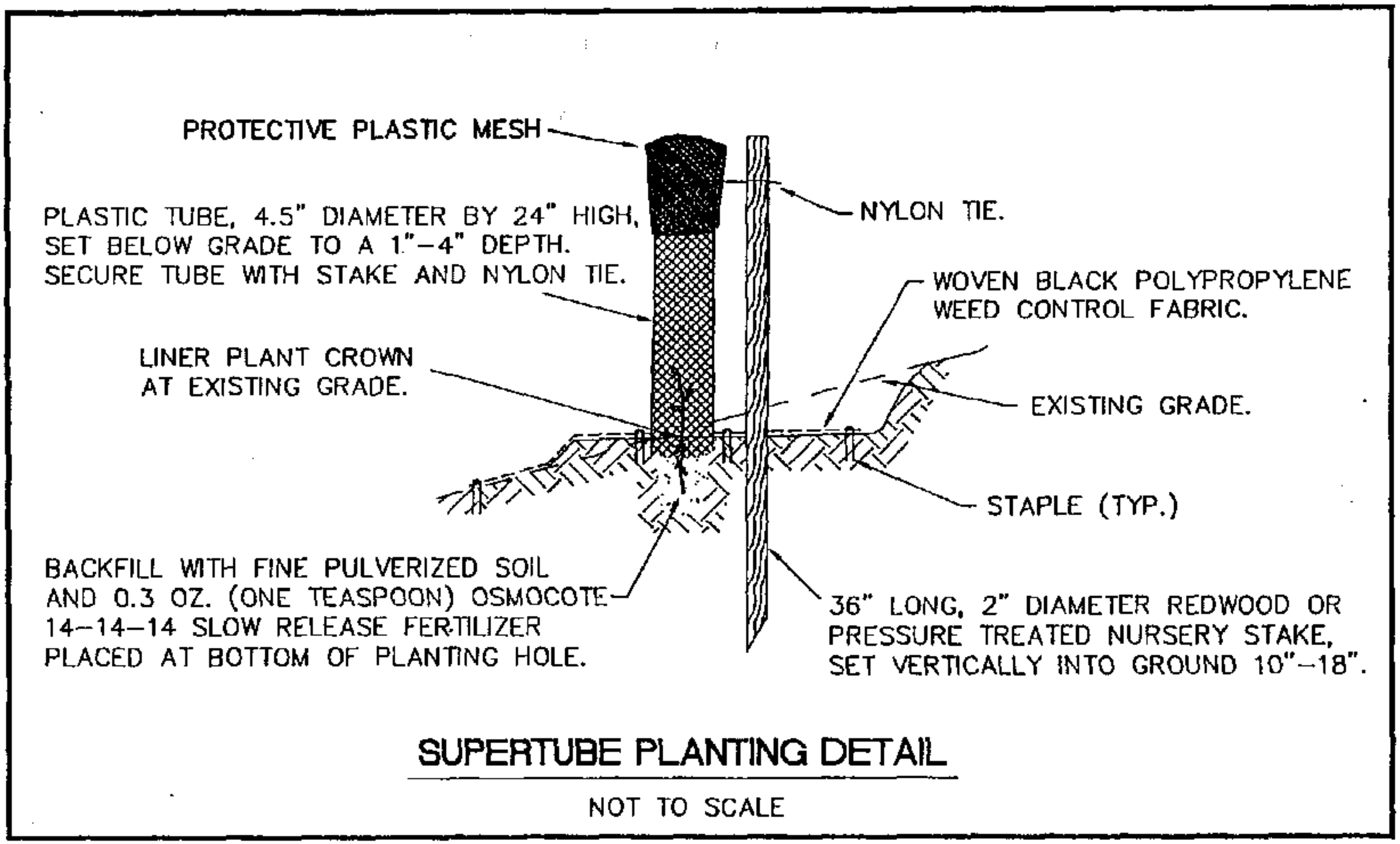


Figure 6-16. Supertube Planting Detail.

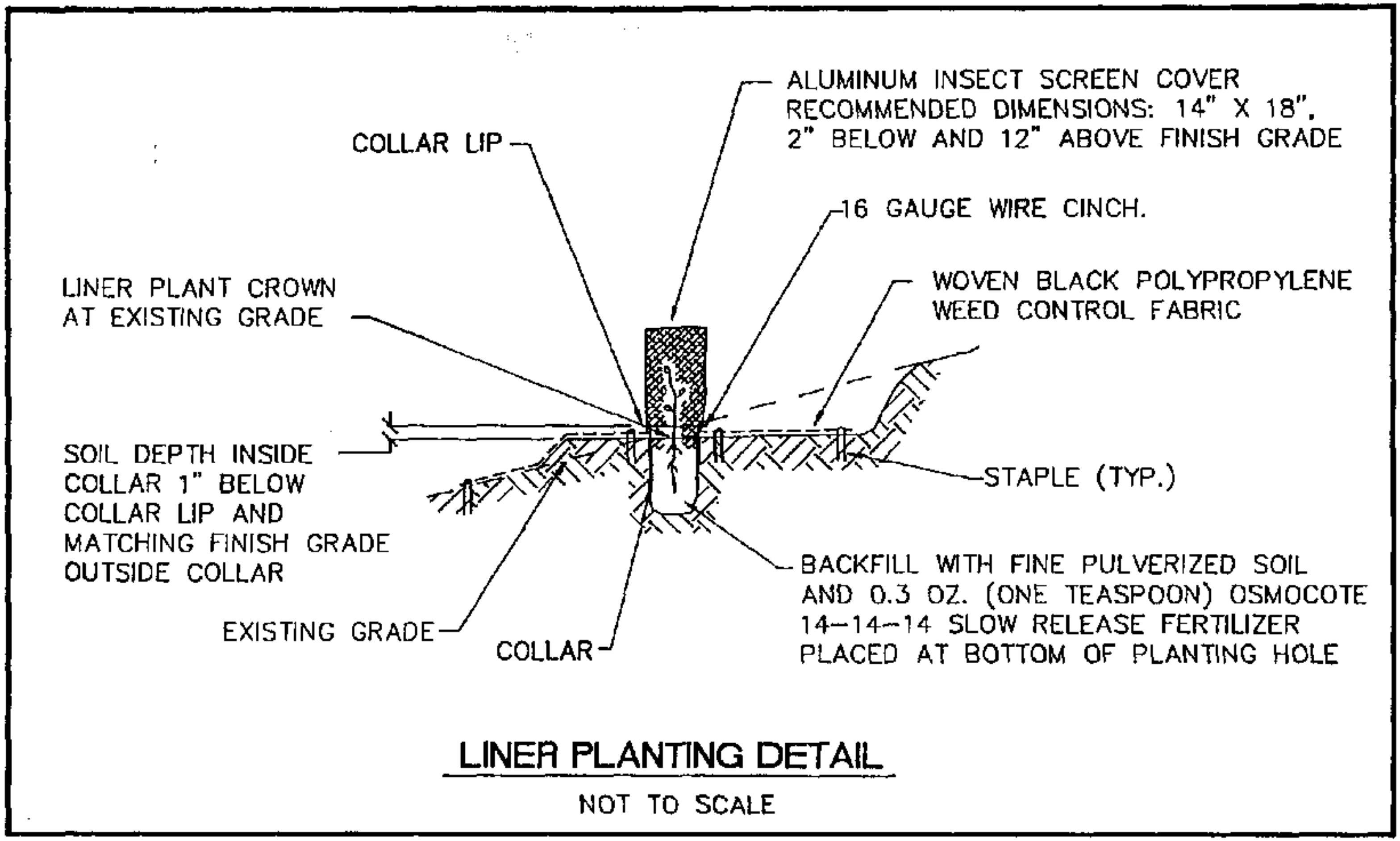


Figure 6-17. Liner Planting Detail.

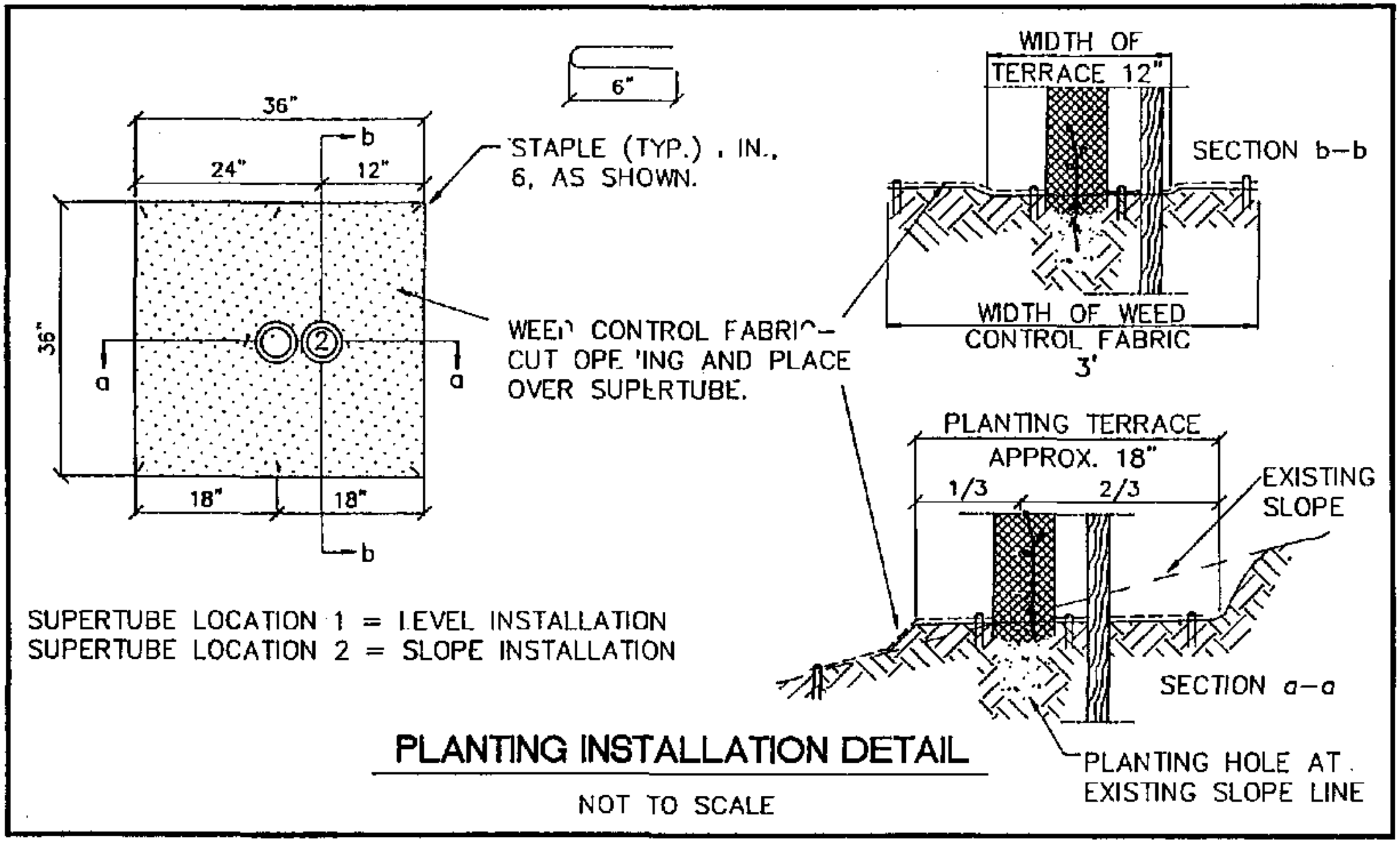
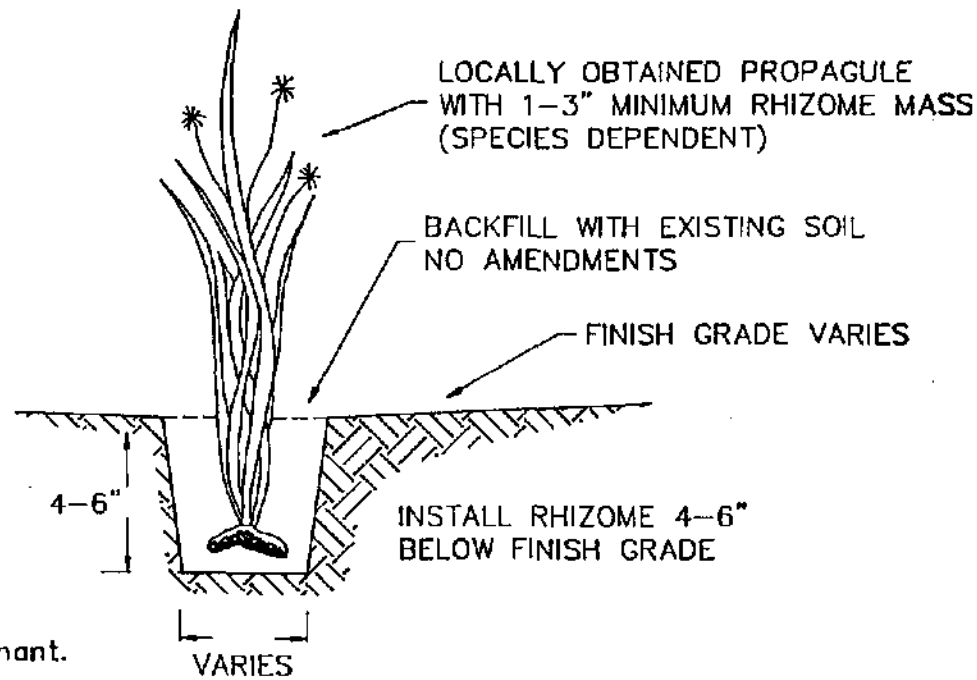


Figure 6-18. Planting Installation Detail.

1. Excavate planting hole sufficient to receive emergent plant and rhizome.
2. Proposed finish grade varies.
3. Collect emergent plants from healthy populations on adjacent sites.
4. Keep emergent plants moist and protected from sunlight from time of collection to time of installation.
5. Install emergent plants on same day as collected.
6. Collect emergent plants in discontinuous patches to avoid excessive disturbance to existing populations.
7. Planting shall occur Nov.–April when emergent plants are dormant.



EMERGENT VEGETATION INSTALLATION

NOT TO SCALE

Figure 6-19. Emergent Vegetation Installation.

Common perennial species found in the Navarro River watershed riparian area and adjacent upslope areas are listed below. Note that this is not an exhaustive list of all species which may occur in the riparian zone, and only includes a limited number of species found in upslope areas, usually those adjacent to riparian corridors within the Navarro watershed.

TREES

Black Cottonwood	*Populus trichocarpa*
Canyon Live Oak	*Quercus chrysolepis*
California Bay Laurel	*Umbellularia californica*
Big Leaf Maple	*Acer macrophyllum*
Madrone	*Arbutus menziesii*
Red Alder	*Alnus rubra*
White Alder	*Alnus rhombifolia*
Willows	*Salix sp*.
Black Oak	*Quercus kelloggii*
Interior Live Oak	*Quercus wislizenii*
California Buckeye	*Aesculus californica*
Oregon Ash	*Fraxinus latifolia*
Douglas Fir	*Pseudotsuga menziesii*
Coast Redwood	*Sequoia sempervirens*
Tanbark Oak	*Lithocarpus densiflorus*
Nutmeg	*Torreya californica* (rare)

SHRUBS

Western Spice Bush	*Calycanthus occidentalis*
Snowberry	*Symphoricarpos alba*
Coyote Bush	*Baccharis pilularis*
California Wild Rose	*Rosa californica*
Toyon	*Heteromeles arbutifolia*
Himalaya Blackberry	*Rubus discolor* (non-native invasive)
California Hazelnut	*Corylus cornuta*
Western Azalea	*Rhododendron occidentale*
Blue Elderberry	*Sambucus mexicana*
Huckleberry	*Vaccinium ovatum*
Cream Bush	*Holodiscus discolor*
California Blackberry	*Rubus ursinus*
Thimbleberry	*Rubus parviflorus*
Poison Oak	*Toxicodendron diversilobum*

VINES

California Grape	*Vitis californica*
Honeysuckle	*Lonicera hispidula*

FERNS

Bracken Fern	*Pteridium aquilinum*
Redwood Sword Fern	*Polystichum munitum*
Maidenhair Fern	*Adiantum jordanii*
Coastal Wood Fern	*Dryopteris expansa*

EMERGENTS

Sedges	*Carex sp.*
Rushes	*Juncus sp.*

MISCELLANEOUS

Wild Ginger	*Asarum caudatum*
Horsetail	*Equisetum sp.*
Slim Solomon	*Smilacina stellata*
Fat Solomon	*Smilacina racemosa*
Nettle	*Urtica dioica*
Redwood Sorrel	*Oxalis oregana*
Periwinkle	*Vinca major* (non-native invasive)

Maintenance

If native plants are locally collected, planted in the correct location, and installed correctly at the right time of year, minimal maintenance will be required. Plantings should be checked for excess browse by rodents, insects or deer, weed competition, and drought stress. To encourage successful establishment, plants can be hand irrigated with a small amount of water during the first summer, and weeds can be removed around the base of each plant in the Fall and Spring. If hardware is being used to protect the plant, it should be checked several times during the growing season to ensure that it is not restricting plant growth. After the plant is established (usually 2-5 years) hardware should be removed.

6.5.5 Grazing/Range Management

Description and Purpose

Rangelands are an important economic land-use activity in the Navarro River watershed. Appropriate grazing and range management help to reduce soil erosion and ensure pasture productivity while maintaining stream health.

In general, grazing of upslope locations in the Navarro watershed does not appear to result in areas extensively denuded of grass, forbes, or other ground cover vegetation. Over-grazing is indicated by a lack of ground cover vegetation which typically leads to sheetwash erosion on hillslopes. Sheetwash erosion has not been identified as a significant contributor to sedimentation of streams in the Navarro watershed (see Section

3.0). However, gullying is an erosion process which has been identified as a significant sediment production source, particularly in grass-and-oak woodland. Over-grazing is a land-use activity which can initiate the formation of gullies. Grazing and range management techniques can be employed to increase vegetative cover and forage production, while preserving soil integrity and preventing sedimentation of streams due to sheet, gully and splash erosion.

Planning Criteria and Applicability

There are a wide variety of range management techniques available to reduce hillslope erosion and sedimentation of streams. Implementation of a specific range management program is based on the experience of the landowner, and is dependent upon a variety of factors, including:

1. type of livestock;
2. slope, topography, rainfall;
3. soil type;
4. presence of exotic plant species;
5. quality of forage material;
6. economic considerations;
7. practicality.

With a few exceptions, the following recommendations are conceptual in nature, and are suggested for consideration when developing a grazing/range management program for a specific property. The preferences of the property owner, with consultation from public or private range management professionals as needed, will determine the particular management approach.

Methods and Materials

Reduction of sedimentation from hillslopes can be achieved in a variety of ways, including:

1. maintaining appropriate livestock stocking rates;
2. controlling livestock distribution through watering, rotation, salting, herding & fencing;
3. altering the time of grazing;
4. increasing vegetative cover through seeding and fertilization;
5. rest-rotation grazing;
6. retention of adequate mulch for erosion control and sustained forage production.

The majority of the open rangelands in the Navarro basin are dominated by annual grasses and forbs. The Natural Resources Conservation Service (NRCS) recommends retention of the following amounts of Residual Dry Matter (RDM) on annual rangelands:

Slopes less than 30%:	1000 pounds per acre
Slopes greater than 30%:	1200 pounds per acre

NRCS recommends that on sites producing 1000 pounds per acre or less, 50 percent of the current year's growth should be left as mulch. This RDM may be adjusted according to site-specific characteristics. Detailed tables (McDougald *et al.* 1991) for estimating RDM and grazing capacity (animal unit months/acre) associated with various slope classes and percent of canopy cover can be obtained from UC Cooperative Extension in Ukiah. The tables are best used to determine initial livestock stocking rates or to estimate proper levels of grazing use.

RDM provides favorable microenvironments for early seedling growth, soil protection, adequate soil organic matter, and a source of low-moisture fall forage for livestock feed (Clawson *et al.* 1982). Stocking rates should be adjusted according to RDM available. RDM availability can be estimated using visual or weight determination methods. Visual methods check the RDM remaining prior to fall rains, using established photos of grazing intensity standards developed for central valley foothills at the San Joaquin experimental range. The photo standards are used for comparison to estimate RDM conditions on landholders' grazing properties. Weight methods are estimated by direct clipping and weighing. The procedure requires clipping over a small sample area (one square foot or 1/10 square meter), weighting the air-dried samples, and calculating the pounds per acre of RDM. Ten to fifteen weight samples are recommended for uniformly representative areas. More detailed descriptions of weight and photo methods for estimating RDM and suggested guidelines for appropriate amounts of RDM (Clawson *et al.* 1982) can be obtained from the UC Cooperative Extension. Landowners may also refer to the California Rangeland Water Quality Management Plan (see references).

Other measures and recommendations for controlling livestock grazing to protect riparian areas are discussed under RLMP 6.5.1.

Maintenance

Rangelands should be monitored for plant cover/forage response to various management strategies, and techniques modified depending upon trends in range condition.

Effectiveness

A long term, comprehensive range and grazing management program can include objectives to reduce runoff and siltation of streams while increasing range production.

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6.6 ROAD-RELATED EROSION CONTROL AND PLANNING

Roads[11] are a major source of erosion and stream sedimentation on most managed forest, ranch and agricultural lands, as well as in areas of land subdivision, development and construction. Roads developed for almost any purpose, including logging, ranching (grazing), farming (including vineyards and orchards) and residential uses, can cause accelerated erosion and sediment delivery to streams. Road construction exposes large

[11] Roads are here defined as vehicle access routes developed for both commercial and non-commercial use. They include public and private roads developed (or now used for) residential access, recreation, commercial activities, and other land uses. Generally, they do not include off-road trails built for hiking or equestrian use, motorcycles, bicycles, or ATV's, or trails constructed by tractors for logging (yarding) or control of wildfires or prescribed burns. These routes have their own erosional impacts, but their construction and use is not described here.

areas of bare soil which is subject to rapid erosion. Compacted road surfaces increase the rate of runoff, and road cuts intercept and bring groundwater to the surface. Ditches concentrate storm runoff and transport sediment to nearby stream channels. Culverted stream crossings can plug, causing fill wash outs or gullies where the diverted stream flow runs down nearby roads and hillslopes.

Roads built on steep or unstable slopes may trigger landsliding which deposits sediment in stream channels. Filling and sidecasting increases slope weight, road cuts remove slope support, and construction can alter groundwater pressures, all of which may trigger landsliding. Unstable road or landing sidecast materials can fail, often many years after they were put on steep hillslopes. Lack of inspection and maintenance of drainage structures and unstable road fills along old, abandoned roads can also result in soil movement and sediment delivery to stream channels.

The overall approach for managing and controlling road-related erosion and impacts within an ownership and in the Navarro watershed should follow a three pronged strategy. This three pronged strategy for roads can be applied on any scale: a single ownership, a subdivision, or the entire watershed. It consists of the following elements: first, an inventory of all roads is undertaken to identify existing and potential sediment sources that could impact stream channels and downstream aquatic habitat (as well as other beneficial uses). From this a transportation plan is developed for each property and for the watershed as a whole. Second, all abandoned and high risk roads are decommissioned. Third, roads (and drainage structures) which are to be retained in the watershed are upgraded to current standards, including the capability of drainage structures and fillslopes to withstand the 50-year storm without failure and with minimal damage.

The first step in controlling road-related erosion on a watershed-wide basis is to inventory all active and potential road related sediment sources, as described in RLMP 6.6.1, *Inventory Existing and Future Road-related Sediment Sources*. Planning for de-commissioning roads on a watershed-wide basis, and a description of the methods used to decommission roads is provided in RLMP 6.6.2*, Decommissioning Abandoned and High Risk Roads*. Erosion-proofing and storm-proofing measures to prevent future erosion and sedimentation are provided in RLMP 6.6.4, *Road Upgrading Practices*, and further described in detail in RLMP's 6.6.5 through 6.6.10. Annual practices to prevent road-related erosion is described in RLMP 6.6.11, *Road Maintenance Practices*.

6.6.1 INVENTORY EXISTING AND FUTURE ROAD-RELATED SEDIMENT SOURCES

Description and Purpose

The results of the sediment budget prepared for this project indicate that roads are one of the main human-induced, and controllable, sediment sources in the Navarro River watershed (see Section 3.0, Table 3-2). Excessive fine and coarse sediments are identified as a source of water quality degradation for both human uses and fish habitat. Sediment-related impacts to fish habitat include loss or reduction of pool volumes and numbers, reduced habitat complexity and fine sediment impacts to spawning gravels (see Section 4.0). To prevent continued impacts, landowners should conduct a comprehensive inventory of roads on each ownership or in each sub-watershed to identify and prioritize treatments for road-related sediment sources. Only those sources of erosion which could deliver sediment to a stream channel need be included in the inventory. The inventory will allow for the development and implementation of cost-effective erosion prevention work along all roads within the ownership or sub-basin. Treatments are meant to control erosion and, at the same time, reduce maintenance costs to the landowner.

Many types of roads exist in the Navarro and each has its own characteristic problems and needs. Roads have three major classes of impacts. First, roads alter the way water moves down the hillslope, often increasing and/or concentrating runoff and diverting flow. Roads also increase the risk of landsliding, especially when they are constructed by sidecasting on steep slopes. Finally, road surfaces accumulate runoff during heavy rains and often discharge this muddy water to stream crossing culverts.

Roads can be classified as permanent (all-season), seasonal or temporary, and as abandoned or maintained. Permanent roads (usually rock surfaced) are subject to winter use and fine sediment erosion. Seasonal and temporary roads are usually unsurfaced and can be damaged by wet weather use. Roads can also be classified as abandoned (unused, and sometimes overgrown) and active (open and maintained) routes. Abandoned roads need to be "put-to-bed" to eliminate unnecessary erosion. Maintained roads should be brought up to current standards to ensure that they will weather large storms without causing significant erosion.

When all roads within a sub-basin or ownership have been inventoried, it will be possible to develop a prioritized list of roads for eventual closure (decommissioning) and erosion-proofing (upgrading) based on their potential for sediment delivery to streams. The analysis and inventory should identify and quantify all potential sediment sources, and provide a list of recommended treatments and treatment costs.

Planning Criteria and Applicability

Road erosion inventories for existing and potential sediment sources must be conducted in a systematic, organized manner. That is, a number of specific, pre-defined observations must be recorded, certain measurements taken, and technically accurate conclusions drawn in the field. Without the core of necessary, accurate information, the inventory data will lack the "authority" needed to provide meaningful, relevant, cost-effective solutions to the most important erosion problems in the watershed or on the ownership.

Road inventories are one part of a three prong strategy for identifying, and controlling or preventing road-related erosion within an ownership or a watershed. First, roads are inventoried and a transportation plan for the watershed (or ownership) is prepared. Secondly, all abandoned and high risk roads are identified and scheduled for temporary or permanent decommissioning. Finally, all retained roads are upgraded to current standards to minimize both chronic and episodic (storm-related) erosion and sediment delivery. This third step is sometimes called "storm-proofing."

Inventories are typically performed by a trained geologist or erosion control specialist, or by field technicians who have received field training and whose work is overseen (for quality control) by a professional. All roads, both abandoned and maintained, are inventoried for active and potential sediment sources. Information collected during the survey includes basic location and site data, data on the nature and magnitude of erosion and the potential for sediment delivery to a stream channel, and data needed to develop treatments and estimates for equipment and labor tasks, including costs. Inventory information typically includes stream crossings; unstable fill slopes (which could fail by landsliding); cut banks, ditches and road surfaces which drain to streams; and other erosion features (including gullies and cutbank landslides) which could deliver sediment to a stream.

Methods and Materials

It is necessary to follow an organized, systematic series of steps in assessing sites of existing and potential road-related erosion. As the first step, an air photo analysis of the watershed or ownership is conducted to help reveal the location of all abandoned and maintained roads, and to determine the road construction history (date of construction) of each road to be inventoried in the field. It is important to identify all the roads that have ever been constructed in the watershed or in the area in question, whether they are currently maintained and driveable, or are now abandoned and overgrown with vegetation. For larger landowners, a preliminary transportation plan is developed at this time, outlining the best long term permanent and seasonal road network needed to manage natural resources.

In the second step, major, potentially treatable or preventable sources of erosion and sediment yield are identified through field inventories and prioritized for treatment during field mapping. For the detailed field assessment, acetate overlays are attached to 9" x 9" aerial photographs and used to record site location information as it is collected in the field. Information recorded on these overlays includes road location, site number and location (road mileage), type or classification of site, erosion features (stream-side landslides, debris torrents, potential debris slides, gullies and gullied stream channels, washed out stream crossings, etc.), stream channels, stream crossings, landings and all culvert locations. GPS (global positioning) technology (if available) can also be used to identify the location of sites for GIS (computer mapping) applications.

A computer database (data form) is filled out with detailed information about each site of potential sediment yield identified in the field. Ideally, the database form is a standard design that all landowners in the watershed will use to characterize problems and develop treatment prescriptions. Depending on the classification of a site (stream crossing, debris slide, gully, road and cutbank erosion, stream side slides, etc.), different portions of the database form are filled in with the relevant information. Basic information is collected for every site. The detailed data collected in the field includes, at the very least, the following information: 1) a unique site number, 2) the location of the site, 3) the type of erosion problem, 4) an estimate of the volume of sediment that would be eroded and delivered to a stream if treatment is not undertaken, 5) the recommended treatment (including estimates of equipment and labor time) and 6) estimated costs.

In the field, identified sites are first classified according to their potential for sediment delivery to stream channels. It is typically the larger sites that account for most of the accelerated (land use related) sediment yield from a watershed. Very small sites are often not worth inventorying. Therefore, it is important to identify a lower threshold of sediment yield below which a site is not identified in the field inventory. In most watersheds, this minimum site size may range from 10 yds^3 to 50 yds^3, depending on the watershed. It is often sufficient to identify those sites where there is a potential to yield at least 25 yds^3 of sediment to a stream channel, as well as the more diffuse or chronic sediment sources such as road surfaces, ditches and cutbanks.

During road system inventories, special attention should be paid to all stream crossings, all stream crossings with a high diversion potential (DP) (where flow would divert down the road if the culvert plugs) and stream crossings with a high failure potential (FP)(e.g.., undersized culverts). Based on past inventory work, each of these categories of stream crossings are assumed to have a high potential for delivering sediment to stream channels. Erosion and failure of stream crossings on abandoned and unmaintained roads, in particular, is likely to eventually occur when culverts plug during large storms. Once erosion has been initiated, sediment lost from these locations will be delivered directly into small streams and, eventually, to the larger fish-bearing streams.

Visibly unstable fillslopes, unstable log landings and unstable hillslopes crossed by either abandoned or maintained logging roads should also be described, especially if they threaten to deliver sediment to a down slope stream channel. To be visibly unstable, the identified site usually exhibits tension cracks, vertical scarps, excessive sidecast on steep slopes and in swales, springs, leaning trees, or other geomorphic evidence suggesting past or pending slope failure.

Once sites are identified and prioritized, general prescriptions for erosion control and erosion prevention are developed for each major source of treatable erosion that, if left untreated, would likely result in sediment delivery to streams. During the field inventory of existing and potential erosion sources, a more detailed analysis of each significant site is performed. This step includes an analysis of the most effective and cost-effective erosion prevention and/or erosion control work that could be applied to each of the sites recommended for treatment, including all sites classified as having a high, moderate or low priority for treatment. *Recommended treatments are generally prescribed only for sites with a potential for future erosion and sediment yield because they are the only ones capable of delivering sediment to downstream fish-bearing stream channels.* Cost-effectiveness evaluation will provide a method for prioritizing all inventoried sites and defining where work should be implemented first.

The analysis of each recommended treatment site includes generalized heavy equipment and labor-intensive prescriptions, as well as procedures, cost estimates and equipment times needed for effective treatment. The sites selected for eventual treatment are the ones that are expected to generate the most cost-effective reduction in sediment delivery to the drainage network and the mainstem stream channel. Sites which may experience erosion or slope failure, but which are not expected to deliver sediment to a stream channel, are not recommended for treatment to protect fisheries resources. General treatments are cataloged in the computer database during field examination of each site. The specifics of the recommended treatments, as well as costs and logistics (equipment types, excavation volumes, equipment hours, etc.) are outlined in this step.

If a sediment source assessment is done well, the logical next step will be for skilled equipment operators, laborers, and erosion control specialists to implement those projects deemed most cost-effective and most beneficial to long term watershed health and the protection of fisheries resources. Implemented projects can consist of both erosion control and erosion prevention work. As a final step in the process, a revegetation program is then implemented on areas exposed by the heavy equipment during erosion prevention work. Revegetation should incorporate both short term erosion control (developing a rapid ground cover) as well as long term revegetation to reestablish the native vegetation.

Maintenance

With the use of trained personnel, the erosion inventory methodology will be accurate in identifying many existing and future sediment sources along roads. However, as time passes new sites of erosion or potential erosion are likely to express themselves and a regular program of road inspection (especially of culverts and fillslopes) and maintenance is needed to minimize future sediment yield from roads in the watershed. The road inventory, once completed, will need updating, with new sites added as they become apparent and old sites removed as they are finally treated.

Effectiveness

Perhaps the most critical step in implementing work outlined in the erosion inventory is determining where money should be spent first. In other words, with limited funding (as is always the case) what is the most important thing to do first? Sites that have been recommended for treatment should be ranked in order of their relative "cost-effectiveness." Requiring proposed work to meet pre-established cost-effectiveness criteria is critical to developing a defensible and objective watershed protection and restoration program. *The cost-effectiveness of treating a work site is defined as the average amount of money spent to prevent one cubic yard of sediment from entering or being delivered to the stream system.* It is usually expressed in units of "$\$/yd^3$" (dollars spent to prevent a cubic yard of sediment from entering a stream channel).

Cost-effectiveness is determined by dividing the cost ($) of accessing and treating a site, by the volume of sediment prevented from being *delivered* to local stream channels. For example, if it would cost $2,000 to access and treat an eroding stream crossing that would have delivered 500 yds^3 (had it been left to erode), the predicted cost-effectiveness would be $\$4/yd^3$ ($2,000/500 yds^3). By using this evaluation methodology a variety of different techniques and proposed projects can be compared against each other using the same criteria: reducing accelerated erosion and keeping eroded sediment out of the watershed's streams.

6.6.2 Decommissioning Abandoned and High Risk Roads

Description and Purpose

Good land stewardship requires that roads either be maintained or intentionally closed ("put-to-bed"). The old practice of abandoning roads, by either installing barriers to traffic (logs, "tank traps" or gates) or simply letting them naturally revegetate, is no longer considered acceptable. These roads continue to fail and erode for decades following abandonment. The proper word for proactive road closure is "decommissioning[12]."

Properly decommissioned roads no longer require maintenance and are no longer sources of erosion and sediment yield to a watershed's streams. The impacts of reopening old, abandoned roads so that they can be correctly decommissioned can be evaluated on a case-by-case basis, but the benefits (large reductions in long term erosion) almost always far outweigh the negative effects (small, short-term increases in erosion from bare soil areas).

Road decommissioning need not be an expensive procedure. Most of the road (perhaps 80 to 90%) requires very little treatment, often limited to ripping and draining. The short term costs of excavating stream crossings (the single most costly procedure) can be balanced against decades of cost savings of no longer having to perform road maintenance or emergency repairs when culverts wash out or cutbanks fail. When needed, decommissioned roads can then be reopened for use by regrading the surface and reinstalling the crossings.

Certain roads in the Navarro River watershed, as elsewhere, are in high risk locations where soils are very erodible and/or slopes are unstable and sediment is delivered directly to fish-bearing streams or their tributaries. These include roads located on steep inner gorge slopes, certain roads within riparian zones, and roads originally constructed on unstable or highly erodible terrain. Many of these roads would never be constructed in the same locations today. High risk roads are also frequently high maintenance roads that require substantial annual effort and expense just to keep open. High risk roads identified during the watershed road inventory should be considered for permanent closure (decommissioning) and erosion prevention. Alternate, low impact routes may need to be developed at the same time to provide stable, low impact access to these areas for future management.

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[12]Decommissioning has been defined as "removing those elements of a road that reroute hillslope drainage and present slope stability hazards. Another term for this is 'hydrologic obliteration'" (USDA, 1993). It involves such tasks as fully excavating stream crossing fills (not just "culvert removal"), excavating unstable sidecast and road fill, decompacting road surfaces and installing road surface drainage (e.g., cross road drains or road outsloping). The decommissioning of unneeded, neglected, and high-impact roads may be one of the most urgent and significant restoration needs, based on the magnitude of ongoing and potential effects to aquatic ecosystems. Unstable, erodible and high risk (e.g., riparian) roads are prime candidates for decommissioning. Unneeded roads that pose little or no threat to aquatic resources should not be targeted for decommissioning on the basis of aquatic protection or watershed restoration.

Planning Criteria and Applicability

A critical first-step in the overall risk-reduction process is the development of a watershed transportation analysis and plan. In developing this plan, all roads in an ownership or sub-watershed should be considered for either decommissioning or upgrading, depending upon the risk of erosion and sediment delivery to streams. Not all roads are high risk roads and those that pose a low risk of degrading aquatic habitat in the watershed may not need immediate attention. It is therefore important to rank and prioritize roads in each sub-watershed, and within each ownership, based on their potential to impact downstream resources, as well as their importance to the overall transportation system and to management needs.

Currently unused, unmaintained and/or abandoned roads should either be brought up to current standards and maintained, or they should be proactively closed (decommissioned) (upgrading procedures are described in RLMP 6.6.3). Road decommissioning techniques include complete stream crossing excavation, permanent surface drainage (by outsloping or construction of cross-road drains), and removal or stabilization of potentially unstable sidecast along roads and landings which could be delivered to a stream channel. All excavated spoil should be placed where neither runoff nor landsliding will cause it to enter a stream. Decommissioning does not necessarily suggest permanent closure. Most decommissioned roads can be rebuilt and reopened at a future date, if they are needed, by simply reinstalling the stream crossings and regrading the former road bed. If they are to be permanently closed, they should be ripped (decompacted) and replanted.

Certain "high risk" roads might be closed permanently. Recognizing and selecting high risk roads for decommissioning is done during the inventory phase of road assessment. When roads are inventoried in the field, it usually becomes apparent which, if any, routes fall into the high risk category. Based on potential threats to the aquatic ecosystem, a variety of roads qualify as "best-candidates" for decommissioning. These often include roads built in riparian areas, roads with a high potential risk of sediment production (such as those built on steep inner gorge slopes and those built across unstable or highly erodible soils), roads built in tributary canyons where stream crossings and steep slopes are common, roads which have high maintenance costs and requirements, and abandoned roads. General techniques for decommissioning (described below) are well documented and tested, and costs and procedures for each type of activity have been established through similar projects in the north coast region.

Overview of Watershed Assessment and Implementation Process

Goal: To identify, prioritize and cost-effectively treat those future sediment sources most likely to impact fish bearing streams if left untreated.

Basin Selection: Biological criteria dictate priority of basins selected for physical assessment.

Assessment Process:

1. Conduct sequential aerial photo inventory
   - a. road construction history (relative to storm history)
   - b. harvesting or other land use history
   - c. sources of erosion and sediment production
2. Perform field inventories of potential sediment sources
   - a. roads and landings
   - b. landslides
   - c. gullies and stream channels
3. Develop treatment prescriptions
   - a. develop site-specific prescriptions
   - b. estimate heavy equipment & labor tasks & times
4. Prioritize sites for treatment
   - a. predict cost of treating each site
   - b. predict sediment savings
   - c. compute cost-effectiveness

Implementation:

1. Implement erosion prevention projects
   - a. "storm-proof" or "erosion-proof" active road systems
     - *upgrade stream crossings*
     - *upgrade culvert sizing*
     - *eliminate diversion potential*
     - *treat unstable road fills (esp. headwater swales)*
     - *excavate unstable road and landing sidecast*
     - *install pre-crossing ditch-relief culverts*
     - *outslope road surfaces / remove ditches*
     - *surface roads*
   - b. decommission inactive, unneeded and abandoned roads
     - *excavate stream crossings*
     - *excavate unstable road and landing sidecast*
     - *treat unstable road fills (esp. headwater swales)*
     - *decompact roads and landings*
     - *outslope surfaces and/or install cross-road drains*
   - c. treat gullies, eroding streams and landslides
     - *redivert streams back into natural drainages*
     - *disperse or divert upslope road runoff*
     - *apply needed erosion control treatments*
     - *plant to revegetate and reforest*

2. Develop and implement needed land use changes
   - a. road planning and location
   - b. road construction practices
   - c. road reconstruction practices
   - d. road maintenance practices
   - e. road abandonment practices
   - f. winter operations
   - g. harvesting practices

Check?___ **EXAMPLE ROAD INVENTORY DATA FORM** *(6/13/97 VERSION)* ASAP?___

GENERAL INFO **Site #:** Planning : Watershed: Photo: Sketch?:
Road: Mileage: Maintained: Abandoned: Driveable?:
Inspector(s): Date: Year built: Maintenance?(Y):
Treat? (Y,N): Sed. Yield (Y,N) Upgrade?(Y): Decommission?(Y):

PROBLEM (circle)- Landslide (fillslope, cutbank or hillslope) Stream crossing Gully
Road bed (rd surface, ditch, cutbank) Ditch Relief CMP Other

Landslide - road fill failure: landing fill failure: deep-seated landslide:
cutbank slide: already failed: potential failure:
dist. to stream (ft): slope(%):

Stream - culvert (Y): bridge (Y): Humboldt (log) (Y): fill (Y):
diameter (in): pipe condition(O,C,R,P) ------> inlet: outlet: bottom:
headwall hgt (in): cmp slope (%): stream class (1,2,3): ditch/rd length (ft) - L: R:
% washed out: D.P. (Y, N): diverted (Y,N)?: plug potential (H,M,L):
channel grad(%): channel dimensions W: D: sed. transport (H,M,L):

Erosion - Erosion Potential (H,M,L):
Past erosion (field-yds): Delivery (%): Size W: D: L:
Future eros (field-yds): Delivery (%): Size W: D: L:

Comment on problem - ____
____
____
____

SOLUTION: Treatment immediacy (H,M,L): Complexity (H,M,L): Mulch area (ft^2):

Treatment-
excavate soil (Y): install critical dip (Y): add TR/DS (Y): (ft):
repair/clean cmp (Y): install/repl cmp (Y): (dia.): (ft): *rock surface (Y): (ft):*
reconst. fill (Y): *clean or cut ditch (Y): (ft):* *outslope rd (Y): (ft):*
rolling dips (Y): (#): *remove berm(Y): (ft):* *inslope road (Y): (ft):*
check cmp size (Y): other (Y): none (Y):

Tot vol excav (field-yds): Vol put back in (yds): Vol removed (yds):
Vol stockpiled (yds): Volume endhauled (yds): Exc prod rate (yds/hr):

Hours- excavator: dozer: dump truck: grader:
loader: backhoe labor: other:

Comment on Treatment: ____
____
____
____

Roads which are of low relative priority for decommissioning include those which follow low gradient ridges, roads traversing large benches or low gradient upland slopes, and roads with few or no stream crossings. Roads that are no longer needed for land or resource management (including abandoned roads) may or may not fall into a high risk classification for removal because of where they are located in the watershed. For example, many dead-end spur roads which lead to cable yarding landings high on the hillslope fit into this category of low priority for decommissioning. Even though these routes might be relatively easy and inexpensive to close permanently, they are not high priority candidates for immediate decommissioning since their removal will do little to protect the downstream aquatic ecosystem.

Once the roads are selected for closure, the specific procedures are the same for all roads, regardless of their former use or location. The goal should be to "hydrologically" decommission the road; that is, to minimize the adverse effect of the road on natural hillslope and watershed hydrology, and, hence, on the aquatic ecosystem. Typically, only a small portion of a road (perhaps less than 20% of the route) will require intensive treatment, even where high risk roads are being decommissioned.

Methods and Materials

General heavy equipment treatments for road decommissioning are relatively new, but the basic techniques have been tested, described and evaluated (Harr and Nichols 1993; Weaver and others 1987a; Weaver and Sonnevil 1984). Decommissioning essentially involves "reverse road construction," except that full topographic recontouring of the road bed is not normally required to accomplish sediment prevention goals. In order to protect the aquatic ecosystem, the goal is to "hydrologically" decommission the road; that is, to minimize the effect of the road on natural hillslope and watershed runoff. From least intensive to most intensive, decommissioning work will include at least some of the following tasks[13] (Table 6-6).

1. Road *ripping or decompaction*, in which the surface of the road or landing is "decompacted" or disaggregated using mechanical rippers (usually ripping teeth mounted on the back of a bulldozer). This action reduces surface runoff and often dramatically increases revegetation rates.

2. *Waterbars and cross-road drains* are installed at 50, 75, 100 or 200-foot intervals, or as necessary at springs and seeps, to disperse road surface runoff, especially on roads that are to be decommissioned. Cross-road drains are large ditches or trenches excavated across a road or landing surface to provide drainage and to prevent the collection of concentrated runoff on the former road bed. They are typically deeper than waterbars and do not allow for vehicle access.

[13] Many of these and other erosion prevention and erosion control techniques are described in the "Handbook for Forest and Ranch Roads" (PWA, 1994).

Table 6-6. Sample Heavy Equipment Techniques for Decommissioning Roads.

Treatment	Typical equipment	Typical use or application
Ripping or decompaction of road bed	D-7 or D-8 size bulldozer with rear-mounted hydraulic ripper	improve infiltration; decrease runoff; assist revegetation
Construction of rolling dips and cross-road drains	D-6 or D-7 size bulldozer	drain springs; drain insloped roads; drain landings
Partial outsloping (local spoil site; fill against the cutbank)	Hydraulic excavator and bulldozer	remove minor unstable fills; disperse cutbank seeps and runoff
Complete outsloping (local spoil site; fill pushed up against the cutbank)	Hydraulic excavator and bulldozer	used for removing unstable fill material where nearby cutbank is dry and stable
Exported outsloping (fill hauled away and stored down-road at a stable site)	Hydraulic excavator and dump trucks; bulldozer at spoil site	used for removing unstable road fills where cut banks have springs and cannot be buried
Landing excavations (usually with local spoil storage)	Hydraulic excavator and bulldozer	used to remove unstable material around landing perimeter
Stream crossing excavations (usually with local spoil storage)	Hydraulic excavator and bulldozer	complete removal of stream crossing fills (not just culvert removal)
Truck end-hauling of spoil materials	Hydraulic excavator and bulldozer	hauling excavated spoil to stable, permanent storage location where it will not discharge to a stream

3. *In-place stream crossing excavation (IPRX)* is a decommissioning treatment that is employed at locations where roads or landings were built across stream channels. The fill (including the culvert) is completely excavated and the original stream bed and natural side slopes are exhumed (uncovered). Excavated spoil is stored at nearby stable locations where it will not erode, sometimes being pushed several hundred feet from the crossing by tractor(s). A stream crossing excavation typically involves more than simply removing the culvert, as the underlying and adjacent fill material must also be removed and stabilized.

4. *Exported stream crossing excavation (ERX)* is a decommissioning treatment where stream crossing fill material is excavated and spoil is hauled off-site for storage. Spoil may need to be moved farther up- or down-road from the crossing, due to the limited amount of stable storage locations at the excavation site. This treatment frequently requires dump trucks to endhaul spoil material to the off-site location.

5. *In-place outsloping (IPOS)* ("pulling the sidecast") calls for excavation of unstable or potentially unstable sidecast material along the outside edge of a road prism or landing, and replacement of the spoil on the roadbed, against the adjacent cutbank, or within several hundred feet of the excavation site. Placement of the spoil material against the cutbank usually blocks access to the road and is used in road decommissioning. In road upgrading, or where a decommissioned road is to be rebuilt in the future, the excavated material can be used to build up the road bed and convert an insloped, ditched road to an outsloped road. Otherwise, you'll need to haul the spoil away to a disposal site (see below).

6. *Exported outsloping (EOS)* is comparable to in-place outsloping, except spoil material is moved off-site to a permanent, stable storage location. Where the road prism is very narrow, where there are springs along the road cutbank, or where continued use of the road is anticipated, spoil material is typically not placed against the cutbank, and material is end hauled to a spoil disposal site. This treatment frequently requires dump trucks to endhaul spoil material.

Only in relatively few instances does road decommissioning have to include full recontouring of the original road bed. Typically, potential problem areas along a road are isolated to a few locations (perhaps 10% to 20% of the road to be decommissioned) where stream crossings need to be excavated, unstable landing and road sidecast needs to be removed before it fails, or roads cross potentially unstable terrain and the entire prism needs to be removed. Most of the remaining road surface simply needs permanently improved surface drainage, using decompaction, road drains and/or partial outsloping. The road surface should receive revegetation treatments in locations where eroded sediment could be delivered to a stream (such as the side slopes to excavated stream crossings), but much of the decommissioned alignment can be left to naturally revegetate from nearby seed sources.

Successfully decommissioning most roads will cost a fraction of complete or total topographic road obliteration, and can be significantly less expensive than road upgrading.

Costs are highly dependent on the frequency and nature of the potential erosion problems along the alignment.

Labor intensive (hand labor) erosion control treatments are often needed on sites where heavy equipment has been used to perform road decommissioning. Hand labor is used to stabilize and revegetate soils exposed by heavy equipment operations. Only the most effective and cost-effective labor techniques should be prescribed. These include mulching, seeding and planting. In general, heavy equipment will perform most of the significant erosion prevention and erosion control work in drainage basins and along road networks.

Maintenance

Decommissioned roads do not need maintenance, if the work is done properly. One of the goals of decommissioning is to remove the road from the list of active routes that require maintenance. It is possible that some minor hand maintenance of erosion control structures will be needed after the first winter, but the road is no longer open for equipment access. If revegetation efforts were unsuccessful, portions of the site may need replanting.

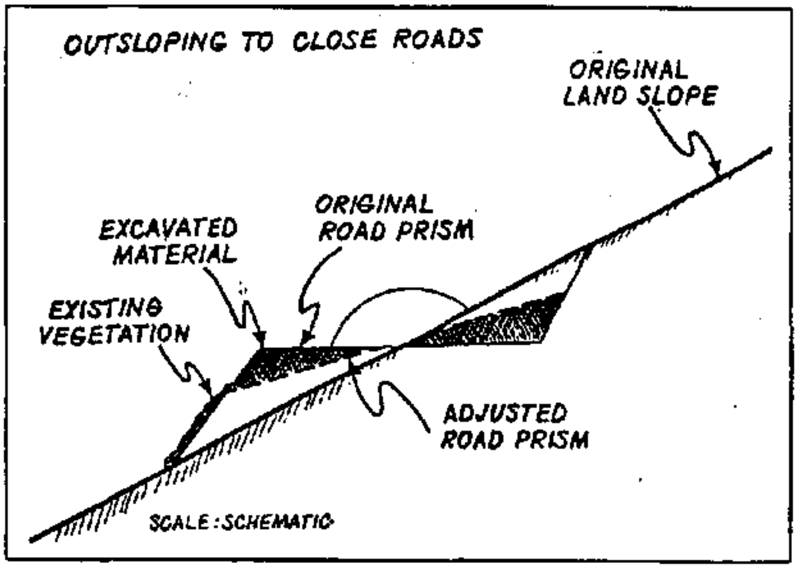
Effectiveness

Like most erosion control and erosion prevention tasks, the effectiveness of each technique used in road decommissioning can be measured by the amount of sediment which is being prevented from entering the stream system. Most decommissioning treatments have a routinely high level of effectiveness. As with any erosion control and erosion prevention treatment, the level of effectiveness is often dependent on several factors: 1) site conditions (how difficult is the road, and its specific sites, to treat?), 2) how well has the site been described, quantified and laid-out by the inventory crew and 3) operator skill (how experienced and skilled is the operator at this type of work). Difficulties or shortcomings with any of these elements can reduce treatment effectiveness and cost-effectiveness.

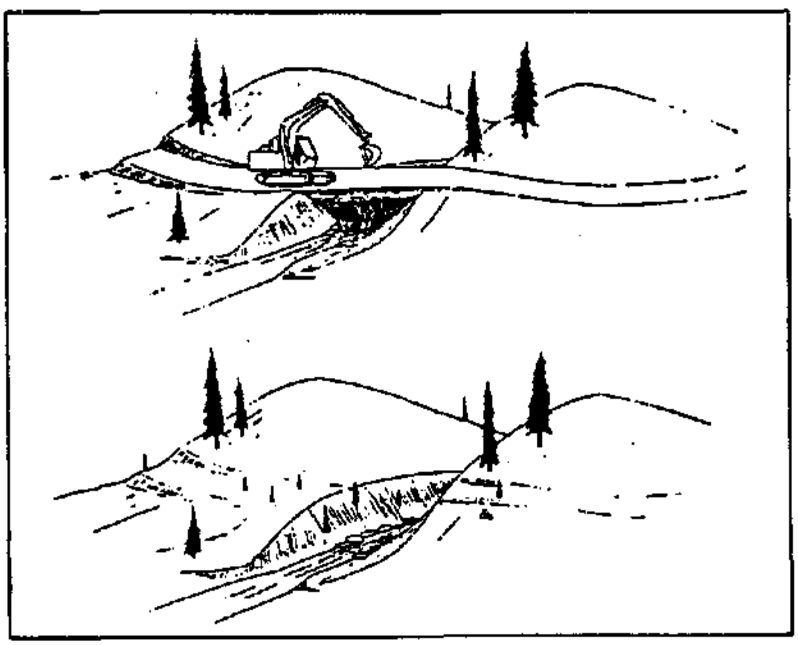
In sections of high risk roads, it is very likely that landsliding is already occurring and/or erosion rates are already high. Road decommissioning, in these cases, will prevent substantial future erosion and sediment yield but it is unlikely to stop or solve all on-going erosion and sediment loss. Successful treatment of these sites will often be dependent on long term revegetation and site stabilization.

Sketch Drawings

Typical measures showing road outsloping (Figure 6-20) and cross-ditch or water bar construction (Figure 6-21) are attached.



Outsloping of roads is perhaps the most extreme example of road decommissioning. Outsloping the beginning of a decommissioned road is a good way to prevent unwanted vehicle or ORV access. In most cases, excavation and outsloping will be used to remove isolated unstable segments of roads and landings where sidecast is visibly unstable and could enter a stream.

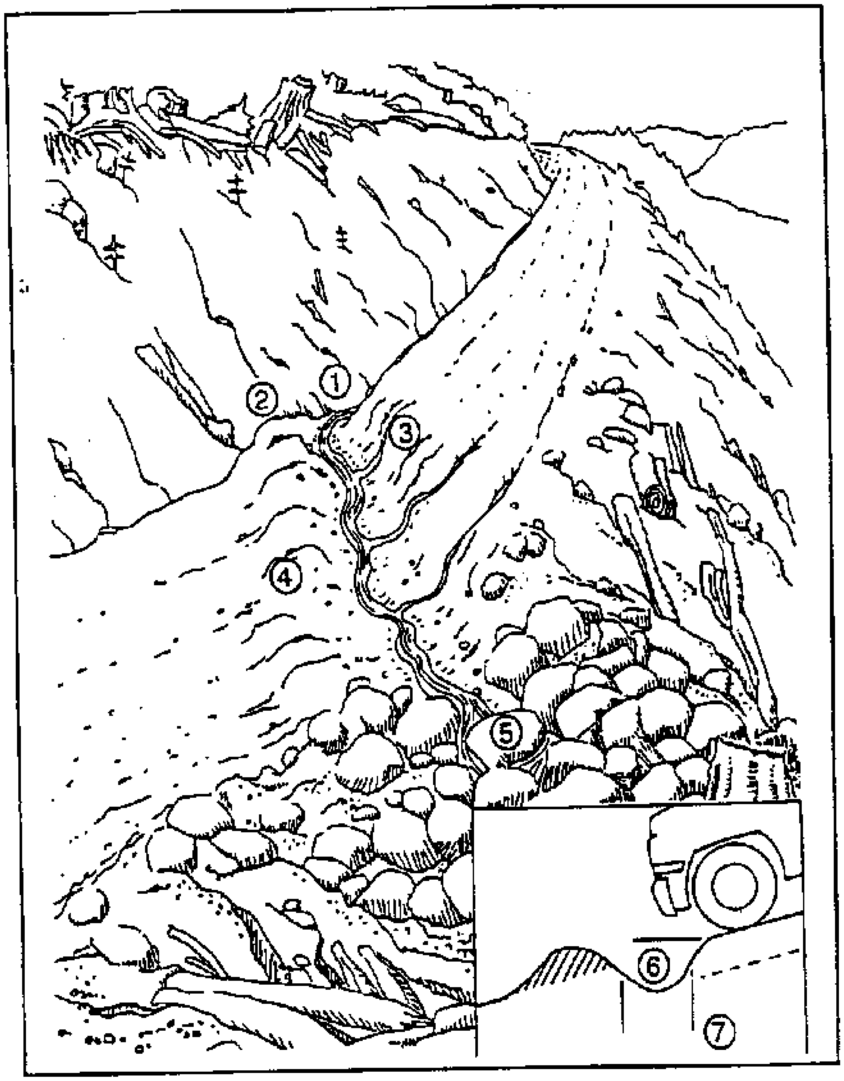


Stream crossing excavation is the other main task of road decommissioning. In this procedure, the entire stream crossing fill is removed down to the original stream bed and the sideslopes are graded to a stable angle and protected with mulch and vegetation. Excavated spoil must be stored in a stable location.

Figure 6-20. Road Outsloping and Stream Crossing Excavation.

In decommissioning, only a small portion of the road will need to be "outsloped" (where unstable fill material is excavated or stream crossing fills are removed). Perhaps 80% of the road bed will simply need permanent drainage.

To decommission a road the road surface needs to be permanently drained so that runoff does not concentrate and cause gullying. Roads should be ripped to promote infiltration and rapid revegetation. Frequent cross drains should be installed to drain the road surface, the ditch and any springs. Cross drains should be dug deeper than normal waterbars so they do not fill up with sediment. The road should be closed to vehicle traffic.



Cross-ditch or water bar construction

1. The cross-ditch is cut into the road bed from the cut bank or ditch line completely across the road surface, extending beyond the shoulder of the road.
2. Physical blockage of the ditch-line down grade from the cross-ditch is required to deflect water flow into the cross-ditch.
3. The cross-ditch should be placed at a minimum skew of 30° to the ditchline – greater on steep road gradients.
4. The excavated material is spread on the downhill grade of the road creating a berm.
5. Water should always be dispersed onto a stable slope with vegetation or rip-rap protection.
6. The cross-ditch berm should dip to allow vehicle cross-over without destroying the ditch.
7. The cross-ditch must be cut to the depth of the ditchline to prevent water ponding and to ensure drainage from the ditchline.
8. Ensure that ditch water is not redirected into different drainage basins.

Figure 6-21. Cross Ditch or Water Bar Construction.

6.6.3 Road Upgrading Practices

Description and Purpose

Road upgrading consists of a variety of techniques employed to "erosion-proof" and to "storm-proof" a road and prevent unnecessary future erosion and sedimentation. Erosion proofing and storm-proofing typically consists of stabilizing slopes and upgrading drainage structures so that the road is capable of withstanding both annual winter rainfall and runoff as well as a large storm event without failing or delivering excessive sediment to the stream system. Work includes such activities as upgrading stream crossings and culvert sizes, eliminating diversion potential, treating or excavating unstable road fills, improving road surface drainage and surfacing roads (including rock surfacing and paving).

Installation of culverts on fish-bearing streams will require a 1601 Streambed Alteration Agreement with the Department of Fish & Game. The Department should be consulted regarding the design and installation of culverts to ensure adequate fish passage. For additional information about the design of culverts for fish passage see the California Salmonid Stream Habitat Restoration Manual.

The goal of road upgrading is to strictly minimize the contributions of fine sediment from roads and ditches to stream channels, as well as to minimize the risk of serious erosion and sediment yield when large magnitude, infrequent storms and floods occur. This is accomplished by upgrading all existing permanent, seasonal and active temporary roads, and their drainage facilities, to current design standards to minimize unnecessary erosion and sediment delivery.

Planning Criteria and Applicability

Upgrading should be performed so that all existing public and private roads, including ranch, agricultural, forestry and residential roads, are brought up to currently accepted standards. If roads are not decommissioned, then they should be targeted for upgrading, regular inspection, and maintenance. For example, among other things, upgrading of forest, ranch and agricultural roads should include surfacing (if roads are to be used during winter months) replacing Humboldt (log) crossings and undersized culverts, upgrading stream crossing culvert sizes to pass the 50-year flood discharge, eliminating diversion potentials at all stream crossings which display a high diversion potential, installing trash barriers and downspouts (where necessary), and eliminating ditch contributions of water and sediment runoff to stream crossings (by employing techniques such as road outsloping, and/or the installation of rolling dips or ditch relief culverts).

Depending on the land use, permanent roads may be needed for long term resource management, for site inspection and maintenance, for fire control, for access to facilities or homes, and for other purposes. Roads which are best suited for retention need to be identified in the transportation planning process for each ownership and sub-watershed. To be protective of fish habitat and the aquatic ecosystem in the watershed, this planning first considers the erosional consequences of road retention, and then the expressed needs for access and for management activities.

Retained roads (those to be upgraded and maintained) are those that are expressly needed for management or as a component of the overall transportation network of a watershed or an ownership. They are typically, but not exclusively, located on stable terrain, where the risk of fluvial erosion, stream crossing failure, storm damage and mass soil movement (landsliding) is lowest. Each retained road is then upgraded and redesigned as necessary, to make them largely self-maintaining or requiring low levels of maintenance.

A host of potential road upgrading treatments prescribed for forest, ranch, agricultural and residential roads have been well tested, documented and evaluated in similar erosion control and erosion prevention projects on the north coast (e.g., BCMF 1991, Furniss *et al.* 1991, Yee and Roelofs 1980). Properly designed and implemented, these measures have been shown to be effective in significantly reducing sediment yield from managed lands.

Methods and Materials

Erosion from roads can be classified into two broad categories: chronic and episodic. Chronic erosion is that which happens every year, regardless of the number of large storms or floods which occur during the winter. It is the result of our disturbing or exposing the land (soil) and concentrating runoff over these exposed slopes. Humans, through a wide variety of land management actions and grading activities, cause runoff to concentrate almost everywhere on the landscape so this type of erosion is widespread. In contrast, episodic erosion is that which is triggered by large storms and flood events. It commonly includes such processes as stream crossing wash outs and landsliding. Both types of erosion can be largely prevented, or strictly minimized, by employing protective land management practices and mitigations.

Chronic erosion - Roads, by their very nature, cut across the natural topography and thereby cause runoff to collect, concentrate and divert. This results in soil erosion. Roads intercept subsurface flow, and collect and concentrate runoff from rainfall. Ditches, berms and insloped roads cause runoff to collect and concentrate. This concentrated runoff can cause erosion in the ditch, on the road, and/or where it is discharged from the road into stream crossing culverts or ditch relief culverts. The best way to control or prevent this type of erosion is to disperse runoff so that it does not collect in sufficient quantities to cause erosion and deliver sediment to streams. Rolling dips, ditch relief culverts and road outsloping are mechanisms that can be used to disperse surface runoff from roads, and thereby minimize or prevent chronic erosion. Fine sediment contributions from roads, cut banks and ditches can also be minimized by utilizing seasonal closures for hauling and travel, by road surfacing, and by converting ditched insloped roads to outsloped alignments (especially at and near the approaches to stream crossings).

Road outsloping is the best method for dispersing runoff. Rain that falls on the road surface flows directly off the road without ever concentrating. Road outsloping is generally limited to roads with a gradient of 10%, or less. Most roads in the Navarro River watershed are insloped and ditched. *Ditch relief culverts* are often installed to break-up ditches so that ditch flow is not able to erode the ditch or the slope area where the culvert discharges. *Rolling dips*[14] are designed to do the same thing, except that they can be constructed to collect just road surface runoff (if they do not intercept the ditch), or both the ditch flow and road surface runoff (where they connect into the ditch system). The more of these diversion structures there are, the better the dispersion of runoff from the road and the less likely that runoff will create serious erosion or deliver eroded sediment to a stream.

If runoff from ditch relief culverts or rolling dips is seen to cause excessive gullying of the fill where it is discharged, it simply means that too much water is being collected and discharged at these points, and that additional dips or culverts are needed to further break-up the runoff. Minor rilling or gullying of the outer road fill is to be expected, but it is not significant if the eroded sediment is not discharged into a stream. Unless the road is outsloped (so that there is no concentration of runoff), it is important to create enough discharge points so that outlet erosion and erosion below each outlet point is minimal and road runoff does not discharge sediment to a stream channel. Outlet points for rolling dips and culverts need to be located as far from streams as possible, and in locations were runoff will not cause landsliding or deliver eroded sediment to a stream.

Recommended treatments for storm-proofing (upgrading) roads and landings not only include these simple techniques to improve road surface drainage patterns, but may also include more comprehensive tasks such as full road reconstruction or road relocation. Road upgrading also involves a variety of treatments used to make a road more resilient to large storms and flood flows. The most important of these include stream crossing upgrading (especially culvert up-sizing and elimination of stream diversion potential) and removal of unstable sidecast and fill materials from steep slopes, as well as and the application of drainage techniques to improve dispersion of road surface runoff.

Road upgrading costs may not differ significantly from those required for road decommissioning. Costs are highly dependent on the frequency and nature of the potential erosion problems along the alignment, the number and size of stream crossings whose drainage structures must be upgraded, the number of bridge installations required, road surface treatments and surfacing requirements, as well as the size (volume) of unstable fills that must be excavated and end hauled to stable spoil disposal locations. The type and intensity of use can also affect upgrading costs. Thus, where rock surfacing is insufficient to eliminate fine sediment erosion during winter use (for example on heavily used subdivision roads), paving may be required. Over the long term, paving may actually be less expensive than decades of annual surface rocking.

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[14] Rolling dips are generally not employed on paved public roads where driving through water might present a hazard. Constructing rolling dips is appropriate, and often preferable, to the use of ditch relief culverts on many forest, ranch and agricultural roads.

From least intensive to most intensive, road upgrading tasks typically include at least some of the following measures[15]:

1. *Rolling dip installation/construction (critical dip),* involves dipping the roadbed at stream crossings on maintained roads where the potential for stream diversion is high, thereby assuring that when culverts plug, stream flow will be directed over the road prism and back into the natural stream channel, rather than down the road bed. Rolling dips are also installed along roads to drain the road surface and disperse excess surface runoff.

2. *Rolling dips, waterbars and cross-road drains* are installed at 200 or 400-foot intervals, or as necessary at springs and seeps, to disperse road surface runoff. Waterbars are also installed on seasonal roads that are closed to vehicle traffic during the wet season.

3. *Installing or cleaning culverts,* includes adding new or larger culverts where they are needed, or cleaning the inlets or outlets of partially plugged culverts on maintained roads. Correct installation procedures are described elsewhere (Pacific Watershed Associates 1994).

4. *In-place outsloping (IPOS)* ("pulling the sidecast") calls for excavation of unstable or potentially unstable sidecast material along the outside edge of a road prism or landing, and replacement of the spoil on the roadbed against the corresponding, adjacent cutbank, or within several hundred feet of the site. Placement of the spoil material against the cutbank usually blocks access to the road and is used in road decommissioning. In road upgrading, the excavated material can be used to build up the road bed and convert an insloped, ditched road to an outsloped road.

5. *Exported outsloping (EOS)* is comparable to in-place outsloping, except spoil material is moved off-site to a permanent, stable storage location. Where the road prism is very narrow, where there are springs along the road cutbank, or where continued use of the road is anticipated, spoil material is typically not placed against the cutbank and material is end hauled to a spoil disposal site. This treatment frequently requires dump trucks to endhaul spoil material. This is typically a decommissioning treatment as part or all of the roadbed is removed.

6. *Road surfacing* is used to stabilize a road for winter use or to minimize the erosion and loss of fine sediments to nearby streams. On wildland roads surfacing typically consists of the addition of 6" to 12" of crushed or quarried rock to a native surface road to allow for wet weather travel or commercial hauling. In some locations, especially for residential roads or public roads, a bituminous surface (chip-seal or asphalt) is used.

[15]Many of these and other erosion prevention and erosion control techniques are described in the "Handbook for Forest and Ranch Roads" (PWA, 1994).

When installing culverts at road crossings of streams landowners should recognize that they have the potential to impede the upstream passage of adult fish. Properly installed culverts should pass fish during at least 90 percent of all anticipated flows (Flosi and Reynolds 1994). Installation of the culvert should provide adequate water depth (Orsborn 1985) to allow fish to successfully swim upstream through the culvert. Velocities inside the culvert should also not be so great as to prevent the upstream passage of fish through the culvert. Some factors to consider during the design and installation of culverts are listed below.

Good entrance conditions - The fishway (culvert) entrance (downstream part) is the single most important part of any fishway system. The fishway entrance must be located such that fish migrating upstream can find the fishway. This means velocities of the water must be high enough and of sufficient quantity to attract the fish but not so high as to prevent fish from passing through the entrance of the fishway. Approximately one-quarter of the diameter of the culvert should be at or below the channel grade to minimize the likelihood of excessive scour below the culvert outlet. Energy dissipators (such as rock rip-rap) or back-flooding weirs can be used to reduce scour.

Controlled velocities and minimum depths in the culvert barrel - The velocity and depth of the water in the culvert barrel is usually controlled by the slope of the culvert, the roughness (degree of "smoothness" inside the barrel) of the culvert, and the discharge through the culvert. Velocity of water and depth of flow in the barrel must be matched to the target species of fish. Generally, the culvert should have at least 12" depth of water. Excess velocities in smooth culverts can be controlled by installing baffles (Flosi and Reynolds 1994).

Culvert length - The length must be short enough to allow fish to successfully swim the entire length of the culvert. The culvert length must be matched to the swimming speeds of the fish otherwise fish will be swept back through the culvert and passage will be prevented.

Exit conditions of the fishway - The exit conditions of the fishway (upstream end) should be designed such that fish can make a smooth transition from culvert to natural stream channel. This means the elevation of the culvert floor and the natural stream bed should be about equal. Depth of flow must be sufficient, at a minimum, to cover the body cavity of the fish and velocities low enough that fish can burst through the exit into the upstream natural channel. The design and construction of a resting pool may be necessary at the fishway exit if the barrel length is near the limit of the swimming capabilities of the fish.

Road cutbanks and road ditches are thought to deliver relatively significant volumes of fine sediment to many wildland watersheds with unsurfaced roads, and they have been found to significantly affect watershed hydrology (Reid 1981, Wemple 1994). Relatively simple treatments can be performed to upgrade road drainage systems to significantly reduce or largely eliminate these watershed effects. Fine sediment can usually be prevented from entering culverted stream crossings by installing ditch relief culverts or rolling dips just up-road from stream crossings, or by outsloping roads in the immediate vicinity of stream crossings. Such treatments also reduce the hydrologic impacts of roads (e.g., increased peak flows and timing of peak flows) on watershed function.

Hand labor is typically used for both revegetation and erosion control work at sites disturbed by heavy equipment, at sites where drainage structures need repair or upgrading, and where hand labor is needed to assist in excavation work. Hand labor is also needed on sections of road that are recommended for upgrading. Labor work at drainage structures include such preventive tasks as adding culvert downspouts and trash racks, adding extensions to culverts, cleaning culvert inlets, cleaning debris out of the channel above a culvert inlet, and assisting in culvert installation or replacement.

Maintenance

One goal of implementing road upgrading measures should be to reduce the level of road maintenance required of roads. Ideally, roads should be self-maintaining, but by their nature all drainage structures, cutbanks, fillslopes and road surfaces will need regular inspection and maintenance to catch any potential problems before they become uncontrollable or deliver sediment to a stream. Clearly, roads and their drainage facilities, no matter how well designed and constructed, will require continuing inspection and maintenance. The techniques for regular road inspection and maintenance are covered in a separate RLMP.

Effectiveness

Road upgrading is a highly effective technique for reducing and minimizing sediment production and yield from road systems in a watershed. Road upgrading should be considered an essential part of the three-pronged strategy for controlling road-related erosion which includes inventory of existing conditions, decommissioning abandoned and high risk roads, and road upgrading.

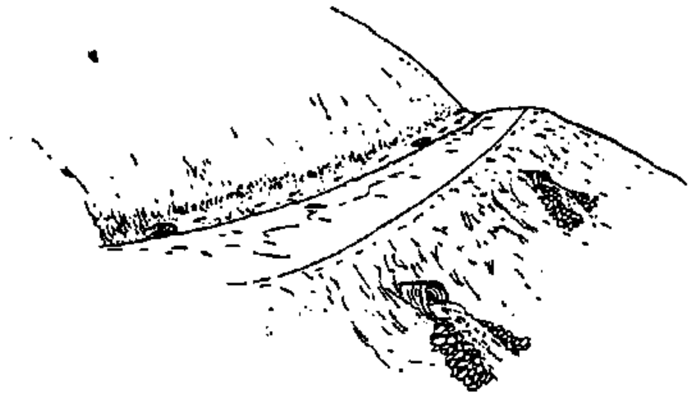
Sketches/Drawings

Typical road upgrading measures (Figure 6-22), and guidance for ditch relief culvert installation (Figure 6-23 and Figure 6-24) are attached.

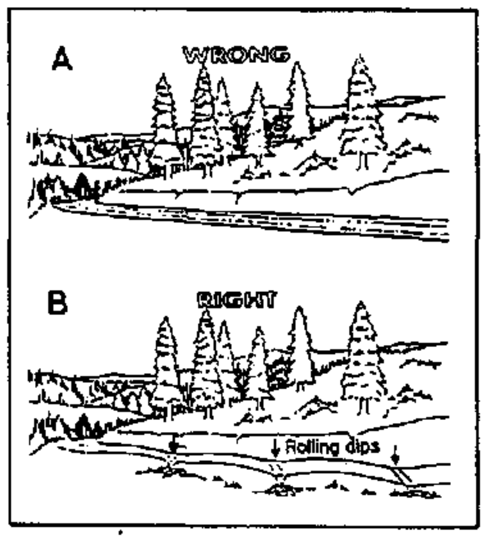
6.6.4 Excavating Unstable Road and Landing Sidecast and Fill Material

Description and Purpose

Many roads (including both abandoned and actively maintained roads) in the Navarro River watershed, especially those located on steep hillslopes, exhibit isolated locations of unstable sidecast and/or fill materials. Many of these road-related landslides can be identified and



One important road upgrading task is to improve and disperse road surface drainage, through the installation of ditch relief culverts, rolling dips and road outsloping (getting rid of ditches wherever feasible).



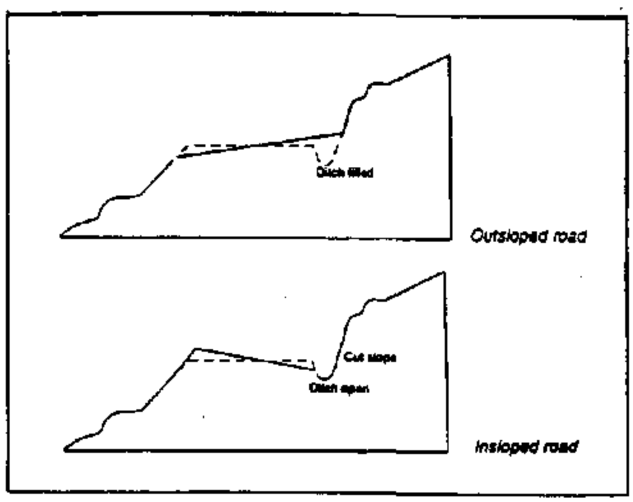
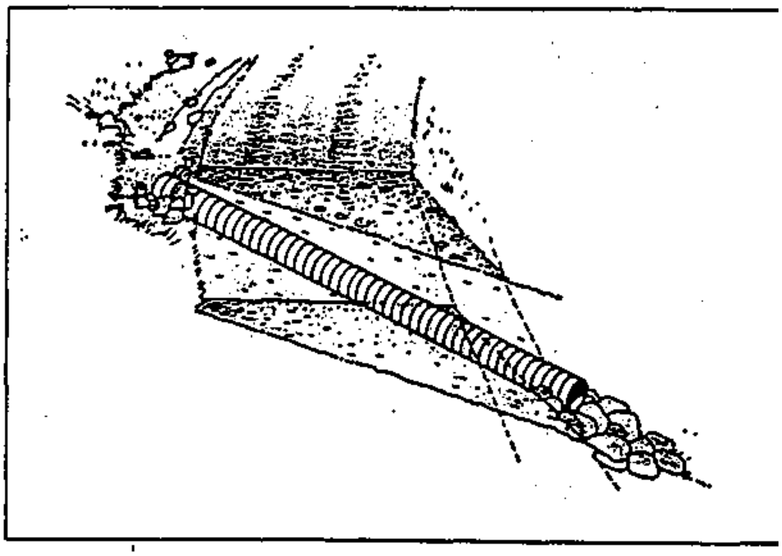


Figure 6-22. Road Upgrading.

Ditch relief culverts and rolling dips are constructed to disperse surface runoff from roads. Culverts should be placed at the base of the fill. If a culvert is placed higher in the fill, the outlet should be protected with energy disipation or a down spout should be installed.



General guidance for spacing of ditch relief culverts and rolling dips is outlined in the table below. In practice, it is generally advised that ditches be broken up with some form of cross-road drain at least every 400 to 600 feet.

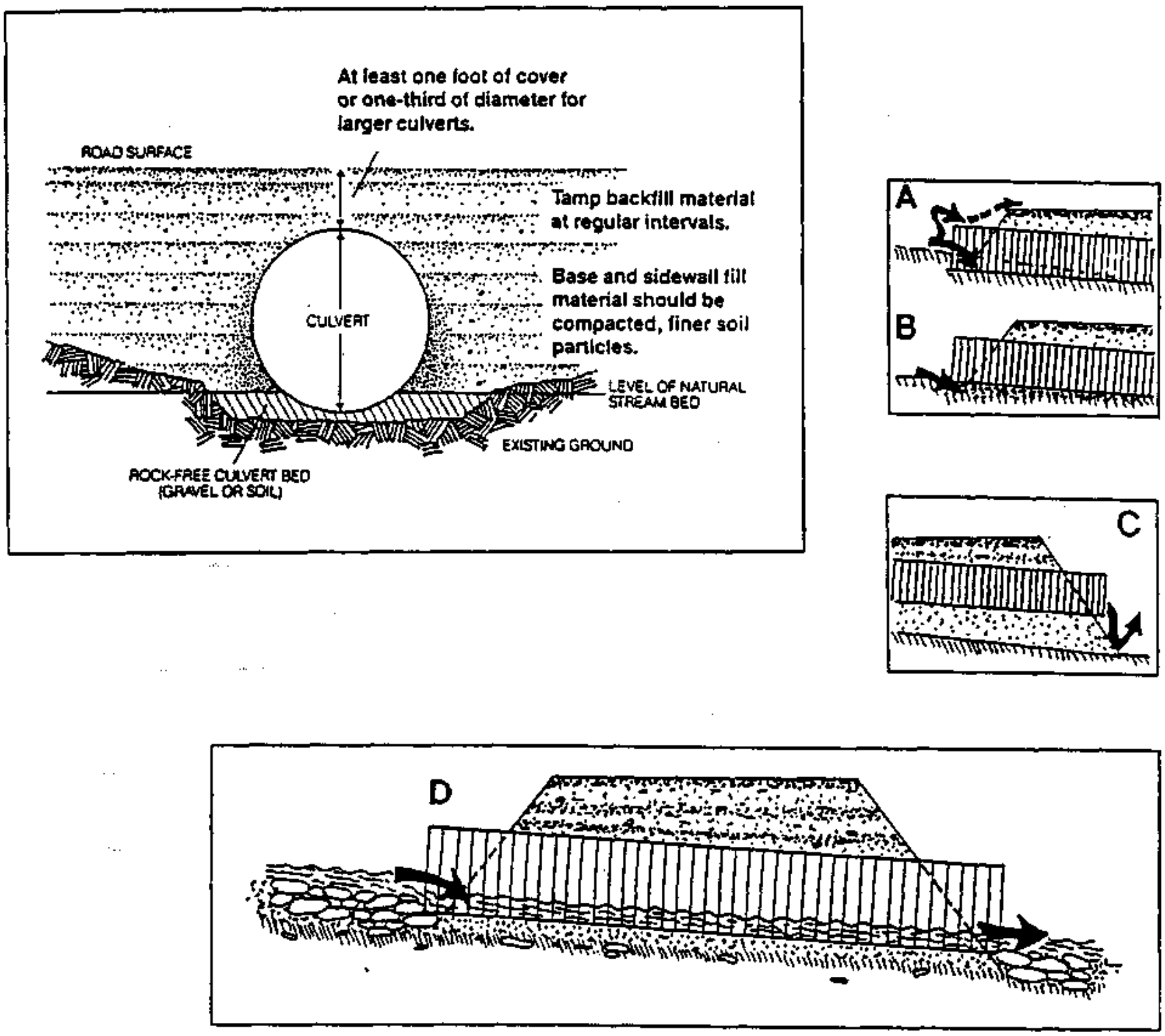
Maximum suggested spacing for ditch relief culverts[1] (ft)					
Road grade (%)	Soil erodibility				
	very high	high	moderate	slight	very low
2	600-800[2]				
4	530	600-800[2]			
6	355	585	600-800[2]		
8	265	425	525	600-800[2]	
10	160	340	420	555	
12	180	285	350	460	600-800[1]
14	155	245	300	365	560
16	135	215	270	345	490
18	118	190	240	310	435

[1] Adapted from Transportation Handbook USDA Forest Service, R-6, 1966. Culvert spacing may be too great in locations where ditch runoff is accumulated and discharged onto steep hillslopes that are prone to gullying. Spacings are designed to control ditch erosion, not culvert outfall erosion, and are based on 25-year storm and precipitation rate of 1-2 in/hr for 15 minutes. If less, multiply by the intensity 0.50, 0.30, etc. If 2-3 in/hr, divide distance in table by 1.50; if 3-4 in/hr, divide by 1.75; and if 4-5 in/hr, divide by 2.00. The U.S. Forest Service also publishes abundant information on preventing and controlling gully erosion below culvert outfalls.

[2] Even with stable ditches, ditch relief culvert spacing greater than about 600 to 800 feet is generally not recommended due to the large volume of road surface and cutslope runoff that would be discharged through the culvert and onto lower slopes during peak runoff periods. Culvert outlet erosion may occur with less than 800 feet of contributing ditch line, so observe local conditions to determine the upper limit of acceptable spacing in your area.

Figure 6-23. Ditch Relief Culverts.

Road upgrading tasks typically include upgrading stream crossings by installing larger culverts and inlet protection (trash barriers) to prevent culvert plugging. Culvert sizing for the 50-year flood flow should be determined by both field observation and calculations using a procedure as the Rational Formula. A forester or hydrologist can help you evaluate each of your stream - crossings and culverts. Upgrading culverts helps "storm-proof the road.



Basic culvert installation procedures are outlined in these diagrams. Proper culvert installation involves corect culvert orientation, setting the pipe slightly below the bed of the original stream, and backfilling and compacting the fill as it is placed over the culvert. Culverts set too low (A), too high (B) or above the original stream bed (C) will be subject to erosion and potential failure. Diagram D shows a properly placed culvert.

Figure 6-24. Culvert Installation.

treated through straight forward excavation. In locations where this material could fail and enter a Class 1, 2 or 3 stream channel[16] it should be excavated and the spoils stored at a stable location. On active roads, this may require endhauling to an off-site location.

Planning Criteria and Applicability

Fillslope excavations are one of the simplest and most cost-effective erosion prevention treatments that can be applied to a road system. First, potentially unstable fills and sidecast areas along existing roads are identified through the watershed sediment source inventory (see RLMP 6.6.1). The presence of the most obvious indicators (including cracks, small scarps, emergent groundwater, moisture loving vegetation within the fill, leaning trees, etc.) suggest which slopes are the most visibly unstable. These are then treated by direct excavation, removing all or most of the potentially unstable material. The excavated earth is either stored locally or hauled off to a stable storage location where it cannot fail or be eroded and delivered into a watercourse.

Methods and Materials

Typically, potentially unstable fill material is removed from the outside edge of the road or along the outside edge of a landing or area of previous spoil disposal. The unstable sidecast or fill is "pulled" back up (to the extent it can be reached) and placed against the adjacent cutbank, or within several hundred feet of the site. This is called "in-place" outsloping in that the spoil is stored locally. Placement of the spoil material against the cutbank usually blocks access to the road and is used in road decommissioning. In road upgrading, the excavated material can be used to build up the road bed and convert an insloped, ditched road to an outsloped road.

Where the road prism is very narrow, where there are springs along the road cutbank or where continued use of the road is anticipated, spoil material is typically not placed against the cutbank and material is end hauled to a permanent spoil disposal site. This treatment frequently requires dump trucks to endhaul spoil material. This type of treatment is often performed along actively maintained roads as a part of road upgrading and erosion prevention work.

Generally, a hydraulic excavator is used to reach as far down the fillslope as is possible (typically about 25 feet) and to excavate a concave profile into the potentially unstable fill materials. The average thickness of the excavated material is dependent on each particular site and should be spelled out by the inventory specialists during the field assessment. On active roads, enough road prism will have to be left to allow for continued traffic. Likewise, the left and right margins of the excavation should have been flagged in the field by the same crew. The finished grade at the excavation site should be a free draining, concave-up

[16] Stream classification is per the California Forest Practice Rules. Class 1 streams are fish-bearing (at some time of the year). Class 2 streams support some type(s) of non-fish aquatic species during some portion of the year. Class 3 streams are those which transport sediment but do not contain aquatic life.

surface. The concave profile (rather than a straight profile) ensures that bulk of unstable fill material will be removed from the outside of the road bench.

Excavated materials should be placed along and against the cutbank, on the inside of a nearby landing or gentle ridge, or be hauled off to a designated, storage location. Spoil material should not be placed on springs or wet areas, or where material could erode or fail and enter a watercourse. All fill sites should be ripped (decompacted) prior to the placement of spoil materials. Fill at the spoil site should be placed onto a road, landing, or skid trail, and against the existing cutbanks, but should not exceed existing cutbank height.

Maintenance

Excavated sidecast or fillslopes should not need maintenance once the potentially unstable material has been removed. If the excavated slope is immediately adjacent a stream channel, and eroded sediment could enter the watercourse, then the bare soil areas should be mulched with straw (4,000 lbs/acre).

Effectiveness

Road fill failures can be categorized as one of two types: 1) those which involve only sidecast materials and 2) those which involve sidecast as well as native ground beneath the sidecast. These later slope failures are usually larger than simple sidecast failures, and they are more difficult to control once movement has been initiated. Usually, the smaller the volume of the potential failure, the greater the likelihood of success in preventing the failure from occurring or delivering sediment to a downslope stream channel. Direct excavation acts in two ways: 1) it removes the unstable material so that there is nothing left to fail or 2) it significantly unloads (un-weights) the top part of a larger failure, thereby reducing the mass of the slide (and the volume of material that could enter the stream if it did fail) and potentially stabilizing the remaining material that is not excavated. Adding weight to the upper part of a slide adds to its instability. By the same logic, removing weight from the top of a slide can act to stabilize a slope that might otherwise fail.

Even if it doesn't prevent the failure, direct excavation can be an effective method for minimizing the volume of potential landslide material that could fail from a road and enter the stream system.

6.6.5 Disconnecting Road Ditches from the Stream System

Description and Purpose

Erosion from road prisms and cutbanks has long been of concern in forested watersheds, since unvegetated roads and cutbanks are an obvious sediment source. Some of this runoff and eroded sediment enters stream channels and adversely affects aquatic habitat. A recently completed study in Oregon indicates nearly 60% of the surveyed road length in several watersheds appear to route water directly to stream channels or into gullies. It was determined that roads might extend the stream network by as much as 40% during storm events, thereby substantially altering flood flows in small watersheds.

In virtually every watershed in the north coast, including the Navarro River, many road-side ditches also drain directly to stream crossing culverts. At these sites, eroded fine sediment from cutbanks, ditches and the road surface is discharged directly into the stream channel (at the culvert inlet) and contributes to downstream impacts in spawning and rearing habitat. Maintained roads are generally less likely than abandoned roads to have culvert failures and related erosion problems. However, roads which are maintained and used regularly are likely to experience substantially greater sediment yield from road surface and ditch erosion processes. On roads which receive substantial traffic, the volume of fine sediment delivered to the stream can be significant. The solution to this problem is straight forward. It involves the installation of rolling dips or ditch relief culverts, or outsloping the road surface, immediately adjacent each crossing in order to divert road and ditch runoff onto well-vegetated slopes where the water and sediment can settle out before reaching the stream.

Planning Criteria and Applicability

Surface erosion along roads comes from four main sources: 1) the road surface, 2) the cutbank, 3) the ditch and 4) the fill slope. The nature and intensity of use of roads (especially those roads used for commercial log hauling or subdivision access), as well as the type and quality of surfacing on the road prism, strongly controls subsequent sediment production from the road bed. Similarly, the erodibility of the soil and the degree of vegetative cover largely controls cutbank erosion rates. The grade (slope gradient) of the road and ditch, the drainage area collecting runoff, the erodibility of subsoils, and grading disturbances control erosion rates along the ditch. Fill slope erosion rates are controlled by the gradient and length of the fill slope, soil erodibility, vegetative cover, and runoff rates.

There are several ways to limit the amount of fine sediment that is delivered to streams from a road. These treatments all function in one of two ways: 1) they divert road and ditch runoff into buffer areas or catch basins along the road where water can infiltrate and/or sediment can settle out before it has a chance to reach a stream, or 2) they prevent water along the road from ever concentrating and then being delivered to the stream. The first method is typically accomplished using ditch relief culverts or rolling dips installed immediately adjacent each stream crossing to drain the road and ditch. The second method, dispersing road runoff and never letting it concentrate, is accomplished by eliminating the ditch and outsloping the road so that road and cutbank runoff drains across the road bed and onto adjacent vegetated hillslope areas.

Methods and Materials

The first step in preventing road runoff from entering the stream system is to locate and inventory each and every location where runoff and fine sediment is currently being discharged to a stream channel. This inventory should identify two such types of sites: 1) approaches to stream crossings where one or both approaching road segments (ditches or road surface) drain toward a stream channel (either to the culvert inlet or over the outside edge of the fill), and 2) ditch relief culverts or rolling dips that carry sufficient flow to cause an outlet gully to form which then carries runoff and sediment from the discharge point to a stream channel. Once the sites of existing or potential discharge are identified, treatments can be prescribed to eliminate the source of runoff and eroded sediment.

To solve the problem of fine sediment contributions from roads, identified sites need to be treated to minimize the discharge of road runoff and eroded sediment to streams. There are several effective ways to reduce the contribution of fine sediment from road ditches. In the inventory, one can simply identify and measure the length of roadside ditch which drains directly into each stream crossing in the basin. These are called "contributing" ditches. As a first choice of treatment, road-side ditches near stream channels should then be eliminated by outsloping the road bed and dispersing runoff rather than collecting and concentrating it in ditches.

Alternatively, ditch relief culverts or rolling dips (called "cutoff structures") could be installed just up-road from each stream crossing so that ditch runoff (and eroded sediment) is diverted and dispersed on the hillslope below the road rather than being discharged through the ditch and into the inlet of the stream crossing culvert. Culverts or dips (which intercept all ditch flow) would need to be installed within approximately 100 feet (or less) up-road of each crossing to achieve maximum effectiveness at reducing sediment contributions to the stream channel. Specific locations for the placement of ditch relief culverts or rolling dips need to be mapped in the field so that sediment and water from ditches can be effectively dispersed onto hillslopes below the road with no threat that it will enter the stream channel. In many instances, the remaining short section of road and ditch between the "cutoff" (rolling dip or ditch relief culvert) and the stream crossing can be outsloped.

Utilizing either solution (outsloping or installation of drainage cutoff structures), it is clear that not all the road ditches in the basin will have to be eliminated, just the ones that drain road and cutbank runoff directly into stream channels. Ditches which drain into ditch-relief culverts that then discharge water and sediment onto vegetated slopes below the road (without producing gullies) are not considered to have a potential for delivery of sediment into the watershed's stream channels. These latter sites are not treated.

Maintenance

Different requirements for maintenance accompany each of the different possible treatments for disconnecting roads and ditches from streams. Ditch relief culverts (a cutoff structure) require the greatest amount of maintenance to keep open and functional. Rolling dips, where they are used as an alternative "cutoff" to ditch relief culverts, require little or no maintenance (other than making sure the grader operator does not eliminate them accidentally). Likewise, road outsloping is a maintenance-free treatment that only requires proper road surface grading (making sure no outside berms are unintentionally constructed or left behind) to ensure that road and cutbank runoff is dispersed below the road rather than down the road and into the stream crossing.

Effectiveness

Each of the methods used to detach the road and ditch system from the stream channel network is highly effective. Compared to many other erosion control and erosion prevention treatments, the effectiveness is high and the costs are relatively low. Most of the work is conducted utilizing heavy equipment (tractor, excavator and/or backhoe), with some labor needed if ditch relief culverts are installed.

Sketches/Drawings

Figure 6-25 illustrates the strategy employed to disconnect road drainage from the stream system.

6.6.6 ELIMINATING DIVERSION POTENTIAL AT STREAM CROSSINGS

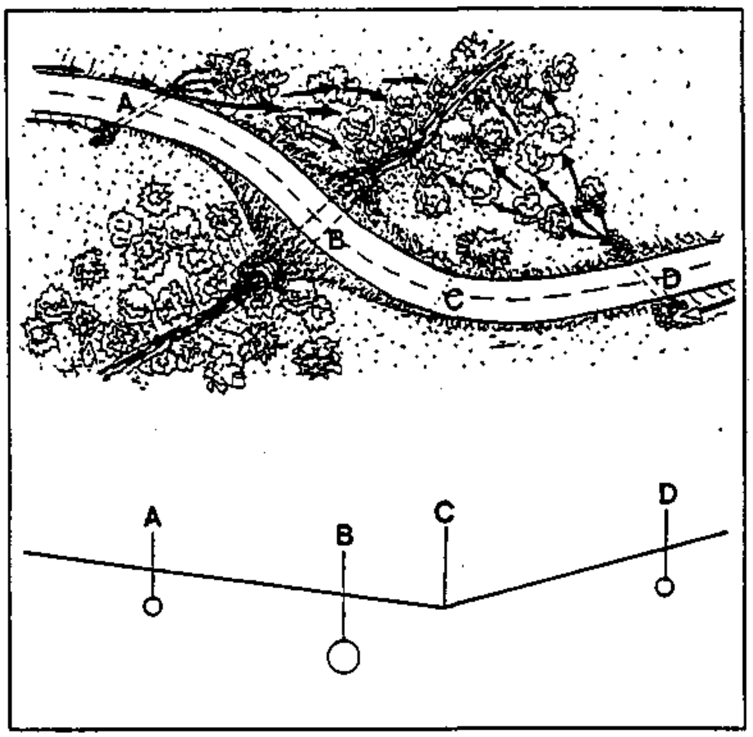
Description and Purpose

A significant source of fluvial erosion on managed wildlands originates from the diversion of streams at road stream crossings. Diversion of streamflow can occur if the stream crossing itself was constructed with a *diversion potential (DP),* where the road and ditch system slope away from the crossing in at least one direction. In this case, when the culvert plugs, stream flow diverts down the road and produces gullies on the unprotected road surface and on nearby hillslopes where the water is finally diverted off the road. Large streams can cause severe erosion and sediment yield. However, even small streams can cause large landslides and gully systems when they are diverted out of their channel.

Stream crossings with a diversion potential are "loaded guns" waiting for a large storm and flood to cause culvert plugging and stream diversion. The threat is compounded where the culvert is undersized or prone to plugging with sediment or woody debris. In contrast, when the stream crossing is constructed with no diversion potential, the stream backs up behind the road and eventually flows over the roadbed and right back into the natural stream channel; it does not divert down the road. At worst, the stream will only erode the volume of material placed in the fill crossing when the road was constructed.

Planning Criteria and Applicability

Treatments to prevent stream diversions are straightforward and inexpensive. All newly constructed stream crossings should be built with no diversion potential, by dipping the road into and out of the crossing. All existing stream crossings which currently have a diversion potential should be reconstructed or “reshaped” with a low point next to the crossing. In this manner, when the culvert plugs and the stream backs up and flows onto the road surface, the water will drain across the road (not down the road) and back into the natural channel. This reconstruction simply involves constructing a rolling dip (called a “critical dip”) immediately adjacent to the crossing, typically on the hinge line (that line which crosses the road at the junction between the stream crossing fill and the natural slope.



This diagram outlines the basic strategy employed to "disconnect" road drainage from the stream system. Rolling dips or ditch reflief culverts are installed at locations A and D to make sure that ditch runoff does not flow directly into the culvert inlet (location B). Instead, road and ditch runoff is dispersed on vegetated ground, and allowed to infiltrate into the soil below the ditch relief culvert. Ideally, road runoff never reaches the stream without first being filtered. Road runoff from the short section of road between A and B is dispersed either by outsloping the road or by directing it to a rolling dip built at location "C" where the runoff can be filtered in the natural vegetation.

Figure 6-25. Disconnecting Ditches from Streams.

Methods and Materials

The first two tasks in this RLMP are to: 1) make sure all new roads are planned, designed and constructed with critical dips at each stream crossing; and 2) inventory every existing road reach or road network to locate all stream crossings which currently display a potential for stream diversion. This inventory can be performed by landowners or equipment operators who have been trained to recognize stream crossings which exhibit a diversion potential. Some crossings are obvious and can immediately be classified, while others (on low gradient roads) are more subtle and may require detailed observations and the use of a clinometer or other slope measuring instrument.

On new roads, it is simple and adds little or no additional cost to make sure the road dips (slopes) into and out of each stream crossing during construction. The low point in the crossing should not be built directly over the culvert, which is often the deepest part of the fill. This could result in significant erosion and loss of the culvert if the crossing fill were to be severely eroded. Instead, the low point (critical dip) should be placed on the "down-road" hinge line which separates the native, intact bedrock materials from the newly placed fill materials of the crossing. This usually occurs within 10 to 30 feet on one side of the center-line of the crossing. When stream flow tops over the fill at this location, it encounters native hillslope materials and the rate and amount of down cutting is likely to be less than if it were centered over the center of the fill.

On existing roads, stream crossings that have been identified as having a diversion potential will require some heavy equipment treatment to reshape the road bed. As with new roads, a critical rolling dip needs to be constructed on the hinge line of the stream crossing fill. The steeper the grade of the road, the more difficult it becomes to build functional rolling dips. On roads steeper than about 10% to 15%, rolling dips become abrupt and steep, making commercial traffic difficult.

Critical dips have several important design criteria. The most important consideration is to make sure the dip is constructed on the down-road hinge line of the fill. Secondly, the critical dip must be the low point on the fill, so that stream flow will be captured and find its way through the dip rather than down the road, into the ditch or across the stream crossing fill at some other point. Often, the ditch adjacent to the rolling dip will have to be filled (plugged) so that stream flow will not be diverted down the ditch. It generally takes about one hour, using a medium-size bulldozer, to construct a critical rolling dip on an existing road. If the road is surfaced, it will need to be resurfaced following the excavation work.

Maintenance

If properly constructed, a critical rolling dip will not require maintenance. Grader operators will have to be trained to maintain the location and function of the critical rolling dips which are built at stream crossings. Poor road surface maintenance practices can quickly obliterate a critical dip, and render the structure non-functional.

Effectiveness

Construction of critical rolling dips to prevent stream diversion is perhaps the most cost-effective technique that can be employed to reduce road-related erosion in wildland watersheds. Properly located and constructed, critical dips are highly effective in minimizing road-related watershed erosion and damage to roads during heavy winter storms.

6.6.7 USING WET AND DRY FORDS

Description and Purpose

Stream crossing culverts are always prone to plugging and failure during large winter storms. When culverts plug, either the streamflow is diverted down the road (creating large gullies) or the stream crossing fill may wash out. Construction of a ford (instead of a culverted stream crossing) allows winter storm-flow to pass over the drainage "structure" without washing out the fill or diverting the stream. The road is built to dip into and out of the crossing, thereby minimizing the crossing fill volume. The bed of the ford is composed of either rock armor (that will not be eroded by the stream) or another non-erodible base (such as concrete). Where needed, the downstream edge of the ford is structurally built up with a non-erodible sill to make a level travel surface over the crossing.

Planning Criteria and Applicability

Not all stream crossings are suitable for the construction of fords. Fords work well on small to medium sized streams where there is a stable stream bottom and vehicle traffic is light. Compared to a culverted fill, they have the advantage of having little fill to wash out during flood flows. Unless wet fords are constructed of poured concrete, they are less desirable in high traffic areas because continued disturbance to the streambed can cause persistent downstream turbidity and fine sediment pollution problems. Dry fords on seasonal roads can often be installed and used with minimal impact to the channel system. In certain situations, where flash floods, high seasonal flood peaks or floating debris are problems, fords may be a practical answer for crossing a shallow stream.

Methods and Materials

Fords of live streams, called "wet fords," are typically composed of streambed gravels, fill, or concrete structures built in contact with the streambed so that vehicles can cross the channel. If possible, a stable, rocky (or bedrock) portion of the channel should be selected for the ford. Fords can be made of permeable trench drains of coarse cobbles and boulders. Low summer flows seep through the fill, and high water discharges flow over the top. During extreme events, however, the ford may be completely washed-out. Permeable fords may be a barrier to migrating fish and installation will require approval by the Department of Fish and Game.

Paving fords across live streams may be necessary to maintain water quality if there is to be regular traffic. Paving consists of a concrete, slightly dish-shaped slab across the watercourse, and a discharge apron or energy dissipator on the downstream side to prevent scour during high flows. The structure should be designed to pass both sediment and debris during high flows. Unless carefully designed and constructed, concrete fords are often plagued by scour around their edges, leaving the ford elevated and impassable. Ford structures are sometimes even moved downstream by large flood flows.

A ford crossing is vulnerable to erosion and can create pollution from several sources. High traffic levels and/or high water flows can cause erosion of both natural and artificial streambed materials. Material placed in the stream or moved about by vehicle traffic can create a barrier to fish migration. Deep water crossings can cause oil products to be released from vehicles as they pass through a wet ford. Streams with high stream banks require the excavation of substantial ramps to get vehicles down to the streambed. These through-cut ramps are often sites of surface erosion and rilling that enters the stream during periods of winter rain.

On small, shallow, ephemeral or intermittent streams a ford may be needed if there is insufficient channel depth to install a culvert. In fact, a rock-lined rolling dip with a rock apron face is generally preferable to permanent culverts on these swales and small watercourses. Fords have the advantage, over culverted fills, of never plugging. For shallow, dry channels, rock-lined dry-fords can be installed as long as they are completely "pulled" or removed at the completion of use, or before the beginning of the winter period (whichever occurs first). Dry fords work well where the approaches to the channel are relatively flat. The road is built to dip across the channel using as little fill as is possible, and any fill along the outside edge of the road can be armored with fabric and appropriately sized rip-rap, or with an over-side drain.

Fords on small streams should be rock armored to prevent erosion of the road surface and fill during periods of runoff. The fill face on the downstream side of the fill can either be protected with rock armor or fitted with a large overside drain (berm drain) to prevent erosion. Unimproved fords, which consist of a stream channel that has been filled with a substantial quantity of soil and left unprotected by armor or surfacing is a hazard to water quality and should not be constructed.

Maintenance

Fords will require periodic maintenance because of damage caused by vehicle traffic or by winter storm flows. Rock armor may need to be replaced when it is washed downstream. The downstream edge of a ford is often subject to erosion if a permanent sill and energy dissipation is not properly installed. Fords made of concrete may become cracked and fall apart if they are not built with steel reinforcing bars. Likewise, it is important to place large, stable energy dissipators at the downstream end of the ford to prevent undercutting and the development of a plunge pool.

Effectiveness

Used in the correct circumstances (shallow stream channels with moderate or gentle sideslopes), and built with appropriate materials (resistant to erosion and transport), fords have several distinct advantages over culverted stream crossings. The use of fords minimizes the volume of material in the stream crossing fill, and hence the potential volume of fill which could be eroded if the crossing were to wash out. In addition, fords are not subject to plugging and stream diversion as are culverted stream crossings. By their nature, ford crossings do not have a diversion potential. Hardened fords are also highly effective as stream crossings in locations where debris torrents commonly cross the road bed and would otherwise plug the culvert or erode the fill.

6.6.8 INSTALLING CULVERT DEBRIS BARRIERS (TRASH RACKS)

Description and Purpose

Floating wood is perhaps the most common cause for culvert plugging, and the consequent failure of stream crossings or diversion of streams during winter storms. A debris barrier (trash rack or debris control structure) at the culvert inlet is a key component of stable culvert design. It acts to prevent plugging of the culvert, and the subsequent overtopping of the fill by flood waters. Plugged culverts are the leading cause of stream crossing failures in the north coastal region and are perhaps the most common road maintenance issue along rural and forest road systems. Debris barriers can be used to lower the probability of stream crossing failure, as well as to reduce the frequency and cost of culvert maintenance.

Planning Criteria and Applicability

Culverts are prone to plugging when woody debris is wedged across the pipe inlet. Debris barriers are constructed upstream from culverted stream crossings where limbs and other large woody debris is likely to be transported downstream to the culvert inlet. Debris barriers are not typically installed at bridges or at ford crossings. In these locations debris is allowed to pass through or under the drainage structure.

Methods and Materials

Creativity and experience can be used to develop a successful design of a debris barrier. Drop inlet "trash racks" have proven to be effective in trapping debris without allowing the culvert to plug. If constructed incorrectly, wooden crib boxes built around the culvert inlet can become clogged with debris and plug the culvert, or significantly reduce its capacity to pass flood waters. The most common problem with trash racks placed over the culvert inlet is that small debris is often trapped by the structure rather than being allowed to pass through the culvert. This small debris can clog the trash rack and actually cause the inlet to plug. As a general rule, debris barriers which are constructed over the inlet to the stream crossing culvert are to be avoided unless the design has been proven to be locally successful.

The design of protective debris barrier structures has been varied, and there are as many successful designs as there have been failures. Debris control is best obtained by some type of grate or "filtering" structure built of inclined poles built across the channel just ***upstream*** from the culvert inlet. The size of the barrier, and the strength of the individual components, is a function of the size of the stream and the woody material it is capable of transporting. Large streams will require large and strong barrier structures. Table 6-7 presents is a guide for selecting an appropriate type of structure based on the dominant type of debris which can be expected.

Maintenance

Debris barriers, by definition, require regular inspection and maintenance. Debris must be removed from the barrier as it accumulates so that the barrier will continue to function as a filter. If the barrier is not cleaned, it may fail catastrophically and send a wave of debris into the culvert inlet, causing it to fail. Debris barriers should be inspected prior to each winter period and during and following each significant winter flood. Some streams will require more frequent inspection and maintenance than others, based on their ability to transport sediment and woody debris. If the barrier is constructed of wood, it will need to be replaced at least every 5 to 10 years.

Effectiveness

The effectiveness of debris barriers is dependent on the design and the maintenance of the structure. If it is improperly designed or poorly maintained, the debris barrier could actually hasten culvert plugging and stream crossing failure. Properly designed, installed and maintained, debris barriers are highly effective in protecting culverted stream crossings from plugging and failure during winter storms.

Sketch Drawings

Figures 6-26 and 6-27 show the design for two types of debris barriers, a debris deflector and a debris rack. Many landowners in the Navarro watershed have developed their own successful designs for debris barriers. One example of a trash rack design from a Navarro resident, for culverts up to 24" diameter, is to install a metal stake in the streambed about one diameter width away from the culvert opening. For larger culverts use two stakes slightly less than one diameter width away. This design has been used to prevent large debris from clogging the culvert, but allows smaller debris to pass through.

6.6.9 INSTALLING CULVERT DOWNSPOUTS (FLUMES)

Description and Purpose

Culvert outlet erosion can be a significant source of preventable erosion and sediment yield from rural and wildland roads. In many locations, “shot-gun” culverts (culverts which emerge high in the fill) cause significant gullying at the culvert outlets and created large gullies in the natural channel downstream from the outlet of the drainage structure. Even

Table 6-7. Guide for Selecting Type of Structures Suitable for Various Debris Classifications (USDT 1964).

Debris Classification	Type of Debris Control Structure							
	Deflector[1]	Rack[2]	Riser[3]	Crib[4]	Fin[5]	Dam & basin[6]	Boom[7]	Sloping inlet[8]
Light floating debris[9]		X		X			X	
Medium floating debris[10]	X	X					X	
Heavy floating debris[11]	X				X			
Flowing debris[12]			X			X		X
Fine sediment[13]			X			X		X
Coarse sediment[14]			X	X		X		X
Boulders[15]	X							

[1] *Deflector:* structures (normally V-shaped) placed at the culvert inlet to deflect debris away from the entrance
[2] *Rack:* structures placed across the stream channel above the culvert inlet to collect debris before it reaches the inlet
[3] *Riser:* a closed vertical structure (usually a pipe) placed over the culvert inlet to cause deposition before flow enters the culvert
[4] *Crib:* open crib-type structure placed vertically over culvert inlet in log-cabin fashion toprevent inflow of coarse sediment and light floating debris
[5] *Fins:* walls and posts built into the channel upstream of the culvert to align woody debris so that it will pass through the culvert
[6] *Dams and basins:* structures placed across well defined channels to form basins which impede streamflow and provide storage space for sediment and debris
[7] *Boom:* logs which float on the water's surface (usually a lake or pond) to collect floating drift before it reaches the culvert inlet
[8] *Sloping inlet and flared inlet:* smooth bottom, funnel shaped, sloping entrance to culvert increases flow velocity and prevents plugging by sediment
[9] *Light floating debris:* small limbs and sticks
[10] *Medium floating debris:* limbs and large sticks
[11] *Heavy floating debris:* logs or trees
[12] *Flowing debris:* fluid mass of fine and coarse sediment and woody debris
[13] *Fine sediment:* silt, sand and small gravel
[14] *Coarse sediment:* coarse gravel, cobbles and small boulders
[15] *Boulders:* large boulders and rock fragments carried as bedload at flood stage

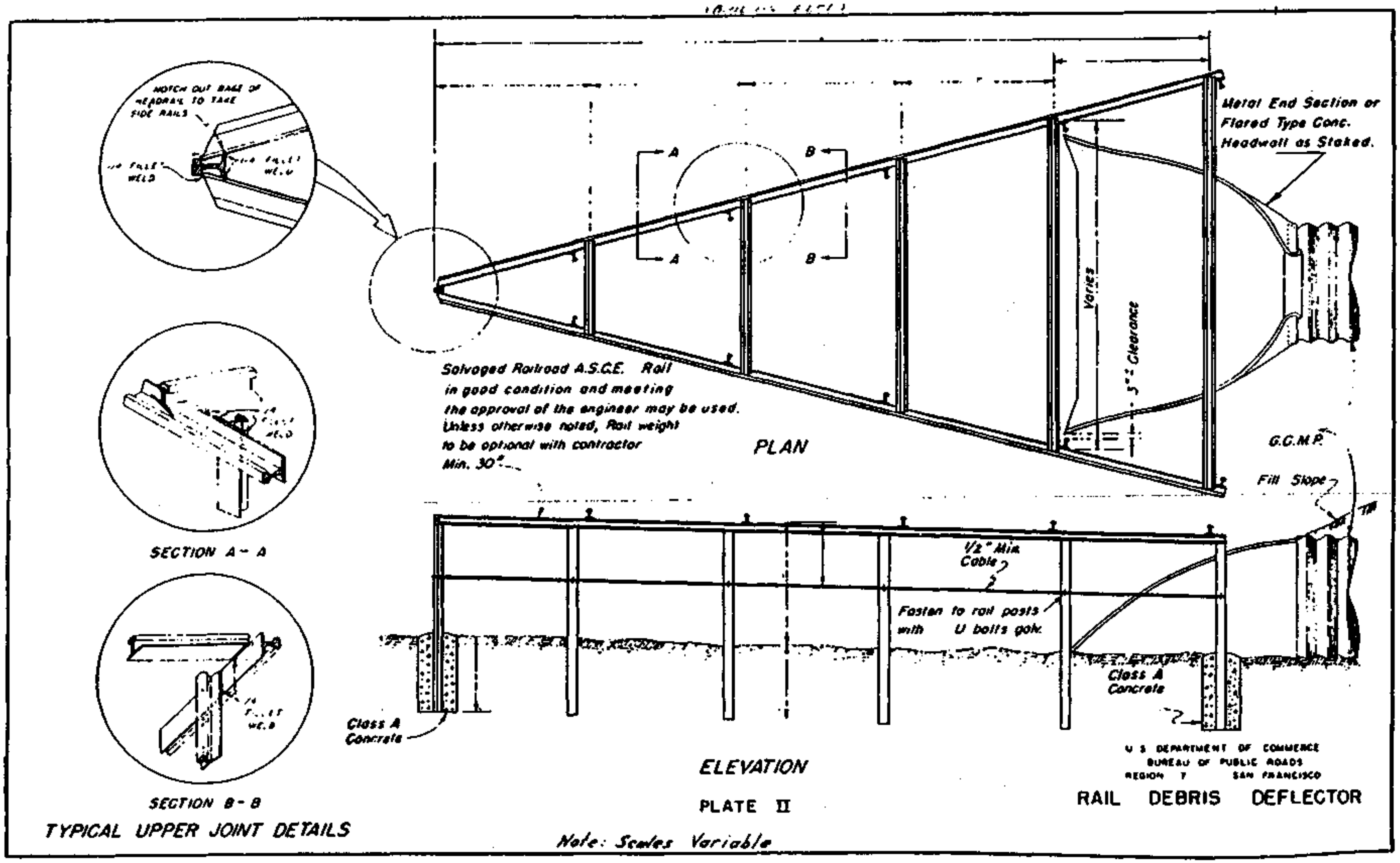


Figure 6-26. Debris Deflector.

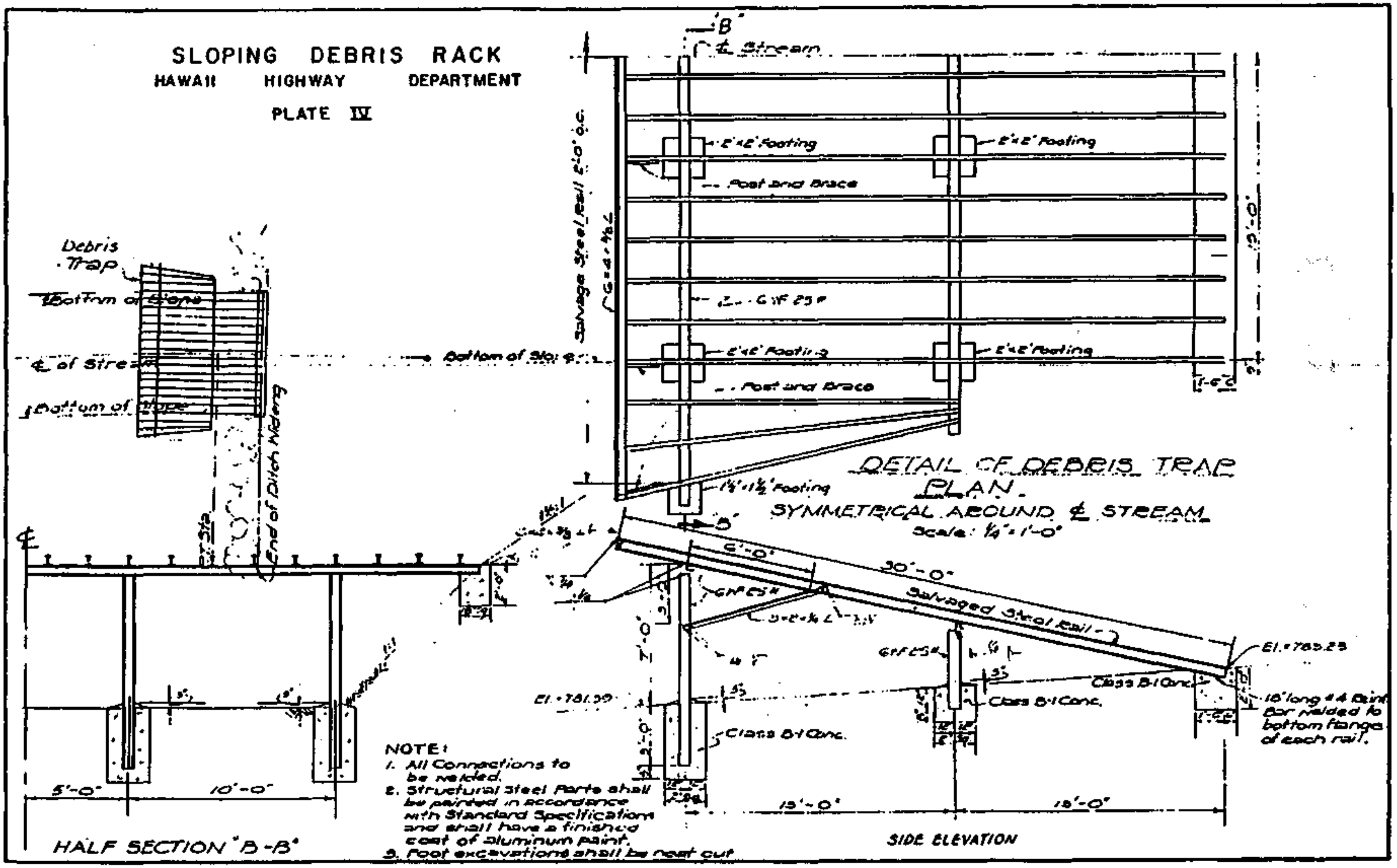


Figure 6-27. Debris Rack.

many older culverts continue to erode and gully through loose fill materials. Energy dissipation, including half-round downspouts and rock armor, are common methods for controlling outlet erosion. These structures may be needed on both ditch relief culverts and stream crossing culverts to prevent high velocity culvert flows from eroding the channel bed or banks or the road fill at the culvert outlet.

Planning Criteria and Applicability

Culvert outlets (at both stream crossings and ditch relief culverts) should extend past the end of the road fill and discharge into the natural channel. If the outlet exits midslope, a flume or downspout should be attached to the pipe end and extended past the fill before flow is discharged into the channel or onto the natural slope. Rock armor or other energy dissipation should be used at the outlet of culverts and flumes to prevent erosion by the fast moving flow. Outlets that are experiencing erosion should be armored or fitted with a downspout.

Methods and Materials

Culvert downspouts may be either full-round or half-round pipes, and they may be either the same diameter, or one size larger diameter than the pipe which emerges from the fill. All downspouts should be designed to carry flow past the base of the sidecast or stream crossing fill and discharge the concentrated flow onto non-erodible materials. Flow through steep culvert pipes is typically rapid. Some type of energy dissipation may be needed if flow velocities or flow volumes are high and would otherwise erode the discharge area.

Half-round downspouts are simple to install. Full round downspouts require a fabricated elbow at the culvert outlet so the downspout can turn downward to follow the fillslope angle. Half round metal downspouts are fabricated from full round culverts by cutting with a metal torch. They are preferable to wooden flumes and sheet metal troughs because of their longer life and durability. Half-round downspouts are typically bolted to the outlet end of the existing culvert, laid along the fillslope and terminated in the natural channel or hillslope. They come in 20 foot lengths and will have to be bolted together to span longer slope distances. If downspouts are to be longer than 20 feet, they should be secured to the hillslope using metal fence posts, bolts and bailing wire.

Maintenance

Half round downspouts can twist or turn (and spill their water) if they are undercut on the fillslope or hit by falling limbs or trees. Half round downspouts will need periodic inspection and maintenance to make sure water is contained in the flume, and that the separate segments do not become detached. If the slope fails or moves slightly, or a falling tree hits the downspout, the segments can detached. Full round downspouts should need less maintenance.

Effectiveness

Ideally, culverts should be installed at the base of the fill and their outlet should extend all the way past the base of the fill. However, many older culverts were installed high in the fill. Downspouts are an effective means of controlling or preventing culvert outlet erosion in these locations. Culvert downspouts up to 24 inches in diameter can usually be installed by hand labor, but larger diameter downspouts will require the assistance of a backhoe to lower and hold the pipe in place.

6.6.10 Road Maintenance Practices

Description and Purpose

Regular road inspection and maintenance is essential to protect roads and to prevent environmental damage. Roads and drainage structures along all roads should be inspected annually, at a minimum, prior to the beginning of the rainy season. Inspections should cover culvert inlets and outlets on stream crossings, ditch relief culverts, and road surface drainage such as waterbars, outsloping, and ditches. In addition to annual, pre-winter road and drainage structure inspections, crews are needed to inspect and perform emergency maintenance during and following peak winter storms.

Maintenance should address the road surface, cutbanks, and fillslopes, as well as drainage structures and erosion control measures. Road maintenance practices include tasks which improve road drainage and tasks which improve road stability. Work may include culvert cleaning, repairing culverts and drainage structures, improving road surface drainage (reshaping, adding rolling dips, adding ditch relief culverts, etc.), and repairing road instabilities. Some of the most important winter maintenance can be performed by hand labor, keeping culvert inlets clear and open. Other problems will require the use of backhoes or other heavy equipment to move large amounts of sediment and debris. All roads which are not properly closed or decommissioned require maintenance.

Planning Criteria and Applicability

Road maintenance, by definition, is designed to improve the condition of a road system and to prepare it for winter storm periods. At the same time, many road maintenance practices can directly impact stream resources if they are not carefully undertaken. All roads used for vehicle travel should be regularly inspected and maintained according to an established or written schedule. If personnel and resources cannot be committed to providing regular maintenance, roads should be built (or rebuilt) as temporary, and then properly closed (decommissioned) upon the completion of operations, but before the first winter period. Temporary roads that have been properly closed do not need continued maintenance and pose little threat to downstream resources. Subdivisions and other multi-owner road systems should develop plans for both emergency maintenance and long term inspection and maintenance activities. Unless written agreements state otherwise, road maintenance is the responsibility of the owner of the property on which the road is located.

Methods and Materials

Specific techniques can be employed to increase the effectiveness of road maintenance practices and improve the protection to stream resources. These observations, not listed in order of importance, include the following general practices:

1. Winter road use: The first rule of maintaining a stable road surface is to minimize hauling and grading during wet weather conditions, especially if the road is unsurfaced.

2. Summer road use: Heavy traffic or hauling on a dry road bed in the summer can churn and pulverize road surface material and create thick, loose layers of soil and rock powder (dust). Summer hauling should be accompanied by dust control and watering to maintain the road surface condition.

3. Grading roads: Road surfaces should be graded only when needed to maintain a stable, smooth running surface and to retain the original surface drainage. Over grading results in unnecessary erosion and increases road surface rock wear.

4. Unwanted berms: Berms that are created by road surface grading often concentrate runoff during winter rains and should not be left along the outside edge of the road. When re-grading roads, avoid constructing berms along the outside edge of the road, where it would act to collect and concentrate road surface drainage. Remove berms where they have been inadvertently constructed by years of grading. Where past grading has piled good surfacing materials along the outside edge of the road, it can be retrieved and worked back into the road bed.

5. Ditch grading: Frequent, routine mechanical grading of ditches is usually unnecessary and can cause erosion of the ditch, undermine cutbanks, and expose the toe of the cutslope to erosion. Ditches should be graded only when and where necessary. Routine mechanical ditch grading should be avoided.

6. Maintenance of seasonal roads: Unsurfaced seasonal roads require almost the same maintenance effort as permanent all-season roads, but are much more sensitive to wet weather use. These roads should not be used when wet, and hauling or other intensive vehicle activity should be limited to dry periods when soils retain their maximum natural strength.

7. Seasonal closure of roads: Gates can be used to discourage wet weather use, but the use of gates or other barriers does not eliminate the need for annual and emergency winter maintenance inspection and repairs.

8. Stream crossing maintenance: Summer culvert inspections and maintenance is often performed at the same time as ditch maintenance. The critical component of successful culvert maintenance is to fix problems before complete failure occurs.

Culverts inlets, and trash racks located upstream from culverts, need to be regularly inspected and cleaned of woody debris to prevent plugging.

9. Cut slope and fill slope maintenance: The key to maintaining cut slopes and fill slopes, including sidecast materials, is to observe and note when and how changes to these features occur. Corrective measures can then be implemented, depending on the problem.

   a) Cut slopes - Typical cutslope problems include excessive raveling, rilling, and slumping which may block the ditch or require frequent ditch cleaning and maintenance. In the long term, it may be necessary to flatten the cutlope, revegetate bare soil areas, widen the ditch (so that it does not plug so easily), install ravel barriers on the slope and at the base, and/or build a retaining structure to contain or prevent slope movement. Often, simply loading the toe of a small cutbank slump with heavy riprap can provide sufficient weight to stabilize the feature. Stabilizing or controlling the movement of larger unstable areas may require analysis by an engineer or engineering geologist.

   b) Fill slopes - Regular inspection and prevention (including excavation) is the key to maintaining stable fillslopes and sidecast areas. Unstable fillslope materials should be excavated and removed, including organic debris, ***before*** they fail. If the potential instability is perched above a stream channel immediate treatment is usually required. Larger fill slope landslides, including those that include the hillslope below the road, may be difficult or effectively impossible to stabilize. Stabilizing or controlling the movement of larger unstable areas may require analysis by an engineer or engineering geologist.

10. Winterizing roads: Before winter, all permanent, seasonal and temporary roads should be inspected and prepared for the coming rains. Winterizing consists of maintenance and erosion control work needed to drain the road surface, to ensure free flowing ditches and drains, and to open all culverts to their maximum capacity. On unsurfaced roads, waterbars may be required at spacings dictated by the road gradient and the erodibility of the soil. Trash barriers, culvert inlet basins and pipe inlets should all be cleaned of floatable debris and sediment accumulations. Ditches that are partially or entirely plugged with soil and debris should be cleaned and heavy concentrations of vegetation which impede ditch flow should be trimmed. This is also the best time to excavate all unstable or potentially unstable fills and sidecast which could fail and be delivered to a watercourse during the coming winter. Once seasonal and temporary roads have been winterized, they should be gated and closed to "non-essential" traffic.

11. Spoil disposal: Spoil material should be hauled to a stable site safely distant from streams, contoured to disperse runoff and stabilized with mulch and vegetation. Excess spoil from maintenance activities should never be sidecast near streams. Berms of excess spoil along the road shoulder should be removed or frequently breached prior to the rainy season. Avoid sidecasting on

approaches to incised stream crossings which are being rebuilt, replaced or widened. Endhaul spoil material, instead of sidecasting, where there is any likelihood of sediment reaching the channel system, especially in rocky slope areas or where soils are locally known to be highly erodible or prone to instability.

12. Outsloping roads: Where feasible, convert insloped roads to a gentle outslope and remove the ditch. If the ditch is necessary, the road surface can still be outsloped. Outsloping roads in appropriate locations can reduce both maintenance requirements and soil erosion.

13. Rolling dips: Emphasize the increased construction and use of rolling dips to drain road surfaces. Rolling dips can also be used to drain the ditch at regular intervals. They are used as a low maintenance, low cost alternative to ditch relief culverts and waterbars.

14. Trash barriers at stream crossings: Construct trash barriers on large or active streams which transport debris. They should be placed somewhat upstream from culvert inlets, to protect the inlet against plugging with organic debris. Trash barriers will require periodic inspection and cleaning, but their use can prevent expensive and damaging stream crossing failures. Smaller stream crossing culverts (up to 24 inch diameter) that have a history of plugging with debris can be protected by installing a fence post about two feet above the culvert inlet. This acts to turn small debris so that it will pass through the culvert and to block large debris that would otherwise plug the inlet.

15. Culvert downspouts: Shot-gun culverts (those which emerge from the fill and discharge flow on erodible sidecast materials) often create large scour holes and/or gullies. Downspouts should be installed on newly installed and existing culverts which show any sign of continuing outlet erosion, in order to carry flow to natural ground below the base of erodible fill material.

16. Culvert sizes: Standardize the practice of using 18-inch culverts as the minimum sized ditch-relief pipe utilized in new road construction and culvert replacement projects, and 24-inch culverts as the minimum diameter for stream crossings.

Maintenance

By definition, most of the features of an active road require regular inspection and maintenance. Especially critical components include stream crossing drainage facilities (especially culvert inlets), road surfaces (to ensure proper drainage), and road fill slopes (especially unstable fill slopes on steep slopes near stream channels).

Effectiveness

Regular inspection and maintenance of roads and their drainage facilities is the only way to minimize unnecessary soil erosion and sediment delivery. First, roads need to be upgraded. Poorly designed and constructed roads will yield substantial eroded sediment regardless of the amount of maintenance that occurs. Second, all permanent (all-season) and seasonal roads must be inspected and maintained before each winter and after each major winter storm (or as problems arise). To be effective, sufficient resources (personnel and equipment) must be available and obligated by the land owner to inspect and maintain roads on the property.

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6.7 HILLSLOPE EROSION CONTROL PRACTICES

RLMP 6.7.1, *Grading and Erosion Control Practices for Construction Sites***,** addresses the general principles and describes specific methods for controlling sediment production from construction sites. Modifications of logging practices to reduce the potential for erosion and sediment production to streams is provided in RLMP 6.7.2, *Timber Harvest Practices*. RLMP 6.7.3, *Gully Prevention and Control Practices*, provides a prioritized approach and some specific measures for preventing and remediating gullies. Prevention and control of sediment production associated with row crop, orchards, and vineyard land-uses are addressed in RLMP 6.8.4, *Agricultural (row crop, orchard, and vineyard) Erosion Control Practices for Uplands and Riparian Corridors*.

6.7.1 GRADING AND EROSION CONTROL PRACTICES FOR CONSTRUCTION SITES

Description and Purpose

Soil erosion and sedimentation from construction sites can be many times greater than that from agricultural and forest practices because of the extreme degree of soil disturbance. As residential pressures and construction activities increase in the watershed, this source of sediment will become more and more important. However, most of this erosion can be significantly reduced by proper planning and construction, and the application of specific erosion control measures at construction sites.

The general principles for controlling sediment from construction sites include the following: 1) diverting clean water from upslope areas around the site (to minimize the amount of water that must be dealt with), 2) minimizing the size of the construction area and the duration of disturbance, 3) employing temporary erosion control measures during construction, 4) protecting drainage and runoff channels which will carry concentrated runoff from the construction site and 5) maintaining each installation and measure to ensure each continues to function for its needed life. A host of specific techniques are available to meet each of these objectives, depending on site conditions.

In addition to sediment from construction sites, other forms of water pollution associated with residential and commercial development are likely to affect water quality in the Navarro watershed, particularly in the more developed areas such Boonville and Philo. Typically, water pollution in developing areas will include oil and grease, nutrients (nitrogen and phosphorus), trace metals, and organic matter. Land-use activities associated with farming may also contribute to water quality problems due to fertilizer use which can add nutrients to waterways, and to pesticides. Roads and highways may contribute runoff contaminated with hydrocarbons and asbestos to stream channels. Illegal dumping is another source of both land and water pollution, as illegally dumped materials may enter streams directly or may leach contaminated water that enters surface and groundwater. These potential water quality problems were not investigated as part of the Navarro watershed restoration planning studies, and are not believed to be an important factor affecting the steelhead trout and coho salmon fishery. Therefore, these types of water quality problems are not specifically addressed in this report. However, as residential and commercial development expands, and farming activities continue in the watershed, consideration should be given to methods for preventing and remediating such water quality problems.

The most recent, well-proven methods for addressing water quality problems due to nutrients, oil and grease, trace metals, and organic matter include the following:

- grassy swales
- oil/sediment separators
- wet ponds
- inlet filters
- porous pavements
- detention basins

Descriptions of these treatment methods, including effectiveness, design, benefits, maintenance, and costs, are provided by the Bay Area Stormwater Management Agencies Association (Richman 1997 and Lichten 1997).

Planning Criteria and Applicability

Erosion control at construction sites can be divided into a number of best management practices applied to provide both temporary and permanent control of sediment. This RLMP will outline the basic practices to minimize the off-site impacts of construction practices on streams. A complete description of each practice, in its various forms, is beyond the scope of this RLMP. However, readily available references (Goldman *et al.* 1986) can provide additional detail on each of the following elements. These erosion control practices are divided into the following basic elements:

1. Diverting flow
2. Managing overland flow
3. Trapping sediment in channelized flow
4. Establishing permanent drainage ways
5. Protecting inlets

Generally, temporary measures may not require engineering analysis and design, whereas permanent drainage and earthwork facilities are likely to need more detailed design work. The County Planning and Building Department, as well as other state agencies (e.g., Department of Fish and Game; Department of Forestry and Fire Protection; North Coast Regional Water Quality Control Board), may have additional requirements for residential and commercial construction projects which are expected to create large areas of bare soil which could impact water quality.

Methods and Materials

Diverting flow - Flow diversions are created or constructed to collect and divert surface runoff around disturbed areas or construction sites to a location where water can be discharged without scouring stream channels or impacting receiving waters. Channels are constructed upslope of disturbed areas, upslope of spoil piles, or in areas to divert runoff to detention basins. Channels should be designed to accommodate the 25-year, 24-hour discharge. The channel should have a trapezoidal cross section with stable sideslopes. It should be excavated into natural ground and sloped such that flow velocities are non-erosive. The channel side slopes should be stabilized with straw mulch and seeded for rapid revegetation. If the channel is to carry discharges which are erosive, the channel should be lined with an erosion control fabric, rock armor, or other stabilizing material along the bed and banks.

Managing overland flow - Overland flow refers to runoff that is flowing over the surface of the land but has not yet collected into channels. Generally, areas subject to overland flow are small in size. Treatments are generally placed on bare slopes (to protect the soil) and on the downslope side of such areas (to capture eroded sediment) as a means of controlling erosion and preventing runoff from causing rilling and gullying.

Cost-effective treatments for bare soils include the following treatments: silt fences, straw bale fences, mulching, and sodding and mulching (including hydroseeding). The former two practices (both forms of sediment fencing) are used to intercept and detain runoff and eroded sediment. The latter two practices are designed to prevent erosion and sediment transport on the bare soil areas of a construction site or disturbed area.

Silt fences consist of geotextile fabric or woven fabric stretched across and attached to supporting posts (usually metal fence posts) and entrenched six inches into the ground.

Straw bale fences consist of a row of entrenched and anchored straw bales. Both types of fences are built on contour across a hillslope. The ends of each fence should be turned upslope to contain runoff and sediment.

Silt fences and straw bale fences are equivalent practices used to intercept and detain storm water runoff and prevent sediment from leaving a construction site. Straw bale fences are generally used to contain small amounts of sediment. Both types of fences are placed around spoil piles and on the downslope side of bare soil areas less than about 10 acres in size. If a channel passes through a disturbed area, fences should be placed along the channel edges to prevent eroded soil from entering the watercourse or channel.

General guidelines for the spacing of both types of fencing on disturbed hillslopes is shown in Table 6-8. Parallel fences may be needed on long slopes or where slopes are steep. The slope behind the fence should be no greater than 50% (2:1). Silt fences and straw bale fences are not designed for use in streams, swales or ditches where concentrated flow is expected. Sediment retention fences within a bare soil area will be more useful and effective if natural runoff from above the construction site is diverted around the disturbed area. Where practical, sediment fences should be installed prior to disturbing the area upslope from the fence.

Mulching and seeding are techniques used to minimize or prevent soil erosion from occurring on bare areas. They are usually used in conjunction with sediment fences. Mulching acts to protect the soil surface from raindrop erosion and minor rilling, and it creates a favorable microclimate for seedling establishment. Mulching can include simple materials such as straw or wood chips, or more specialized nets and mats of various compositions. Straw mulch should be applied at a rate of at least 3,000 to 4,000 lbs/acre (70 - 90 lbs/1000ft2 (1 bale = 80 lbs)). A good application should conceal most of the bare soil beneath. In windy areas or where slopes are steeper than about 40%

Table 6-8. Suggested Maximum Slope Length Between Parallel Erosion Control Fences for a Given Slope Gradient.

Slope (%)	Maximum slope length (ft)
<2%	100 feet
2% - 5%	75 feet
5% - 10%	50 feet
10% - 20%	25 feet
> 20%	15 feet

Table 6-9. Sediment Trapping Techniques for Various Drainage Areas.

Drainage area of project site (acres)	Typical sediment trapping technique
Less than 2 acres	filter fabric barriers straw bale barriers temporary diversions
Less than 5 acres	sediment traps
Less than 150 acres[1]	sediment retention basins

[1]Regardless of the project area, disturbed sites greater than about 10 acres of bare soil will require the construction and use of at least one sediment retention basin. Large sediment retention basins should be designed by a qualified engineer or erosion control specialist.

(2.5:1), straw will need to be secured to the soil surface either by punching, by the use of a covering net, or a tackifier. The application procedures for mats or nets are provided by the manufacturer of the erosion control materials and should be closely followed. They typically involve overlapping guidelines and stapling instructions.

To be effective, seeding should be performed prior to October 31 so that a well established ground cover has been established when heavy rainfall occurs. Seeding usually employs a mixture of grass and legumes, but can also include native brush and tree species for a more permanent vegetative cover. Seeded areas should be mulched after the seed has been applied so that both immediate and long term protection will be afforded. Depending on soil conditions, fertilization may be needed to develop a continuous cover. Preferred rates for seeding and fertilization are area-specific and are available from seed distributors, the NRCS, and the UC Cooperative Extension.

Trapping sediment in channelized flow - Channelized flow refers to concentrated runoff flowing through depressions, swales or channels. This RLMP describes how to trap sediment carried by channelized flow. The specific practices to be employed vary with the drainage area of the project site (Table 6-9). Each of the available practices cause flow velocities to slow sufficiently to allow coarse sediment to settle out and accumulate behind barriers or traps.

For small drainage areas, where channels are to carry low discharges and low velocity flows, diversions and barriers can be employed to trap sediment. *Filter fabric and straw bale barriers* (as shown in the attached diagrams) are constructed perpendicular to and across the channel and entrenched into the channel and sideslopes. The spacing between barriers is determined by both drainage area and channel slope. Each fence should have a contributing drainage area not exceeding 1 to 2 acres. The difference in elevation between fences should not exceed two-thirds the height of the barrier. Straw bale barriers are often employed in areas of lower discharge and slower velocity, and are never used in intermittent or perennial streams. They are typically less effective than filter fabric barriers.

Sediment traps are small temporary basins designed and constructed to trap sediment in channelized flow courses. They are useful for drainage areas less than about 5 acres and have an efficiency of 70% to 80% (clay-sized particles will not settle out in these small basins). The trap should have a length:width ratio of not less than 2:1, a minimum depth of 2 feet and embankment sideslopes of 2:1, or less. The outlet of the basin should be sized for the 25-year flow and should have energy dissipation to prevent erosion. The maximum height of the sediment trap embankment (crest) should be 5 feet, with a top width of four feet and an outlet elevation at least one foot below the embankment crest.

Sediment basins are the largest of the sediment trapping devices described here. They are used where drainage areas are less than 150 acres where other sediment retention devices are not adequate to prevent off-site sedimentation. These large structures may come under the definition of “dams” and may be subject to other local, state or federal codes (check with the California Department of Fish and Game and the California Division of Dam Safety). Sediment basins and embankments should be designed by an engineer or erosion control specialist. The basin should include a principal spillway, a dewatering outlet and an emergency overflow spillway. The length/width ratio of the basin should be between 2:1 to

5:1, the latter being preferable. The sediment storage volume should be sufficiently large to contain the estimated annual sediment volume from the drainage area. The principal spillway (typically a horizontal culvert with an anchored vertical riser in the retention basin) should have a 10-year, 24-hr peak flow capacity. It should also have dewatering holes to allow for dewatering of the basin in no less than three days following a runoff event. The culvert inlet should have a debris barrier to prevent plugging. The embankment should have a minimum top width of four feet and sideslopes of 2:1, or less. The native soil beneath the embankment should be stripped of organic debris prior to construction. An emergency overflow spillway should be constructed to have sufficient design capacity for the 25-year, 24-hr flood. It should have a minimum elevation of at least one foot higher than the principal spillway. Its outlet should be protected with energy dissipation and it should discharge to a stable drainage way. For safety, sediment basins should be surrounded by fences.

Establishing permanent drainageways - Some construction sites will create locations for permanent channels or waterways. These channels will require permanent stabilization practices to protect them from erosive flows. The three main types of permanent channels include grassed waterways, geotextile-lined grassed waterways and rock or concrete lined waterways.

Stabilization of newly constructed channels will occur through the use of vegetation in combination with physical structure (armoring). The types of channels where this practice is suitable includes active swales, ditches and diversions. In general, channels can be lined with vegetation to control erosion if velocities do not exceed 3 to 4 ft/sec. Generally, channels less than about 3% gradient may remain unlined. If flow will intermittently exceed these velocities, if flow is to be continuous, or if the channel is steeper than 3%, the channel should be lined with geotextile fabric or rock rip-rap. In all cases, channels should have sufficient capacity to conduct the 25-year, 24-hour peak storm discharge, with no steeper than 2:1 sideslopes.

Of the three, *Grassed waterways* are the least protective method for channel stabilization. They consist of a constructed channel that is shaped or graded to required dimensions and established with vegetation that is suitably dense so that the channel remains stable during flow events. They are employed to protect the soil surface of ditches and small channels from erosion and to slow the velocity of flowing water. Grassed waterways need to be constructed and completely vegetated prior to receiving expected runoff.

Where flow velocities are expected to be high, geotextile fabrics can be used to anchor and reinforce the vegetation to produce *geotextile-lined grassed waterways*. Manufacturers provide specific design criteria and installation instructions for a variety of channel applications and one or more products. These instructions should be closely followed to assure project success and channel stability, especially in regards to the burial of fabric edges and fabric overlap procedures. Fabric linings serve as temporary channel protection until vegetation can become suitably established. A variety of natural fabrics (such as jute netting) and synthetic materials and grids can be employed to protect the channel under moderate and high velocity settings.

Gravel and rock is the simplest and most traditional type of channel lining. Depending on the availability of rock, it may also be relatively expensive. Rock linings can be made to withstand most stream velocities if the proper size rock is chosen. The construction procedure is to: (1) construct channel, (2) place a filter layer of finer material (or filter fabric) on the soil, and (3) place the layer of rock on the filter layer. It is important the rock is placed not only on the channel bed but also up both channel banks to an elevation above the design flood level. Engineering tables exist for selecting proper rock diameter based on the channel bottom slope and channel dimensions, and for determining proper rock size based on a calculation of expected flow velocities in the channel (for example, see the "Erosion and Sediment Control Handbook," 1986, by Goldman and others).

Protecting inlets - The above listed measures are not 100% effective in preventing erosion. For this reason, it is important to provide filtering of storm water at all conveyance structure inlets to prevent sediments from reaching lakes, streams and other water bodies. Thus, all temporary storm drain, catch basin, and culvert inlets at construction sites should be protected with straw bale barriers, filter fabric barriers or equivalent filtering mechanisms. The design of the filtering mechanism or barrier is similar to that for sediment traps where flow velocities are slowed and sediment is allowed to drop out before water is conducted through the pipe and discharged into the receiving waters.

Maintenance

Maintenance of each practice will be necessary to ensure proper functioning. Above all, the entire site needs to be thoroughly inspected following each rain to ensure that all possible sediment sources have been identified and properly treated. Any untreated sources will need immediate treatment. Most specifically, all structures need to be inspected after the first storm flow, and on a regular and frequent basis for at least the first year after that, to ensure they continue to function as designed and constructed. Any problems that develop need to be repaired immediately. In addition, sediment retention and sediment filtering structures need to be emptied of deposited sediment on a regular basis prior to reaching 50% of their storage capacity.

Diversion channels and grass-lined waterways need to be inspected and maintained until at least such time as the vegetative cover is completely established. Silt fences need to be inspected within 24 hours of each rainfall or daily during prolonged rainfall. Repairs need to be made immediately. Straw bale barriers need regular inspection for undercutting and flow between bales. Mulching that has moved or become ineffective should be immediately supplemented with additional mulch until vegetation is suitably established. Seeding may need to be watered immediately after planting to develop a continuous cover. Seeded areas will need to be reseeded if the ground cover is not complete.

Effectiveness

Structural erosion control and erosion prevention measures require proper construction to function effectively. Poorly or improperly constructed measures will not function, and can sometimes cause erosion that would not otherwise have occurred. Most sediment retention measures have a design efficiency of about 70% to 80%, with the fine sediments (clay) passing through the system and into receiving waters. Most erosion control measures (mulching and seeding) can be highly effective at controlling fine sediment loss and movement from bare soil areas. Channel erosion control measures can be effective if properly designed and installed, but improper construction can result in serious erosion and downstream sedimentation. Finally, frequent inspection and maintenance is key to having a highly effective erosion and sediment control program at construction sites.

Sketches/Drawings

Typical installation measures for straw bale fences (Figure 6-28), silt fences (Figure 6-29), diversion structures (Figure 6-30), sediment traps (Figure 6-31), and straw bale barriers and pipe slope drains (Figure 6-32) are attached. Table 6-10 summarizes surface erosion control and revegetation practices for construction sites.

6.7.2 Timber Harvesting Practices

This RLMP is intended to supplement the Forest Practice Rules for landowners who wish to ensure that their timber harvest activities do not adversely impact water quality and fish habitat. Landowners interested in protecting stream resources may find it necessary to go beyond the minimum requirements of the Forest Practice Rules, and to establish more comprehensive and higher standards for timer land management and timber harvest operations.

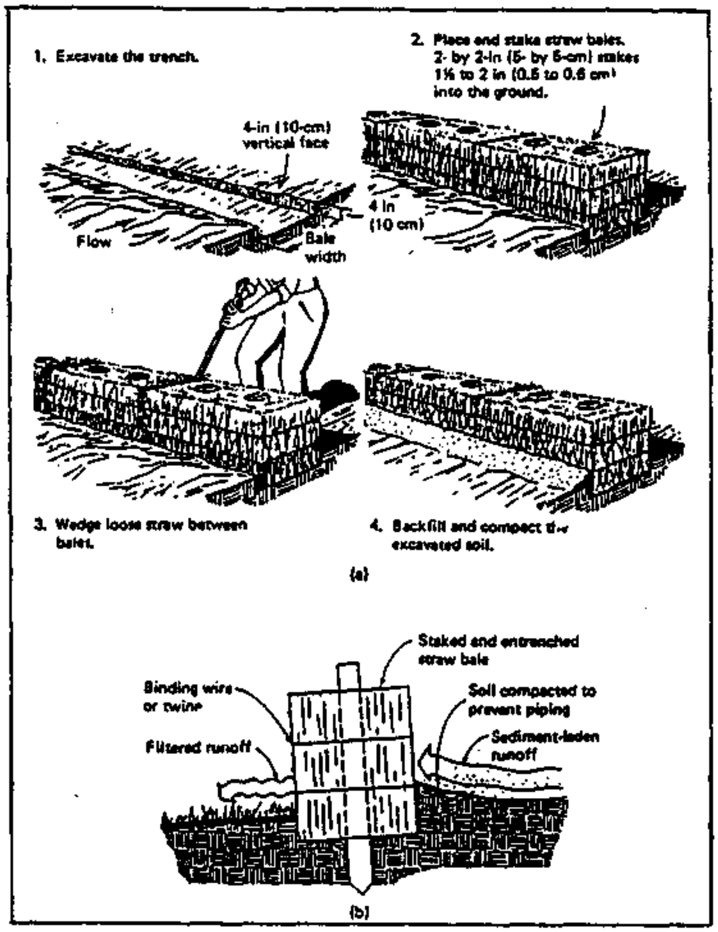
Timber operations of particular concern for their potential impact on streams, and which may not be adequately addressed in the Forest Practice Rules, include harvesting and road building on steep, potentially unstable inner gorge slopes, on steep streamside slopes, and within riparian areas. Recommendations to address road-related impacts are discussed in the RLMP's in Section 6.6 of this section. Additional recommendations to address impacts related to timber harvest on unstable slopes and in riparian areas are discussed below. Timberland owners should consider these recommendations when drafting their THP's or NTMP's, and in the general management of their lands.

Description and Purpose

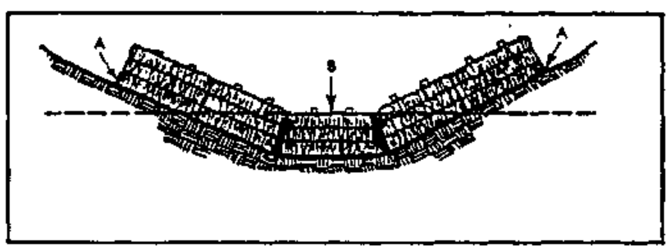
Certain types of timber harvesting practices, including road building, conducted on steep and/or unstable hillslopes can result in increased rates of landsliding and sediment delivery to stream channels. In many coastal watersheds, including the Navarro River, this is one of the leading sources of management-related sediment production and yield. Road construction on these slopes can result in relatively high rates of road failure, sidecast failures, persistent maintenance problems and high maintenance costs. Modification of

Proper installation techniques for straw bale sediment retention structures at construction sites. Straw bale barriers such as those shown in the diagrams are for short term erosion control only. They are typically used only during the life of the active construction project and may have to be rebuilt or replaced if the project last for more than about 6 months.

To be effective, the bales must be dug into the ground, they must be securely staked in place and they must be firmly abuted against each other. When used in ditches (middle diagram), gaps between the bales must be stuffed with additional straw and they must extend up the side slopes to prevent flow from diverting around the structure.



Construction of a straw bale barrier. (*a*) Installation sequence. (*b*) Cross section of a properly installed straw bale.



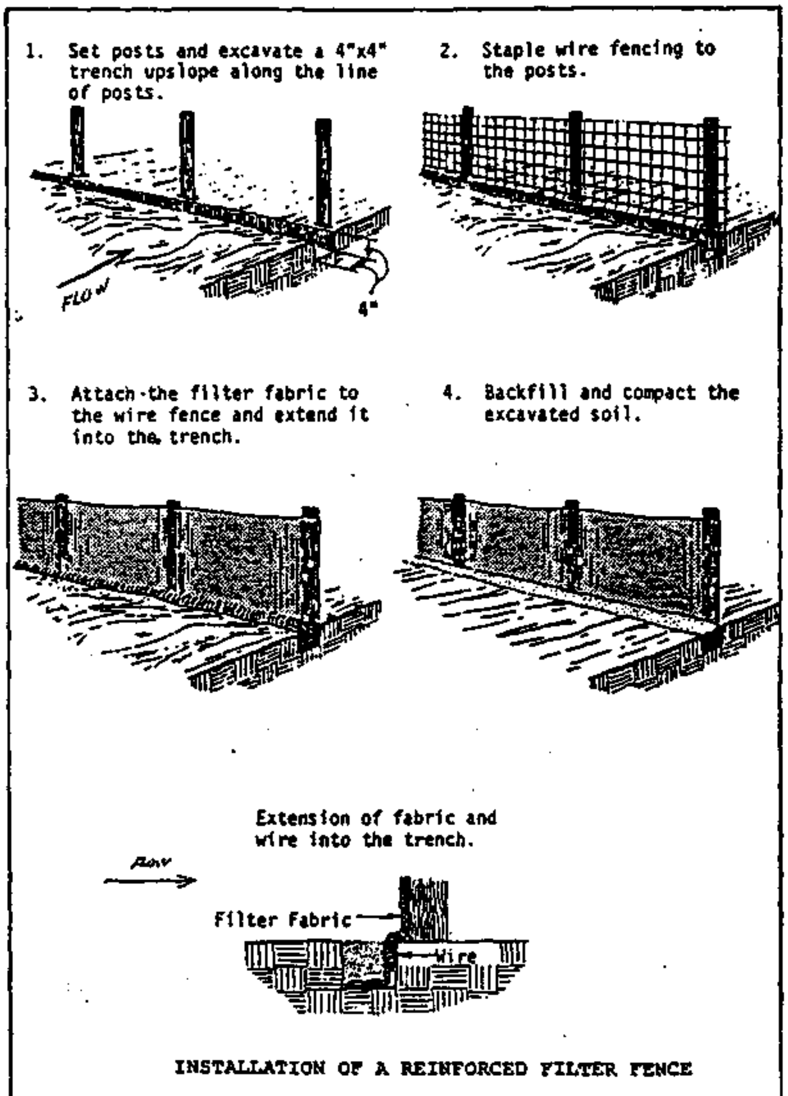
Proper placement of a sediment barrier in a swale. Points *A* should be higher than point *B*.

(*a*) Incorrect and (*b*) correct abutment of straw bales in a trench.

Figure 6-28. Straw Bale Fence.

Proper installation techniques for filter fabric sediment barriers or fences at construction sites. Fabric barriers can last several years if they are properly maintained and repaired.

To be effective, the fabric must be set into the ground in a shallow trench so that water does not flow under the structure. Metal fence posts or heavy stakes are used to streatch and wire the fabric in place. When used in ditches (lower diagram), the ends of the fence must extend up the side slopes to prevent flow from diverting around the structure.



Source: Adapted from Installation of Straw and Fabric Filter Barriers for Sediment Control, Sherwood and Wyant

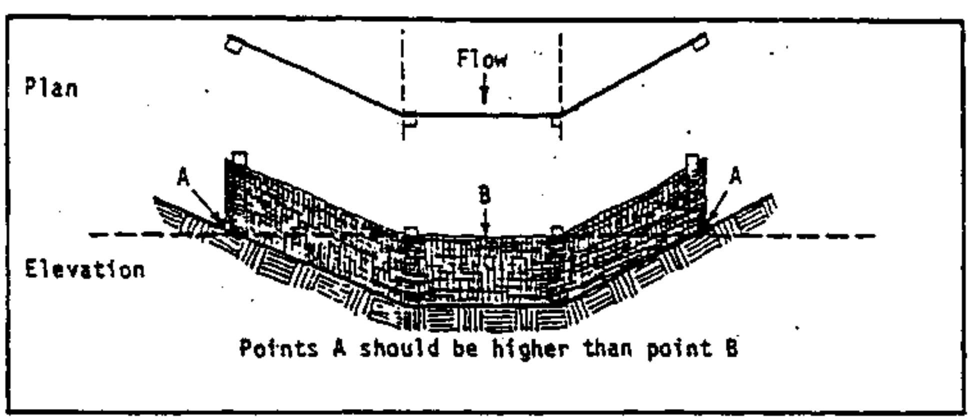
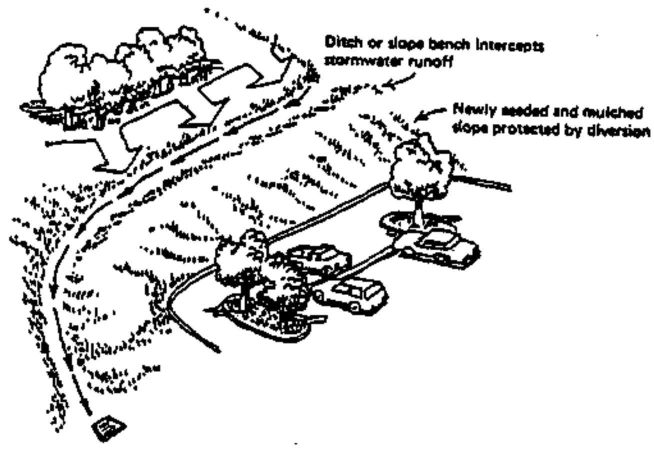


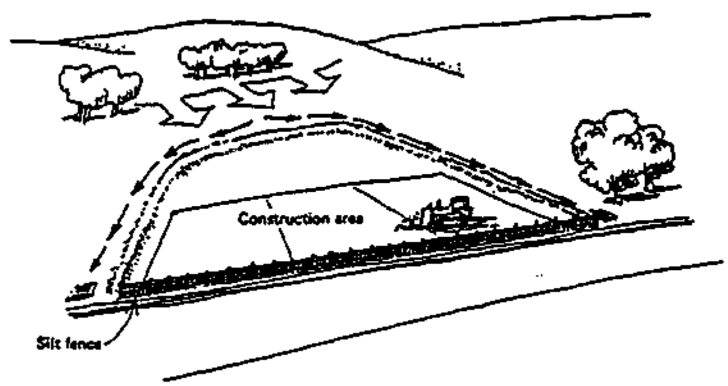
Figure 6-29. Silt Fence.

Examples show the use of diversion structures (ditches, swales, dikes and insloped benches) to direct natural surface runoff away from construction sites. This helps dewater the site and reduces erosion.

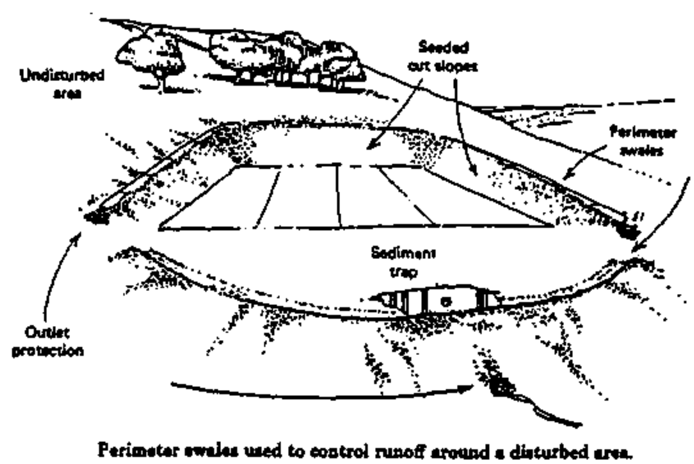
The bottom figure also shows a sediment trap constructed below the disturbed area to trap eroded sediment before it can be transported off site.



Diverted runoff drains to a stable outlet.



Perimeter dike prevents runoff from crossing a construction area.



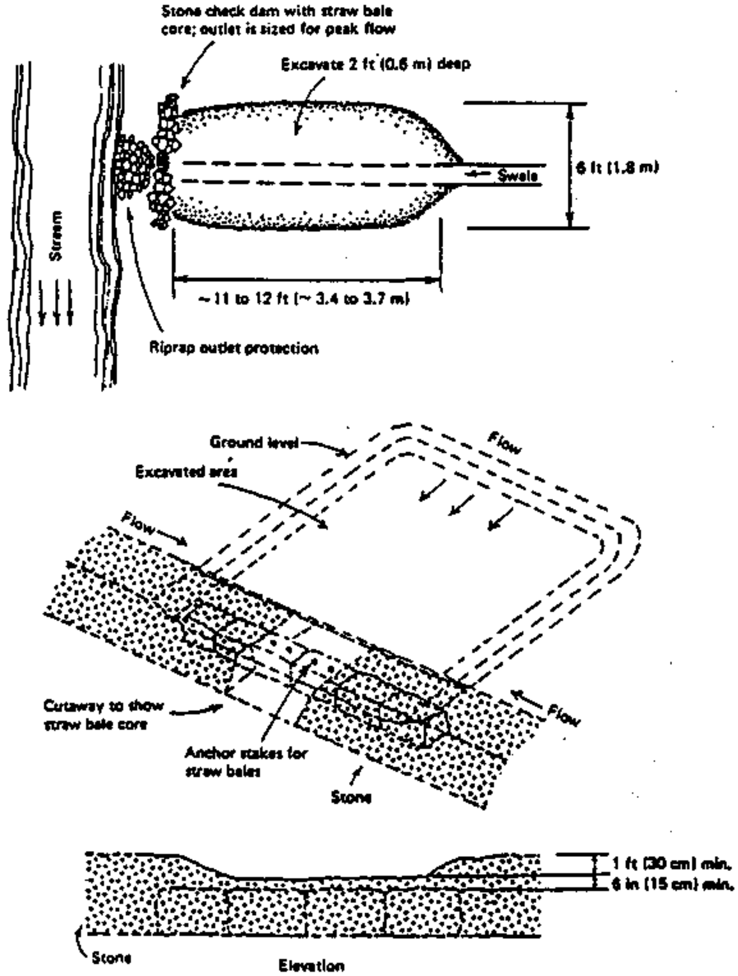
Perimeter swales used to control runoff around a disturbed area.

Figure 6-30. Diversion Structure.

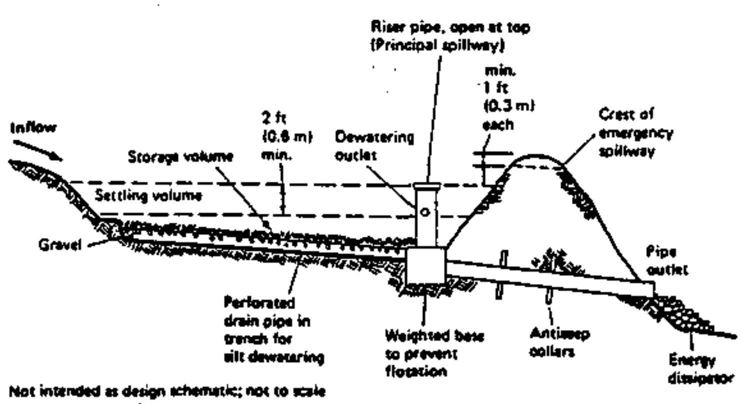
Sediment traps and sediment basins can be constructed downslope from construction sites to collect runoff and filter sediment before it is discharged into streams.

Some of the typical construction details are shown on the diagrams. Important considerations include the volume and surface area of the retention or settling pond, the height and composition of the "dam" and outlet protection that is needed to prevent downstream erosion.

Large sediment basins should be designed by an engineer or experienced erosion control specialist.



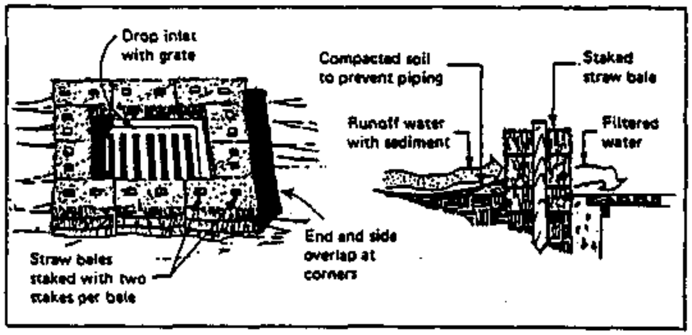
Excavated sediment trap.



Typical features of a sediment basin.

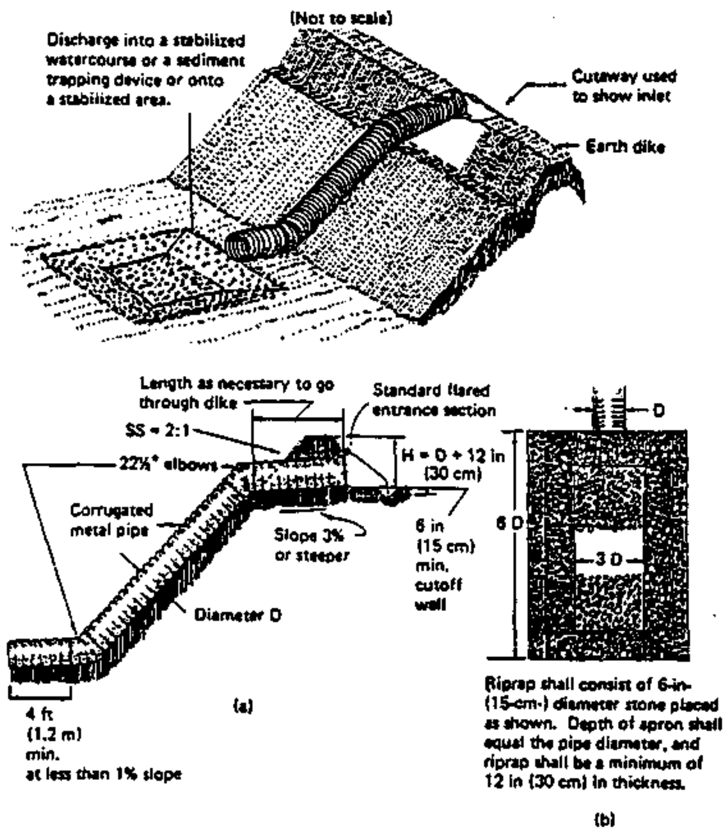
Figure 6-31. Sediment Traps.

Straw bale sediment barriers are used to prevent sediment from entering culvert inlets or storm drains on public streets and subdivisions from nearby construction activities. Runoff is filtered by the straw bales until the construction site is stabilized and erosion is no longer occurring. A filter fence barrier can also be used.



Straw bale drop inlet sediment barrier. (11)

Pipe drains (culverts) can also be installed to temporarily transport runoff over an unprotected slope during construction activities. This prevents gullying of the steep slope. Pipe drains used along roads to carry road runoff over a steep fill slope are often called downspouts or down drains.



Pipe slope drain. (a) Profile; (b) riprap apron plan. Drainage area must not exceed 5 acres. (Adapted from 14)

Figure 6-32. Straw Bale Barriers and Pipe Slope Drain.

Table 6-10. Summary Table of Revegetation Techniques.

Treatment	Comments	Effectiveness before plant establishment[b]	Effectiveness after plant establishment[b]	Approx. cost,[c] $/acre ($/ha)	Short-term cost-effectiveness[d]	Combined short- and long-term cost effectiveness[d]
1. Seed and fertilizer broadcast on the surface; seed not covered with soil; no mulch.	Inexpensive and fast. Effective only on rough seedbeds with minimal slope and erodibility where seed will be covered naturally with soil. Suitable for remote or noncritical areas where machinery cannot be taken.	0	1–4	330 (820)	0	6
2. Seed and fertilizer drilled.	Lowest-seed-mortality method, but limited to friable areas no steeper than 3:1. Soil must be loose before drilling. Plants establish only in rows. Rates of seed and fertilizer may be reduced by 50%.	0	6–8	210 (520)	0	33
3. Seed, fertilizer, and 1500 lb/acre (1.7 t/ha) wood fiber applied hydraulically.	Common hydromulch mix in California. Advantages include holding seed and fertilizer in place on steep and smooth slopes where there may not be an alternative method. Only a minimal mulch effect. Seed is not covered with soil.	2	3–5	790 (1950)	3	8
4. Seed, fertilizer, and 3000 lb/acre (3.4 t/ha) wood fiber applied hydraulically.	More effective than treatment 3 in some cases. Provides more of a true mulch effect than treatment 3 provides.	4	4–6	1280 (3160)	3	7
5. Seed and fertilizer broadcast with hydroseeder. Straw applied with blower at 3000 lb/acre (3.4 t/ha) and anchored with 300 lb/acre (337 kg/ha) wood fiber and 60 lb/acre (67 kg/ha) organic binder.	Very effective as energy absorber and in encouraging plant establishment. Straw forms small dams to hold some soil. May be weedy depending on straw source. Not for cut slopes steeper than 2:1 or longer than 50 ft (15 m). Cost increases significantly when slopes are over 50 ft (15 m) from access or application is uphill. Mobilization costs are high.	5–7	7–9	1000 (2470)	6	14
6. Seed and fertilizer broadcast with hydroseeder. Straw broadcast at 4000 lb/acre (4.5 t/ha), rolled to incorporate and then broadcast again at 4000 lb/acre (4.5 t/ha) and rolled again.	Common on highway fill slopes in California. Very effective. Not possible on most cut slopes. Top-of-slope access is required for rolling equipment. High mobilization costs.	6–8	8–10	1540 (3810)	5	10
7. Jute or excelsior mats held in place with wire staples. Seed and fertilizer as in treatment 1.	Good on small sites and critical slopes. Very expensive. Weed-free. Not recommended on rocky soils. Loses effectiveness if not entirely in contact with soil. More effective if applied over straw.	7–9	8–10	15,800[e] (39,040)	1	1

[a]Source: Burgess Kay, University of California, Davis, and Robert Crowell, Cagwin & Dorward, Landscape Contractors and Engineers, San Rafael, California.

[b]1 = minimal, 10 = excellent. Ratings assume treatments are properly applied.

[c]1984 west coast contract prices.

[d]Cost-effectiveness = 1000/cost per acre/effectiveness rating
The higher the number, the more cost-effective the treatment is. The short-term cost-effectiveness was computed by using the effectiveness rating for "before plant establishment." The combined short- and long-term cost-effectiveness was computed by using the sum of the effectiveness ratings for before and after plant establishment. When the effectiveness rating was a range, an average rating was used in the calculation.

[e]East coast costs for this treatment are considerably lower [$6050 to $13,310/acre ($14,960 to $32,890/ha)]. (6) See Tables 3.6 and 3.7 for additional cost data.

harvesting and roading practices in these and other sensitive geomorphic locations (such as inner gorges along stream channels and steep headwater swales) can be employed to reduce future management-related slope failure and sediment delivery. Prior to developing site-specific land management practices for such areas, potentially susceptible slopes must first be delineated through the use of aerial photographic analysis, field inspections and modeling.

Planning Criteria and Applicability

It is important to first identify which slopes are potentially sensitive to land use, and then to apply appropriate protection to these areas. A variety of measures can be employed to reduce disturbances to unstable or potentially unstable slopes. In these areas, landowners may choose to utilize uncut buffers, light selection cuts or other methods which retain understory vegetation and a significant portion of the existing overstory vegetation with specified re-entry intervals aimed at maintaining substantial forest cover. Except in unusual cases, road construction should be avoided on steep, potentially unstable inner gorge slopes along the Navarro River and its tributaries. Other possible preventive treatments in these identified sensitive areas might include strictly limiting timber harvesting on *visibly unstable inner gorge slopes*, on all *steep and potentially unstable inner gorge slopes* and on *steep (>65%) stream-side slopes* adjacent to Class I and Class II streams, depending on site-specific field reviews at the time of the pre-harvest inspection. Road construction on the latter stream side slopes should be limited to designated stream crossings and should employ full bench endhaul construction techniques.

Methods and Materials

Steep streamside slopes contain some of the most unstable land of the Navarro River watershed. Inner gorge slopes are characterized by steep slopes which commonly exceed 70% and locally exceed 90% in steepness. In addition, emergent groundwater, hydrophilic (water-loving) vegetation (willows, cat-tails, horse-tails, etc.), fractured and weak bedrock and zones of deep colluvial deposits (loose rock and soil) often characterize much of the inner gorge or steep streamside slopes. Many existing landslides in the watershed are found on concave or bowl-shaped, streamside hillslopes where groundwater tends to accumulate and concentrate. These factors are all suggestive of the natural instability of many steep, stream-side slopes, and slope movement is a recent occurrence at many of these sites. Other areas exhibit landslides that have occurred on these sensitive slopes since the forests were harvested.

Three common locations where land use activities are especially likely to cause landsliding (debris torrents and debris slides) and the direct delivery of large volumes of sediment to the Navarro River and its tributaries include: 1) steep inner gorge slopes, 2) lower hillslope positions along deeply incised tributary streams (streams with steep sideslopes) and 3) steep headwater swales (steep slopes at the head or point-of-origin of stream channels). Harvesting, tractor yarding and, especially, road construction in these areas can substantially increase the likelihood of landsliding and sediment delivery from these sensitive slopes during large storms.

Roads and harvesting on sensitive hillslopes, including steep inner gorges and main stem streamside slopes: Roads constructed on the steep inner gorge slopes along the main channel of the Navarro and its major tributaries have locally been associated with large slope failures which delivered substantial sediment to stream channels. For example, in the North Fork, roads account for about 60% of the estimated sediment production, and bank erosion and shallow landsliding account for the remaining 40% (see Table 3-1). Most of these processes are associated with steep inner gorge slopes, hillside hollows and stream-side corridors (Technical Appendix A). These trends occur throughout the Navarro River watershed. Thus, suggestions for harvesting and road location, which are described below, include avoiding and/or modifying practices in riparian areas and along steep, potentially unstable inner gorge locations; steep, wet headwater swale areas and steep stream-side slopes of large tributary streams.

Clearcut harvesting and road construction (or reconstruction) are likely to trigger failure of some steep stream-side and inner gorge slopes which are currently marginally stable or showing signs of instability (including leaning trees, abundant emergent water, convergent (swale-shaped) topography, steep slopes and/or recent scarp development). In these potentially unstable areas, harvesting may have to be deferred or harvesting techniques may have to be modified to successfully prevent widespread slope failures from occurring during the future storm events.

Roading and harvesting on steep tributary sideslopes: Although more geographically confined, the inner gorge slopes along deeply incised tributaries to the Navarro River (for example, mainstem Navarro downstream of Floodgate Creek, North Fork Navarro, upper South Branch North Fork Navarro, upper Mill Creek, lower Rancheria Creek and many of its tributaries such as Dago Creek and Bear Wallow Creek, and mainstem Indian Creek above its confluence with Anderson Valley) represent likely sites for fillslope failures, native hillslope failures and stream crossing failures, with resultant sediment delivery to the channel system. These channel sideslopes often display widespread zones of emerging groundwater, as well as either mottled, deeply weathered, highly unstable soils, or deep colluvium. Roads built across these lower hillslopes typically fail shortly after construction and are abandoned or remain as extremely high maintenance areas. Failures of stream crossings and fillslopes built on the approaching hillslopes deliver large quantities of sediment to the tributaries.

Road construction in steep headwater swales (hollows): As typical forest roads cross a hillslope, the fill/cut ratio is usually the greatest in swales (topographic depressions). These relatively deep, wide fill wedges appear to impede subsurface groundwater flows. This results in elevated pore pressures and leads to hillslope failure in areas of steep, wet slopes. Headwater torrents often originate where landings or roads have been built across these steep, wet swale areas. Improved road and skid-trail location and design can prevent many potential headwater debris torrents that would otherwise be associated with road construction.

General recommendations: It is recommended that steep inner gorge, stream-side and hillslope hollow sites throughout the Navarro River watershed receive detailed geological evaluation prior to developing specific harvesting or road building plans to determine areas where harvesting should be deferred or avoided, and what specific harvesting, yarding and road building techniques would have the least adverse impact on slope stability and be most protective of fishery resources.

It is far more effective and cost-effective to avoid sites of potential instability when an area is logged or roads are constructed. Early recognition, and subsequent mitigation or avoidance of such sites is critical. Once roads have been built on unstable hillslopes, or stabilizing vegetation has been removed, there is little that can be done to retroactively stabilize the hillside and control landsliding. Individual sites of potential debris slides (such as those in steep, headwater swales) and stream crossings can be treated through excavation, but larger scale features cannot effectively or economically be treated once instabilities have begun.

When possible, the following practices should be employed in order to minimize the potential for land use-caused hillslope failure and sediment delivery to the Navarro River and its tributaries:

1. Avoid constructing roads on steep inner gorge slopes along the Navarro River and its major tributaries. Instead, build roads above the slope-break and cable yard logs up to gentler, more stable ground. For inner gorge slopes steeper than 60%, there should be detailed geotechnical planning and design of any proposed road. Consider decommissioning roads which already exist in these locations, especially if there are known stability problems.

2. Employ cable yarding (or helicopter yarding), rather than tractor yarding, on main stem and tributary inner gorge slopes and steep stream-side areas that are to be logged in the future. Harvesting proposals for inner gorge slopes and for unstable or potentially unstable slopes should be field reviewed by a geologist or engineering geologist.

3. When soils and slopes exhibit unstable characteristics (as determined by field inspection), consider eliminating clearcutting in favor of retention or the use of less intensive harvesting. For example, employ techniques such as light selection, using thin corridors during three or four separate entries over a 50 to 60 year period so that a stand of mature trees is always retained on the potentially unstable slopes.

4. Consider leaving substantial, mature buffer strips of 100 feet or more along stream channels to enhance slope stability, reduce stream temperatures, and for organic debris recruitment (see RLMP 6.5.3 for discussion of buffer strips.

5. Known unstable areas, areas of abundant emergent groundwater and zones of unstable or sheared, mottled soil materials (especially in inner gorge areas) should be excluded from logging plans.

6. Where it is necessary for roads to cross steep, wet, headwater swales, two road design practices could lessen the incidence or magnitude of failures: 1) minimize the amount of fill placed in swale areas by reducing the width of the road and

following the hillslope contours more closely, and 2) provide adequate drainage through and/or under road prisms, using french drains, gravel blankets, or synthetic drainage blankets. Such potentially unstable sites should be identified during the planning process and avoided during the construction phase.

7. Where it is necessary to construct roads across incised or deeply incised stream channels, the approaches to these crossings should be constructed as full bench roads with the spoil materials endhauled to a stable storage location. Sidecast construction should be avoided.

8. Where roads must be constructed across unstable or potentially unstable inner gorge slopes or other high risk areas, the alignments should be considered temporary. Stream crossings should be excavated, landings should be kept to the minimum size possible, and uncompacted fills should be physically removed before the first winter following operations. Roads built in these locations should be field-reviewed by a geologist or engineering geologist.

Maintenance

A variety of techniques aimed at reducing slope failures on steep and potentially unstable inner gorge and stream side slopes have been discussed. Harvest-related recommendations are preventive measures designed to maintain slope stability in sensitive hillslope locations. These measures require no special maintenance other than the maintenance of substantial, mature vegetative cover. Mitigation measures related to road construction techniques, such as full bench construction, endhauling, minimizing landing size and other techniques require periodic inspection to determine if slope stability problems are developing, and then removal or stabilization of any unstable road or hillslope materials if conditions warrant.

Effectiveness

Prevention is the most effective and cost-effective technique for reducing sediment delivery from harvesting and road-related mass movement processes on steep stream-side and inner gorge slopes. Once harvesting has occurred, there is little that can then be done to stabilize or mitigate any resulting landslides in the harvest areas.

Similarly, if roads trigger mass movement processes involving original ground, they often occur quickly and cannot be mitigated. Prevention is the best tool to make sure land use practices in sensitive slope locations do not adversely affect slope stability and sediment yield.

Sketches/Drawings

Figure 6-33 illustrates the common locations where debris landslides originate in watersheds.

6.7.3 Gully Prevention and Control Practices

Description and Purpose

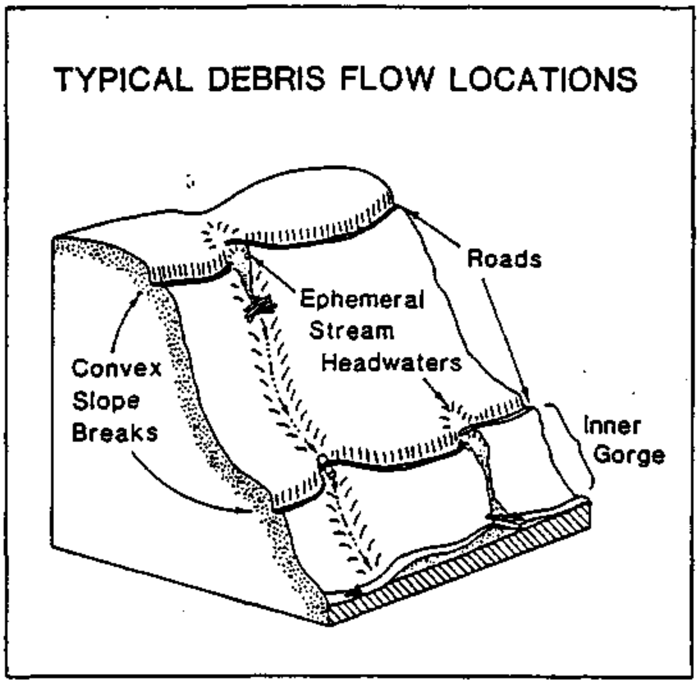
Gully erosion on forested lands, agricultural properties and ranch lands is a significant source of fluvial erosion and sediment delivery to stream channels in the Navarro River watershed (see Section 3.0, Table 3-1). Strategies for preventing new gullies and controlling erosion within existing gullies and gully systems are needed to reduce sediment delivery to local streams and to conserve soil on managed lands. Recognizing the causes of increased hillslope erosion provides the only sound mechanism for preventing similar sediment production and yield from occurring in the future. A variety of prevention methods are discussed in this RLMP and, as a last resort, structural and non-structural techniques for controlling gully erosion are described.

Planning Criteria and Applicability

Gullies are much more effectively treated by prevention than by employing expensive control measures after erosion has already been initiated. Where gullying has already occurred, cost-effective erosion control treatments can best be designed for existing gullies by first determining the cause of the on-going erosion. Thus, gullies should not be routinely treated with expensive control structures and other measures if the cause (the unnatural source of increased runoff) can be identified and the flow redirected back into the natural watercourse where it belongs. As a first measure, gully prevention treatments will include measures to prevent the concentration and diversion of water from managed lands, especially along road systems but also within agricultural and grazing areas. With existing gullies, control measures first concentrate on dewatering active gullies, recontouring and revegetation. Only then are other, less cost-effective secondary erosion control measures considered, including the use of check dams and rock armor.

Methods and Materials

Gullies are defined as newly eroded channels with a cross section larger that 1 ft^2 (1' by 1'). Some gullies are natural, but often gullies form because of some human action that causes runoff to collect and concentrate on an area that did not previously carry such volumes of flow. Gullies often form on or downslope from construction sites, in sloping agricultural areas (both crop lands and range lands) where large expanses of soil have been exposed, or in areas where roads (or skid trails) collect, divert and discharge concentrated runoff.



This block diagram shows the most common locations where debris landslides originate in watersheds. Landslides commonly occur on steep slopes, especially on steep streamside slopes (often called "inner gorge slopes") and in steep swales at the head of tributary stream channels. Roads built across such slopes can significantly increase the risk of landsliding. Timber harvesting and other types of de-vegetation (such as forest fire or heavy grazing in grassland areas), as well as construction activities, can also increase the landslide risk in these areas. If possible, it is best to avoid land use activities on sensitive slopes, or to modify or reduce the the effects of land use by employing special practices recommended by a geologist.

Figure 6-33. Typical Debris Flow Locations.

Gully control can be one of the most important restoration methods employed in watershed management. Three gully prevention and control measures should be applied in order:

1. Catchment improvement to reduce and regulate runoff (a gully prevention method),

2. Diversion of surface runoff (both a prevention and control measure) and

3. Structural stabilization and revegetation of gullies (a control method).

Gully prevention is almost always easier, more effective and less costly than controlling a gully after it has formed. The best strategy is to prevent gullies from forming in the first place rather than trying to control them after they have developed. Prevention treats the source and cause of the erosion. Preventive treatments are generally permanent and require little or no maintenance. Prevention is accomplished by *reducing runoff* from managed areas, by *dispersing runoff* and by *directing and retaining runoff* to stable sites where gullying will not occur.

1. *Gully prevention through catchment improvements* - Many land management practices cause soil disturbance, disturb natural drainage patterns and increase runoff from hillslope areas. These actions can cause gully erosion. Runoff reduction is perhaps the single greatest tool for preventing gully erosion from managed areas. On-the-ground techniques for reducing runoff include:

   a) forest fire prevention (vegetation management to reduce forest fire intensity),

   b) grazing control to maintain an effective ground cover and reduce soil compaction,

   c) prevention of large grass fires,

   d) revegetation of open areas, disturbed areas and burned areas,

   e) maintenance of soil fertility on land which is under forestry or agriculture,

   f) use of agricultural cover crops during fallow periods and between commercial plantings,

   g) control of road construction and mining (dispersing runoff),

   h) minimizing exposed soil during construction activities, and

   i) the immediate stabilization and control of moderate sheet and rill erosion and incipient gullies in forest, rangeland and cultivated areas.

In addition to proper land management practices aimed at *reducing or minimizing runoff*, runoff from managed areas and sites, runoff may be retained, dispersed and/or diverted to stable areas. Each of these practices can prevent gully erosion. *Retention* measures can include such practices as the construction of infiltration ditches, basins and ponds which temporarily hold water, reduce storm-period runoff and result in increased infiltration of water which otherwise would have runoff.

2. *Gully prevention and control through runoff dispersion and diversions* - Gully prevention is also dependent on *dispersing* runoff from managed areas, by making sure runoff does not collect and concentrate in unprotected areas. This type of prevention practice is most appropriate along roads where ditches and berms commonly concentrate surface runoff and cause gully erosion. Road runoff can be dispersed by employing rolling dips and ditch relief culverts, or by outsloping the road bench so that runoff is uniformly dispersed along the alignment. This type of flow dispersion can nearly eliminate road-related gullying.

Gully erosion can also be prevented by *diverting* concentrated runoff away from erodible slopes and onto stable or non-erodible areas. Examples of the use of diversions to prevent gully erosion include ditching above construction sites (to reduce runoff within the disturbed construction area), the construction of waterbars on roads and skid trails to divert runoff onto stable areas (this is also a dispersion technique) and the construction of critical rolling dips at stream crossings on roads to direct stream flow back over the road when the culvert plugs. Diversion ditches or channels, regardless of where they are constructed, should always be built with a low gradient and designed to carry the volume of water which can be expected to flow through the channel during periods of maximum runoff.

3. *Gully control through structural stabilization and revegetation* - Gullies can form on hillslopes either from general increases in surface runoff (caused by over grazing, forest fire, grading, etc.) or from diversion or concentration of a runoff source (stream diversion, culvert outfall, etc.). Once a gully has formed, treatment to control continued erosion and gully enlargement can be both expensive and potentially ineffective. The best possible treatment for a developing gully is to divert the runoff from the head of the gully to a stable location where it will no longer cause erosion. Once this is performed, the former gully can often be refilled, recontoured and revegetated, or it can be left without additional treatment (because it no longer carries significant flow it should stabilize and naturally revegetate).

On certain slopes, engineered or vegetated waterways can be constructed by filling and recontouring gullies which have formed. This technique is usually limited to small first order channels where gullying has developed due to land disturbance, such as grazing, or to diversions which have since been corrected. A broad new channel is created in a different location (adjacent to the filled gully) that has a lower gradient and is wider (5:1 sideslopes) than the gully. It is then quickly revegetated and may be stabilized with erosion control fabric to provide for immediate protection. This new channel will be stable if it is well vegetated, if disturbance is controlled (e.g., fencing to eliminate riparian grazing) and if runoff volumes are not excessive for the site. This technique is preferable to the installation of check dams or other structural controls because it is permanent and requires little or no maintenance.

As a last resort, if flow cannot be diverted out of a gully, or the gully cannot be stabilized by recontouring, a structural measure may be needed to control continued gully erosion. Controlling gully erosion using structural erosion control measures is not a simple task, and it is not always successful. Construction techniques must be thoughtfully designed and accurately implemented for the measure to work as intended. In addition, most structural measures require substantial and continued maintenance for success.

Gully control structures should usually be viewed as a temporary aid in long term vegetative recovery of the gully. Structures provide immediate protection when nothing else will work. Properly installed, they are designed to stabilize the bed of the gully, allow the channel bottom to revegetate and thereby promote revegetation of the banks. Vegetation perpetuates itself and represents the long-term, permanent control in most situations.

A variety of structural measures are available to temporarily stabilize an enlarging gully. These most commonly include check dams (made of a variety of materials) as well as channel armor. To be effective, each of these techniques must follow certain rules and accomplish certain tasks. Incorrect design, construction, or maintenance will most certainly result in failure of one or all of the structures at a site. Design criteria include the following elements:

1. For rock armor, the armoring material must continuously cover the bed of the gully and extend up the banks sufficiently to contain the maximum expected discharge.

2. Where rock armor is used, it must be sufficiently large to prevent transport downstream, yet small enough to ensure that flow is not deflected by the armor against unprotected gully banks. A variety of rock sizes should be used.

3. For check dams:

    a) Each dam must be excavated sufficiently into the bed and banks to prevent undercutting or lateral piping,

    b) Each dam must be made of materials which will last as long as is required for permanent vegetative stabilization to develop on the gully bed and banks,

    c) Each dam's spillway must be designed to pass the design (peak) discharge expected for that channel over the center of the dam,

    d) Each dam must be spaced such that the ponded sediment behind one extends upstream to the base of the next dam (the structures must protect the bed of the gully from flowing water - water is no longer allowed to flow directly on the eroding stream bed),

    e) Each dam must have energy dissipation below its spillway such that the energy of the cascading water falls entirely on the dissipator,

f) Wing walls and other measures may be needed to protect the dams from lateral cutting and failure.

g) Each dam site, including the banks and bed of the gully, must be planted with rapid growing woody species (such as alder, willow, baccharis, etc.).

h) Each dam must be inspected and repaired, as necessary, after each flow event.

The main function of check dams is NOT to store sediment behind the structures. Rather, check dams are designed to prevent continued channel down cutting by creating a new, artificial stream bed on top of the gully bottom. Water only flows on the ponded sediment behind each dam and over each hard structure, but never on the erodible stream bed. Similarly, channel armor protects the entire gully from erosive flow, thereby preventing continued gully enlargement. As might be expected, channel armor typically requires less maintenance than check dams and is less likely to fail. Both types of structural treatment need to be followed with a variety of plantings to provide for permanent channel stabilization.

Maintenance

All gully prevention and gully control measures will require at least some inspection and maintenance; some measures will require extensive maintenance. Of the three mechanisms of prevention or control described above, watershed improvements to reduce or minimize runoff or to retain water for infiltration is the most permanent type of treatment. These prevention measures will typically require the least maintenance. Depending on site conditions, treated watershed areas may need replanting and some hand labor may be needed to prevent rilling and gullying of exposed areas until vegetation has become re-established. Grazing and exclusions will need to be monitored and repaired until vegetation has become self sufficient.

Gully prevention and control measures which act by dispersing or diverting surface runoff will also need periodic inspection and maintenance. Road outsloping, rolling dips and newly installed ditch relief culverts along roads will need to be checked after each storm during their first year and periodically thereafter. Repairs may be required to ensure their proper functioning. Ditches, waterbars and other diversion structures, likewise, need regular inspection and maintenance.

Structural stabilization measures, including check dams, typically require substantial and frequent maintenance to be successful. Check dams will need to be inspected after every storm to check for evidence of existing or potential problems. Piping of water under or around check dams needs to be stopped (plugged) immediately.

Plunge-pool erosion below a check dam spillway needs to be stopped by installing better energy dissipation. Any problems which are resulting in continued gully erosion, or any problems which are being caused by the erosion control structures need to be repaired quickly. Once a single dam fails by undercutting or lateral erosion, adjacent dams are likely to fail very soon.

Effectiveness

Gully prevention and control measures can be highly effective if they are well designed, properly constructed and religiously maintained. Watershed improvement practices, such as grazing restrictions in riparian areas and along gullied channels, can be a very effective technique for controlling erosion provided cattle continue to be excluded or managed to maintain effective vegetative cover. Failure to maintain such measures can quickly result in deteriorated conditions. The effectiveness of structural gully control measures, such as check dams, is directly dependent on proper construction and continued maintenance. Because of their high maintenance requirements, structural measures should be employed as a last resort.

6.7.4 Agricultural (row crops, orchards, vineyards) Erosion Control Practices for Uplands and Riparian Corridors

Description & Purpose

The sediment budget study for the Navarro watershed indicates that the largest sources of sediment supplied to streams is from bank erosion, road-related erosion, and gullying. Agricultural (row crop, orchard, and vineyard) activities (see RLMP 6.5.1, *Exclusionary Fencing*, for discussion of erosion control practices specifically related to agricultural ranching activities) which can result in an increase in these types of erosion processes include the building of roads, clearing, landform grading and cultivation practices that alter runoff and drainage patterns, and encroachment on the riparian corridor. Although not a significant factor in sediment production on a watershed-wide scale in the Navarro basin, agricultural practices may also contribute sediment to streams due to sheet erosion and rilling on bare, exposed soils. Road-related erosion control planning is briefly addressed here. More detail on design considerations are covered in the *Roads* resource section. Measures to reduce the other sources of erosion, loss of soil fertility, and sediment delivery to streams are described below.

Planning Criteria & Applicability

Orchards and viticulture are probably the most significant agricultural activities in the Navarro watershed. Most of these agricultural activities are taking place in the Anderson Creek basin, lower Indian Creek basin, and in tributaries which drain directly to the mainstem Navarro, such as the Mill Creek drainage. As these land-uses expand, there is a greater potential for increased sediment production which can adversely impact fish habitat. Agricultural activities which take place on hillslopes or within the riparian corridor, are the most likely to cause erosion problems and sediment delivery to streams.

Methods and Materials

(1) Prior to initial land-clearing for installation of new orchards or vineyards, a development plan should be prepared with adequate provision for erosion control and drainage. Emphasis should be placed on erosion prevention, rather than sediment control. Permanent prevention measures are much less expensive and more effective in

the long-term, rather than rehabilitation and restoration measures to retain sediment on-site.

The development plan should provide a general description of the existing site conditions, including soil type, natural features, and critical areas such as gullies, swales, springs and seeps, slides, and eroding streambanks. Proposed erosion control measures, including a description of drainage systems, vegetative control measures, and stormwater runoff control measures, should be described. Underground piping, subsurface drainage tiles, retaining walls, permanent surface diversions, grassed waterways, road layout, and installation of cover crops, can be designed with the assistance of the USDA Natural Resources Conservation Service, or other knowledgeable professionals. The Hillside Vineyard Manual section of the *Napa River Watershed Owner's Manual*, prepared by the Napa County Resource Conservation District, provides guidance for preparation of a development plan, as well as vineyard design, layout, and economics.

(2) Some of the problems related to access roads in vineyards and orchards are associated with:

- inadequate maintenance
- wet weather use on unsurfaced roads
- inadequate road drainage and water control
- improper and inadequate stream crossings
- inadequate cross-slopes
- improper construction and fill compaction
- excessively steep cut and fill slopes
- road construction at toe of unstable slopes

General planning considerations for roads should include:

- avoid high erosion hazard sites and slide prone areas such as seeps, concave slopes, hummocky terrane (indicative of earth flows which are unstable)
- as feasible, preferentially place roads on ridgelines or flatter slopes
- avoid locations on long, steep, unstable slopes
- reduce concentrated flows in drainage ditches and on the road surface by providing cross drainage, culverts, rolling dips, and outsloping.

(3) Most new hillside vineyards will require some form of clearing, ripping, and terracing. Water flow on terraced benches is a critical consideration for hillside development. Even properly insloped benches can be a problem if the cross-slope gradient is too great or too little. If the slope is too steep, the velocity of the water can increase causing gullying and drainage system failure. If the bench's slope gradient is too shallow, water may not leave the hillside fast enough to avoid saturation, bench failure, and spillage over the front of the bench. It is therefore important to determine the soil type, its porosity, infiltration rate and capacity, before designing terraces. In general, water should not flow along benches for more than approximately 800 feet to reduce opportunities for concentrated flow and gullying to develop. It is important to consult

with the NRCS or a qualified soils engineer, as well as with neighboring vineyards, as part of the design and layout process.

Consideration should also be given to non-terraced vineyard designs on hillslope locations. In some cases the amount of cut-and-fill required to construct a terraced vineyard may generate more land disturbance and a greater risk of erosion than non-contoured designs that employ other erosion control practices to disperse and slow runoff. The use of cover crops is one such important practice (see cover crops, below)

(4) Cover crops can be either permanent, perennial grasses or used as an annual cover and tilled into the ground each year. Permanent cover crops such as Blando Brome and Zorro Fescue, are very deep-rooted, reseeding winter annuals which will not dry-out during the summer months. This provides the advantage of having ground-cover in place and well developed with the onset of the first fall rains. Temporary cover crops are short-lived annual grasses such as barley or ryegrass, which must be sowed in the fall and require several months before they become well established. Cover crops are currently being used extensively in some orchards and vineyards in the Navarro watershed. The benefits of using cover crops include:

- erosion control
- improved soil health
- direct and indirect cost savings

Vegetative cover provides erosion control by increasing the capacity and rate of water infiltration along root channels developed through the soil horizons. It also reduces splash erosion (from the force of raindrops which can detach soil particles), reduces runoff velocity, and traps and filters sediment. Improved soil health is due to the added soil porosity for better water penetration and to increased air penetration, and generation of organic matter. A properly chosen and managed cover crop can produce a net increase in topsoil. Cost savings accrue due to fewer tractor trips through the vineyard to manage weeds, reducing maintenance and fuel costs.

As a rough estimate, installation costs for permanent cover crops range between $145-230 acre, and temporary cover crops between $84-$100/acre. Information on the use and selection of cover crops can be obtained from the UC Cooperative Extension Service, NRCS, AV Farm Supply in Philo, and the Mendocino County Farm Supply in Ukiah.

(5) Mulches can provide temporary erosion protection and aid in vegetation establishment. Mulches should be used in locations which are susceptible to sheet erosion caused by runoff, such as swales, vineyard, ranch, and orchard road surfaces, on steep slopes, and bare soil areas which have no protective vegetative cover. Conventional mulches provide protection from splash erosion and sheet runoff, where velocities are not very high.

Hay and straw are the most common dry mulch materials. Rice straw may last up to three times longer than other straw materials, and is generally cheaper. Application rates on gently sloping terrain typically range from 1.5 to 2.0 tons/acre. Long straw mulches with fiber lengths ranging from 4 to 8 inches are the most effective because they provide the best interlocking and surface coverage. Loose straw mulch should be anchored in place using crimping techniques (by hand or equipment). On steeper slopes, tackifying agents should be used such as latex solutions, vegetable gums, or other compounds that attach the mulch fibers to each other and to the ground. Overlying erosion control nets may also be used to hold mulches in place.

(6) Soils which are stockpiled as a result of landform grading, road construction, terracing, and other earth moving work should always be stabilized so that runoff will not transport the stockpiled material to streams. Select relatively flat terrain which is not adjacent to streambanks or to other drainage features for stockpiling earth materials, and grade the material to a stable angle. Use protective covers such as mulches, plastic sheeting, straw bales, or erosion control nets to prevent erosion and subsequent transport by runoff from the site.

(7) Use appropriate road designs and layout to minimize surface erosion, water diversions at culverts, gullying, and fill failures (see RLMP's related to road erosion).

(8) Protect the riparian corridor. Agricultural activities which encroach on the riparian corridor and remove vegetation can de-stabilize streambanks and initiate bank erosion. Bank erosion can eventually result in the loss of valuable agricultural lands. Over the long-term, preventative measures which maintain and protect riparian areas will be much more cost-effective than instituting remedial bank erosion control and stability measures. The best means for protecting the riparian corridor is to establish and maintain a buffer strip (see RLMP 6.5.3 for discussions related to buffer strips).

<u>*Maintenance*</u>

No maintenance is required for preparing a well-considered development plan which considers how to prevent and control erosion problems related to the design of vineyards, orchards, and roads. The best and most cost-effective means of controlling erosion is to consider preventative actions, before problems begin. Similarly, establishing a riparian buffer zone requires no maintenance activities.

Maintenance will be required for permanent cover crops. Mowing or disking is necessary to control crop height. To ensure self-perpetuation, the timing of mowing or disking is important. If the seed head is mowed or disked into the ground before maturity, the next year's seed source is destroyed. Cover crops should also be fertilized periodically to extend their useful life, usually about 10 to 20 years when properly maintained. Annual maintenance costs for permanent cover crops are about \$70-\$85 acre, with no maintenance costs for temporary cover crops. Mulches must be renewed, often on a seasonal or even storm-event basis, as they decompose or are washed-out by runoff.

<u>*Effectiveness*</u>

Up-front land-use and land management planning, and establishing riparian buffer zones, are considered the most important and effective tools for reducing erosion and sediment delivery to streams. The use of cover crops and mulches have been found to be very effective approaches to reducing sheet erosion and gullying.

6.7.5 BIBLIOGRAPHY/REFERENCES FOR HILLSLOPE EROSION CONTROL PRACTICES

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US Department of Agriculture. 1985. Hillside Vineyards Unit Redwood Empire Target Area, prepared by the Soil Conservation Service, Davis, California

Nevada Conservation Commission. 1994. Handbook of best management practices, Carson City, Nevada, 245 pages + appendices.

Spence, B. C., G. A. Lomnicky, R. M. Hughes and R. P. Novitzki. 1996. An ecosystem approach to salmonid conservation. Management Technology, TR-4501-96-6057, 356 pages. December 1996.

USDA. 1993. Forest ecosystem management: an ecological, economic and social assessment. Report of the Forest Ecosystem Management Assessment Team. July 1993.

US Dept of Transportation. 1995. Best management practices for erosion and sediment control. Report No. FHWA-FLP-94-005. 108 pages + appendices.

Wisconsin Dept. of Natural Resources. 1989. Wisconsin Construction Site Best Management Practice Handbook. Wisconsin D.N.R. Nonpoint Source and Land Management Section, Chapters 1-7.

6.8 CONSERVATION EASEMENTS

DESCRIPTION AND PURPOSE

Conservation easements are permanent, deeded land use restrictions for public benefit conservation purposes. They are established voluntarily by landowners who want to protect certain land uses and natural resources (e.g., agriculture, forestry, fish and wildlife habitat, watershed functions, open space) by limiting or prohibiting others (e.g., subdivision, residential development, removal of riparian vegetation, etc.) The specific terms of the easement will vary with the characteristics of the specific property, the restoration and conservation goals of public benefit trying to be achieved, and the owner's desired on-going land uses.

Conservation easements are granted by the landowner to an appropriate government agency or to a qualified charitable non-profit land trust as grantee. The grantee is then obligated to monitor and enforce the terms of the conservation easement created by the landowner. No other rights are transferred to the grantee. All rights not specifically restricted by the landowner in the conservation easement are retained by the grantor. The property stays in private ownership and use that is consistent with the terms of the easement. As with any property, the land can still be sold, transferred, or passed on to heirs. The rights and responsibilities of actual land management remain with the property owner.

Conservation easements can be granted either through their sale or donation by the landowner to the grantee, providing compensation to the grantor for the public benefits of the easement. The value of the easement is based on the appraised financial value of the land use restrictions (e.g., residences not built, sub-divisions not sold, timber not harvested). While some limited government funding is available for the purchase of conservation easements, the great majority of easements are made by charitable donation. A charitably donated easement can provide sometimes significant income tax deductions to the grantor. The creation of a conservation easement can also provide potentially significant estate tax reductions. (Specific IRS requirements for tax deductibility of conservation easements can be found in Internal Revenue Code Section 170(h)).

The revenue or tax benefits obtained through the creation of the conservation easement can help defray the landowner's costs of watershed restoration or conservation. The public, in turn, is served by the assurance that restoration or conservation projects and their gains to water quality and the fishery will not be harmed by future land uses.

Planning Criteria and Applicability

Conservation easements can be used in the Navarro River watershed to support the implementation of a variety of recommended land management practices.

1. They can provide immediate benefits in sub-basins and stream reaches with existing fish habitat and riparian forest cover. In these instances, the purpose of the easement is conservation of existing natural resources, to ensure against

further loss of essential habitat. Areas identified in Section 5.0 for Coho Salmon and Steelhead Conservation and Restoration are excellent candidates for the use of conservation easements.

In-stream flows to benefit the fishery can also be better maintained by landowners making their voluntary limitations on water diversions permanent through the terms of a conservation easement.

2. Conservation easements are also very useful for RLMP's that require relatively long time periods to be most effective, such as re-establishment of riparian vegetation, especially large mature conifers, and the eventual recruitment of future large woody debris into streams. (See especially 6.6.3 Riparian Corridor Protection and Restoration)

3. They are also an effective means to permanently restrict especially harmful practices so that future managers do not consider those options. This might include prohibiting or greatly limiting future timber harvest or road building on steep inner gorges (as per RLMP 6.8.2). Future sub-division and extensive residential building that require new road systems, grading of unstable soils, water development and/or deforestation could be prohibited through a conservation easement. (This might be especially desirable in the melange terrain and headwaters areas with steep and unstable slopes.)

4. A conservation easement can protect the beneficial results of restoration activities that require considerable investment to accomplish (such as riparian fencing, reforestation for habitat, road removal) against future loss, degradation or the repetition of poor practices.

In general, conservation easements can be used to help achieve the goals for conservation and restoration of fish habitat and water quality through site-specific, permanent land use restrictions.

Methods and Materials

Conservation easements are usually created jointly by the landowner and their desired grantee organization. Each conservation easement is designed for the specific site conditions of the subject property. Based on field study, advice from appropriate resource specialists, and discussion, a general conservation plan is usually drafted first describing the public benefit "conservation values" and objectives as well as proposed restrictions for the property. Once the terms of the general conservation plan are agreed to by the grantor and grantee, then the legal Deed of Conservation Easement is drafted. The landowner should be advised by legal counsel as this is a serious, binding commitment to conservation.

Included with the Deed is a "Baseline Report" which describes the condition of the property and the resources to be protected at the time of the easement's creation. This document is used as the baseline for future monitoring. Depending on the property's resources and complexity of the easement, timber inventories, vegetation maps, wildlife surveys or other information may be required to be developed.

Once the conservation easement documents are completed to the grantor and grantee's satisfaction, they are signed and recorded with the county. The grantee will then have the obligation to monitor the terms of the easement at least annually, and to seek legal remedies if the terms are violated. With the grant of a conservation easement, typically provisions are made for a "stewardship endowment" to be maintained and invested by the grantee land trust to defray its monitoring costs through time. The endowment usually is funded by a charitable donation made by the landowner for this purpose.

As described above, the specific terms of the easement will vary according the site and the goals to be accomplished.

Once the easement terms are known, an appraisal can be prepared to determine its value if the landowner is selling or donating the easement. A charitable tax deduction can be taken by the landowner equal to the easement's value in the year of the gift (with any remainder carried forward against taxes for five succeeding years).

Limited funding for conservation easement acquisition or for costs associated with conservation easements may be available from certain government agencies or non-profit conservation organizations. (See Implementation Plan for lists.)

Maintenance

Conservation easements are maintained jointly by the landowner and the easement grantee. As the landowner retains all management responsibilities, and other obligations of ownership, they bear primary responsibility for maintenance of the easement. The land trust or other grantee is there to ensure the public benefit and guarantee the easement is not violated through time by periodic monitoring of the property. If disputes over interpretation or enforcement of the easement occur, they are dealt with according to the stated dispute resolution provisions of the easement. Using the judicial process, remedies for violations usually include injunctive relief, restoration, and damages.

Effectiveness

Conservation easements have been in use since the 1930s, with wider application growing since 1976 when easement tax-deductibility was confirmed in the Internal Revenue Code. Millions of acres of land are under conservation easement in the U.S. to protect habitat, ecosystems, open space, scenic beauty and agriculture. Violations of easements have been relatively rare and usually do not occur with the original grantor, but with a successor.

Conservation easements can be affordable, flexible, site-specific conservation tools useful on individual properties with sensitive natural resources. They are most effective, though, when used by private landowners in a specific area, like the Navarro River watershed or a sub-basin, widely to accomplish "landscape level" conservation objectives cooperatively, such as the restoration of riparian habitat across multiple ownerships.

Organizations with information:

The Land Trust Alliance
Trust for Public Land
California State Coastal Conservancy
Anderson Valley Land Trust
Pacific Forest Trust

7.0
DEMONSTRATION PROJECT DESIGNS

7.1 INTRODUCTION

Future activities to address water quality and aquatic habitat conditions in the Navarro watershed will require landowners to adopt two broad restoration strategies. The first strategy is to develop an effective protection and conservation program. Protection and conservation may take various forms, for example, designating riparian buffer strips, limiting logging and road development in inner gorge locations, preventing salvage logging which removes large woody debris from the channel, and establishing conservation easements to protect existing habitat and prevent harmful practices. These conservation strategies and others, are described in Section 6.0, *Recommended Land Management Practices*.

The second strategy is to develop site-specific restoration plans and designs which can be implemented by landowners. Such site-specific plans might include riparian revegetation to provide shade, bio-engineering techniques to stabilize eroding streambanks, in-channel treatments to enhance pool habitat, and road up-grading practices to reduce erosion and sediment delivery to streams. Many of these site-specific restoration actions are also described in Section 6.0.

This section provides examples of seven site-specific restoration plans, referred to here as demonstration projects, which were developed in cooperation with individual Navarro watershed landowners. The demonstration projects are intended to be illustrative of the types of remedial treatments which may be used to restore water quality and fish habitat conditions. The seven demonstration projects represent common types of problems which many landowners might encounter. These include four different examples of road-related erosion problems and three types of re-vegetation projects to reduce streambank erosion and increase shading. The projects were selected because of their relevance to improving water quality and aquatic habitat conditions, and the land-owners' interest in participating in the development of this Plan. Residents of the Navarro watershed are encouraged to see the demonstration projects sites and to discuss them with the landowners.

It is anticipated that future grant funding sources will be obtained for implementation of the demonstration projects. Due to budget constraints, demonstration projects could not be prepared to provide examples of all of the critical conditions that limit or impair water quality and fish habitat (such as bio-engineering techniques to improve streambank stability, methods to create pool habitat, etc.). However, there are several examples of on-going bank stability projects in the Anderson Valley which landowners have planned and implemented apart from the demonstration projects developed in this Plan.

The remainder of this section is devoted to the demonstration project plans which include text descriptions, tables, maps, and illustrations. The demonstration project plans provide sufficient information and detail to be implemented under the supervision of qualified individuals with relevant experience in landscape ecology, geomorphology, engineering, or other related professional fields. However, they are presented here for illustration only. Actual implementation may require some additional site-specific information or other variations as recommended by the actual contractor and accepted by the landowner. It is instructive that many of the demonstration projects will not only improve water quality and aquatic habitat conditions, but over the long-term are likely to reduce costs to landowners for the maintenance of roads, or for the repair of eroding streambanks and the loss of land.

Regardless of which strategies individual landowners may choose to apply, restoration programs at the watershed scale cannot be truly effective without the cooperation of many landowners. The scale of water quality and aquatic habitat problems in the Navarro watershed will necessitate a long-term partnership between landowners, along with support and assistance from state and federal agencies, to successfully achieve restoration goals. It is hoped that landowners will consider these demonstration projects as a learning opportunity that will foster further discussion, agreement, and cooperative action.

7.2 REVEGETATION PROJECTS

Protecting and improving the riparian corridor has been identified in this Plan as an important land management practice which will improve water quality and fish habitat conditions (Section 6.0, *Recommended Land Management Practices*). Riparian vegetation provides shade over stream channels which reduces water temperatures, and enhances streambank stability reducing erosion and stream sedimentation. In mature forests, riparian vegetation is the source of large woody debris which promotes the development of pool habitat, and improves the quality of pools by introducing cover elements.

Three revegetation demonstration projects were selected, and are described below. For each demonstration project a site map was prepared indicating revegetation zones and listing the species and number of plants designated for each zone. Detailed illustrations of appropriate planting methods to be used with each species and accompanying descriptive notes on planting technique and care are provided.

7.2.1 SEGAR PROPERTY DEMONSTRATION PROJECT

The Segar demonstration project is located adjacent to Highway 253 (Figure 7-1). An unnamed intermittent stream channel, approximately 225 feet in length, flows through the property to Soda Creek. The intermittent channel has incised into its streambed immediately downstream of the culvert outfall on the south side of the highway. This incision has resulted in streambank erosion, widening the channel, and delivering sediment to Soda Creek.

ZONE A

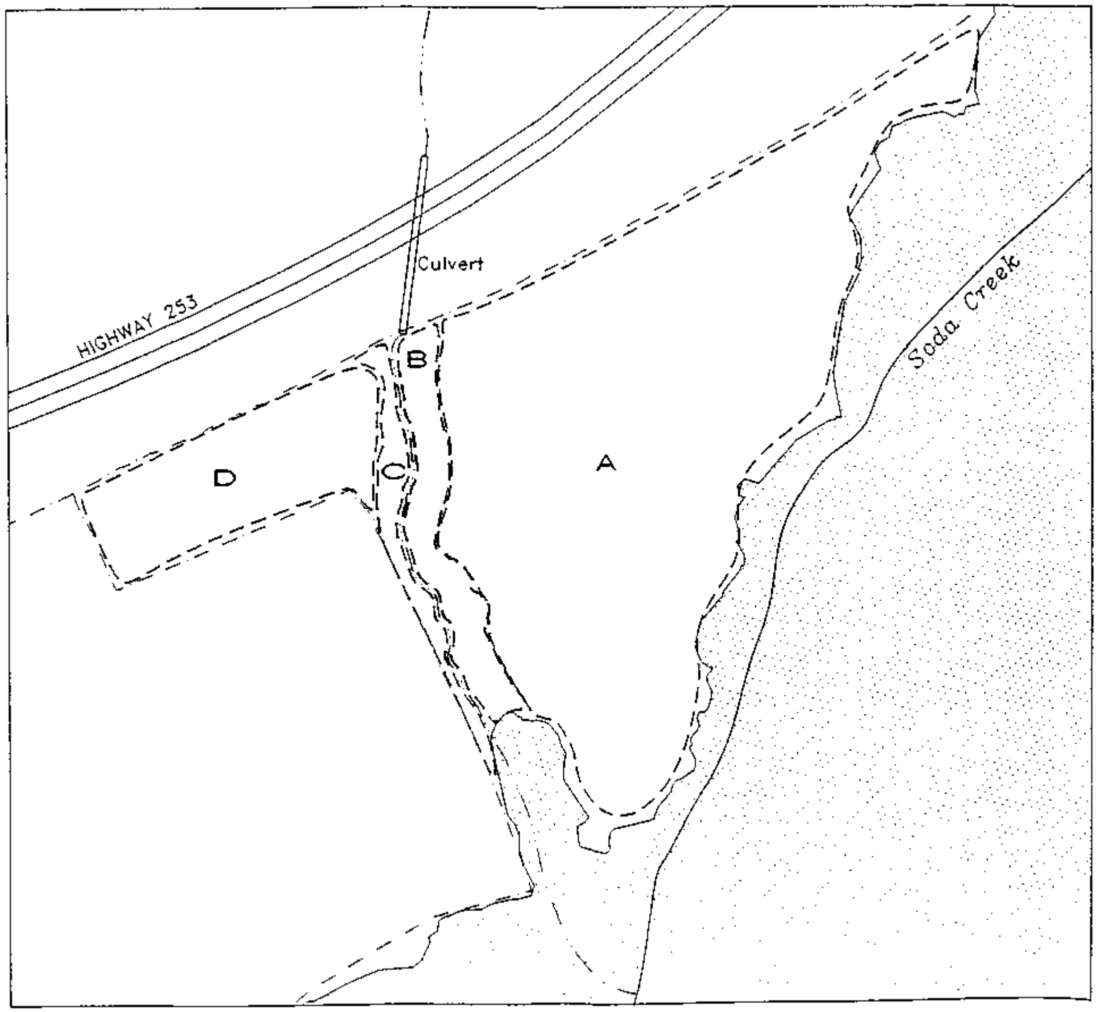
ACER MACROPHYLLUM	50
AESCULUS CALIFORNICA	20
ARBUTUS MENZIESII	20
QUERCUS AGRIFOLIA	40
QUERCUS KELLOGII	20
QUERCUS WISLIZENII	10
UMBELLULARIA CALIFORNICA	50
HETEROMELES ARBUTIFOLIA	120
TOTAL	330

ZONE B

RUBUS URSINUS	40
SALIX SP. (SPRIG)	50
SAMBUCUS MEXICANA	30
SYMPHORICARPOS ALBUS	40
CAREX SP.	20
JUNCUS SP.	100
TOTAL	280

ZONE C

ACER MACROPHYLLUM	5
AESCULUS CALIFORNICA	5
QUERCUS AGRIFOLIA	5
UMBELLULARIA CALIFORNICA	5
ROSA CALIFORNICA	5
RUBUS URSINUS	5
SAMBUCUS MEXICANA	5
TOTAL	35



ZONE D

ACER MACROPHYLLUM	5
AESCULUS CALIFORNICA	20
ARBUTUS MENZIESII	5
UMBELLULARIA CALIFORNICA	20
ROSA CALIFORNICA	10
RUBUS URSINUS	10
SAMBUCUS MEXICANA	25
TOTAL	95

75 0 75
1" = 75'
1 : 900 SCALE

Map Data Source:
WAC Aerial Photograph, 1996
Site Visits, 02/98
GPS Data, 03/98

Note: All locations are approximate.

ENTRIX

FIGURE 7 - 1

SEGAR PROPERTY DEMONSTRATION REVEGETATION PROJECT

NAVARRO WATERSHED RESTORATION PLAN

LEGEND
REVEGETATION ZONE
EXISTING VEGETATION
INTERMITTENT STREAM
FENCE

PREPARED BY: *CIRCUIT RIDER PRODUCTIONS, INC.*
DESIGN: K. GAFFNEY
DRAWN: K. GLEDHILL
SCALE: 1" = 75'
DATE: 03-18-98

The intermittent stream and adjacent floodplain are mostly devoid of native vegetation, providing minimal canopy cover and wildlife habitat. Revegetation with locally collected native plants is recommended to improve streambank stability and minimize erosion, provide shade, structure and nutrients, and to enhance the site for wildlife and birds. During flood events, vegetation on the floodplain will also promote deposition of sediments carried by Soda Creek, thereby improving water quality. Figures 7-1, 7-2, and 7-3 show the revegetation planting plan for the Segar property.

7.2.2 ANDERSON VALLEY HIGH SCHOOL DEMONSTRATION PROJECT

The Anderson Valley High School site is located at the confluence of Robinson and Anderson Creeks (Figure 7-4). Because of substantial bank erosion, and the desire to protect the adjacent property, the toe of the bank slope was armored with rip-rap. When the rip-rap armoring was installed, native vegetation was not included as a component of the project. The steep streambanks are approximately 20-30 feet above the channel bed.

This site is heavily disturbed, with exotic plant species and sparse native vegetation. The rip-rap zone provides minimal canopy cover and shading over the stream which does little to reduce high summer water temperatures in Anderson Creek.

The Anderson Valley High School demonstration project specifies installation of locally collected native willow plant material to be incorporated into the rip-rap (Zone E), as well as planting of more drought tolerant species above the rip-rap zone (Figures 7-4, 7-5, and see Figure 7-3 for planting details). The plants which are incorporated into the rip-rap will provide shade over the stream channel, as well as nutrient and structural contributions to the stream. As the plants higher up on the streambank (Zone D) increase in stature, they will provide late afternoon shade over the channel. In general, revegetation will reduce surface erosion along the streambank, promote sediment deposition, and enhance habitat for fish, birds and terrestrial wildlife.

7.2.3 BRADFORD RANCH DEMONSTRATION REVEGETATION PROJECT

The attached drawings (Figures 7-6, 7-7, also see Figure 7-3), depict a revegetation plan for a site on Highway 128 near Boonville, along Robinson Creek. The landowner is currently implementing a stream stabilization and erosion control project in collaboration with the Natural Resources Conservation Service (NRCS). The revegetation component is intended to complement project elements such as exclusionary fencing, bank stabilization, and erosion control features.

A significant portion of the creek, approximately 2,600 feet within the project area, is devoid of native vegetation providing little habitat and leaving the creek exposed to sunlight. Revegetation with locally collected native plant species will increase the number and diversity of native plants on site, provide shade and improve habitat for fish, as well as wildlife and birds.

PLANT LIST

SCIENTIFIC NAME	COMMON NAME	NUMBER OF LOCATIONS	CONTAINER SIZE	INSTALLATION METHOD	SPACING (F.O.C.)
TREE SPECIES:					
ACER MACROPHYLLUM	BIG LEAF MAPLE	60	SUPERCELL	SUPERTUBE	8' - 10'
AESCULUS CALIFORNICA	CALIFORNIA BUCKEYE	45	DIRECT SEED OR TREEPOT	DIRECT SEED OR SUPERTUBE	8' - 10'
ARBUTUS MENZIESII	MADRONE	25	SUPERCELL	SUPERTUBE	8' - 10'
QUERCUS AGRIFOLIA	COAST LIVE OAK	45	SUPERCELL	SUPERTUBE	8' - 10'
QUERCUS KELLOGII	BLACK OAK	20	SUPERCELL	SUPERTUBE	8' - 10'
QUERCUS WISLIZENII	INTERIOR LIVE OAK	10	SUPERCELL	SUPERTUBE	8' - 10'
UMBELLULARIA CALIFORNICA	CALIFORNIA BAY LAUREL	75	SUPERCELL	SUPERTUBE	8' - 10'
SHRUB SPECIES:					
HETEROMELES ARBUTIFOLIA	TOYON	120	SUPERCELL	SUPERTUBE	4' - 6'
ROSA CALIFORNICA	CALIFORNIA WILD ROSE	15	SUPERCELL	SUPERTUBE	4' - 6'
RUBUS URSINUS	CALIFORNIA BLACKBERRY	55	TREEBAND	SUPERTUBE	4' - 6'
SALIX SP.	WILLOW	50	DORMANT CUTTINGS	DORMANT SPRIG INSTALLATION	2' - 4'
SAMBUCUS MEXICANA	BLUE ELDERBERRY	60	DEEPOT	SUPERTUBE	4' - 6'
SYMPHORICARPOS ALBUS	SNOWBERRY	40	TREEBAND	SUPERTUBE	4' - 6'
EMERGENT SPECIES:					
CAREX SP.	SEDGE	20	TRANSPLANT	EMERGENT PLANT INSTALLATION	2' - 4'
JUNCUS SP.	RUSH	100	TRANSPLANT	EMERGENT PLANT INSTALLATION	2' - 4'
TOTAL:		740			

NOTES:

1. Planting should be installed in the winter months of November-January, once rainfall has moistened the soil to a depth of 10 inches or greater Planting should be completed by mid-February.
2. Planting technique shall be predominantly liner sized seedlings enclosed in protective hardware with weed control fabric, (see Liner Planting Details, Sheet 3)
3. Each planting spot shall be marked in the field with a color coded (to species) surveyor flag. Flags should remain at each planting spot after plant installation.
4. Plantings will require frequent irrigation during the first dry season after planting. Irrigation should begin in April and continue into October. Approximately two quarts of water should be applied directly to the plant. Watering interval should be 7 to 10 days depending on weather conditions.
5. Plants should have all weeds removed from around the stem three times each year for three years following installation. Weed removal should be performed once in February, April and December each year.
6. Protective hardware and weed control fabric should remain in place for 3 to 5 years following plant installation.
7. The exact planting locations of each species shall be determined in the field after construction. Those species requiring high soil moisture, (i.e. Acer macrophyllum, Carex sp., Juncus sp., Rosa californica, Rubus ursinus, Salix sp.) shall be planted in lower elevations of the planting zones.

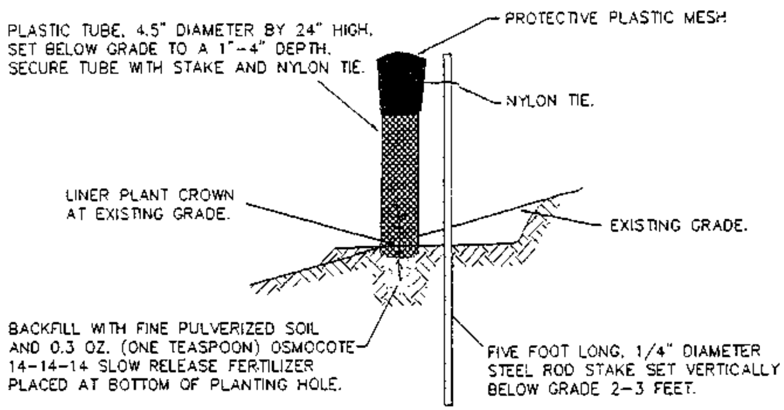
ENTRIX

FIGURE 7 - 2

SEGAR PROPERTY DEMONSTRATION REVEGETATION PROJECT

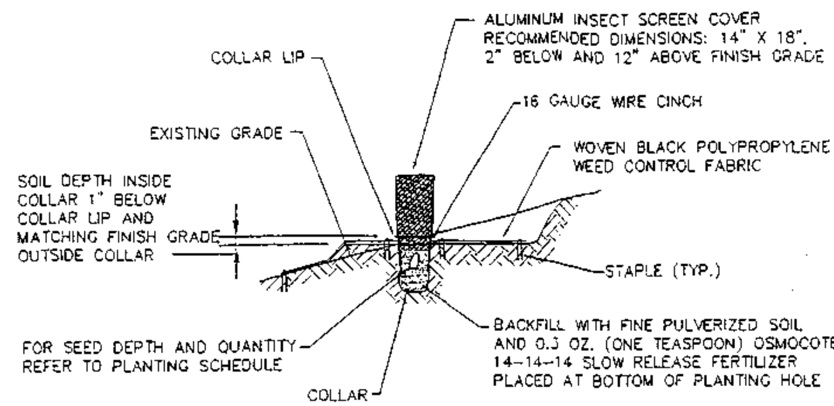
NAVARRO WATERSHED RESTORATION PLAN

PREPARED BY: ***CIRCUIT RIDER PRODUCTIONS, INC.***
DESIGN: K. GAFFNEY
DRAWN: K. GLEDHILL
SCALE: NO SCALE
DATE: 03-18-98



SUPERTUBE PLANTING DETAIL

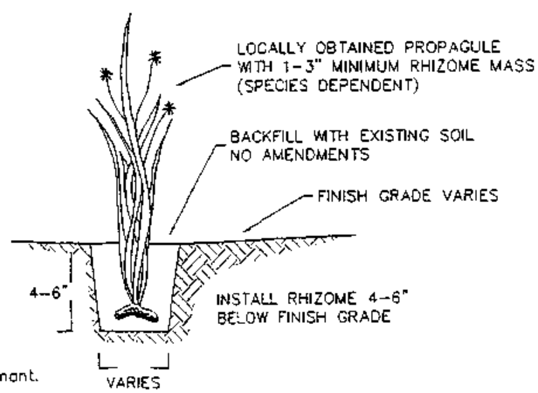
NOT TO SCALE



DIRECT SPOT SEEDING DETAIL

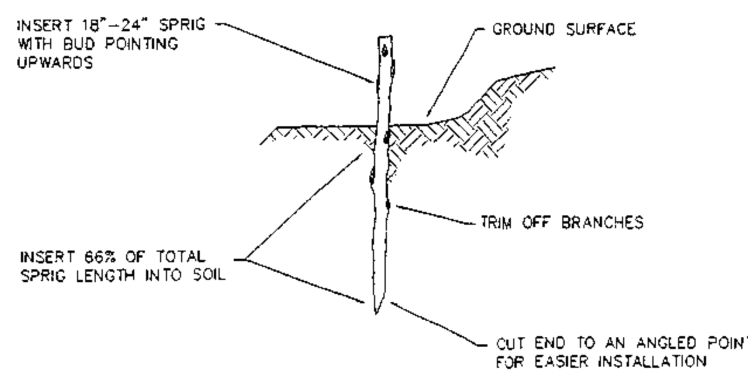
NOT TO SCALE

1. Excavate planting hole sufficient to receive emergent plant and rhizome.
2. Proposed finish grade varies.
3. Collect emergent plants from healthy populations on adjacent sites.
4. Keep emergent plants moist and protected from sunlight from time of collection to time of installation.
5. Install emergent plants on same day as collected.
6. Collect emergent plants in discontinuous patches to avoid excessive disturbance to existing populations.
7. Planting shall occur Nov.-April when emergent plants are dormant.



EMERGENT VEGETATION INSTALLATION

NOT TO SCALE



DORMANT WILLOW SPRIG INSTALLATION

NOT TO SCALE

ENTRIX

FIGURE 7 - 3

DEMONSTRATION REVEGETATION PROJECT
PLANT INSTALLATION DETAIL

NAVARRO WATERSHED RESTORATION PLAN

PREPARED BY: ***CIRCUIT RIDER PRODUCTIONS, INC.***
DESIGN: K. GAFFNEY
DRAWN: K. GLEDHILL
SCALE: NO SCALE
DATE: 03-18-98

ZONE A

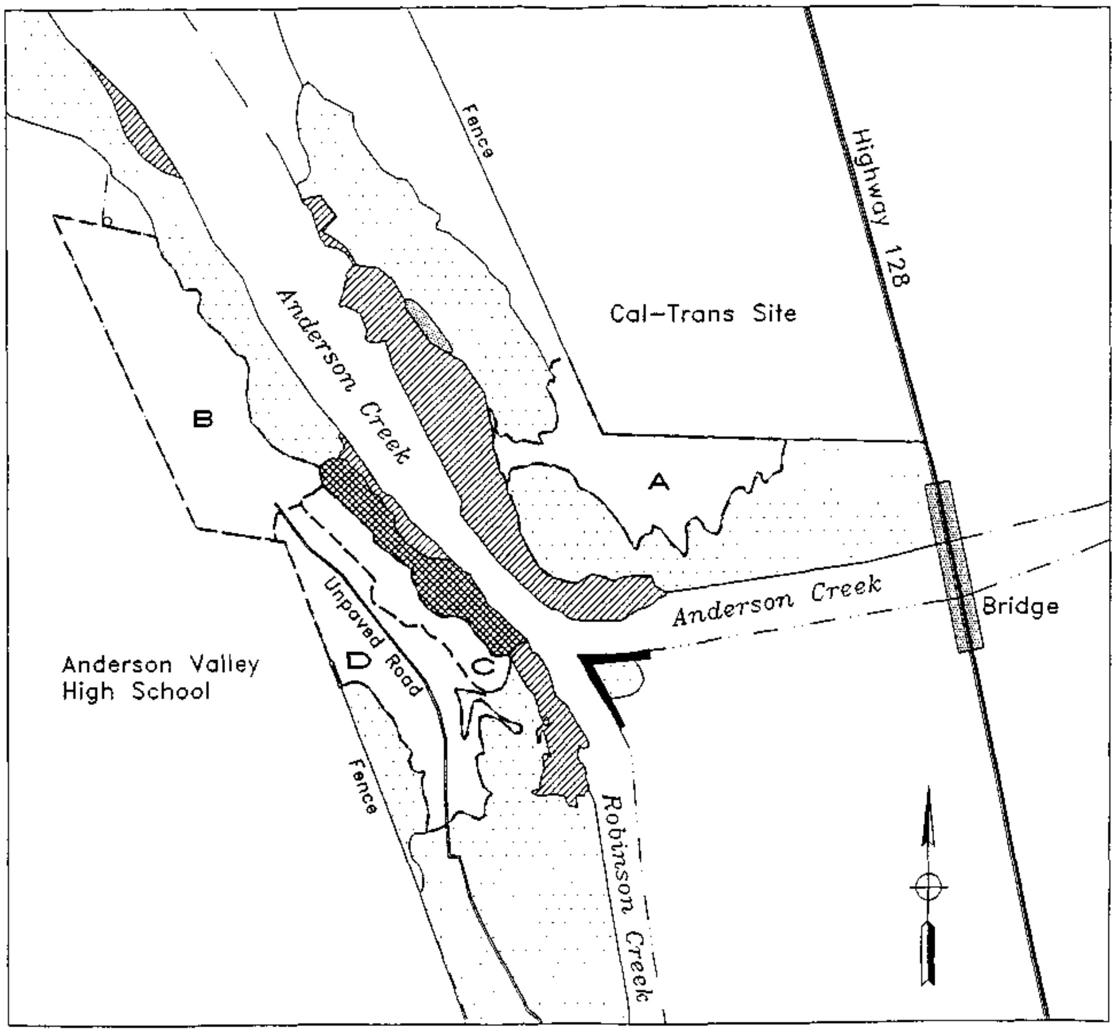
RUBUS URSINUS	40
SALIX SP. (LINER)	100
SALIX SP. (SPRIG)	100
SAMBUCUS MEXICANA	30
SYMPHORICARPOS ALBUS	40
CAREX SP.	100
JUNCUS SP.	100
TOTAL	510

ZONE B

ACER MACROPHYLLUM	50
AESCULUS CALIFORNICA	20
ARBUTUS MENZIESII	20
QUERCUS AGRIFOLIA	40
QUERCUS KELLOGII	20
QUERCUS WISLIZENII	10
UMBELLULARIA CALIFORNICA	50
HETEROMELES ARBUTIFOLIA	120
TOTAL	330

ZONE C

ACER MACROPHYLLUM	20
AESCULUS CALIFORNICA	20
QUERCUS AGRIFOLIA	5
UMBELLULARIA CALIFORNICA	10
HETEROMELES ARBUTIFOLIA	20
ROSA CALIFORNICA	20
RUBUS URSINUS	20
SAMBUCUS MEXICANA	5
TOTAL	120



ZONE D

ACER MACROPHYLLUM	40
AESCULUS CALIFORNICA	30
ARBUTUS MENZIESII	40
UMBELLULARIA CALIFORNICA	100
ROSA CALIFORNICA	50
RUBUS URSINUS	50
SAMBUCUS MEXICANA	100
TOTAL	410

ZONE E

(AT BASE OF RIP RAP)

SALIX SP. (SPRIG)	200
TOTAL	200

100 0 100

1" = 100'
1 : 1200 SCALE

Map Data Source:
WAC Aerial Photograph, 1996
Site Visits, 11/97
GPS Data, 12/97

Note: All locations are approximate.

ENTRIX

FIGURE 7 - 4

ANDERSON VALLEY HIGH SCHOOL
DEMONSTRATION REVEGETATION PROJECT

NAVARRO WATERSHED RESTORATION PLAN

LEGEND

- REVEGETATION ZONE
- EXISTING VEGETATION
- GRAVEL BAR
- RIP RAP
- EROSION ZONE

PREPARED BY: *CIRCUIT RIDER PRODUCTIONS, INC.*
DESIGN: K. GAFFNEY
DRAWN: K. GLEDHILL
SCALE: 1" = 100'
DATE: 7-7 03-10-98

PLANT LIST

SCIENTIFIC NAME	COMMON NAME	NUMBER OF LOCATIONS	CONTAINER SIZE	INSTALLATION METHOD	SPACING (F.O.C.)
TREE SPECIES:					
ACER MACROPHYLLUM	BIG LEAF MAPLE	110	SUPERCELL	SUPERTUBE	8' - 10'
AESCULUS CALIFORNICA	CALIFORNIA BUCKEYE	70	DIRECT SEED OR TREEPOT	DIRECT SEED OR SUPERTUBE	8' - 10'
ARBUTUS MENZIESII	MADRONE	60	SUPERCELL	SUPERTUBE	8' - 10'
QUERCUS AGRIFOLIA	COAST LIVE OAK	45	SUPERCELL	SUPERTUBE	8' - 10'
QUERCUS KELLOGII	BLACK OAK	20	SUPERCELL	SUPERTUBE	8' - 10'
QUERCUS WISLIZENII	INTERIOR LIVE OAK	10	SUPERCELL	SUPERTUBE	8' - 10'
UMBELLULARIA CALIFORNICA	CALIFORNIA BAY LAUREL	160	SUPERCELL	SUPERTUBE	8' - 10'
SHRUB SPECIES:					
HETEROMELES ARBUTIFOLIA	TOYON	140	SUPERCELL	SUPERTUBE	4' - 6'
ROSA CALIFORNICA	CALIFORNIA WILD ROSE	70	SUPERCELL	SUPERTUBE	4' - 6'
RUBUS URSINUS	CALIFORNIA BLACKBERRY	110	TREEBAND	SUPERTUBE	4' - 6'
SALIX SP.	WILLOW	400	DORMANT CUTTINGS	DORMANT SPRIG INSTALLATION	1' - 2'
SAMBUCUS MEXICANA	BLUE ELDERBERRY	135	DEEPOT	SUPERTUBE	8' - 10'
SYMPHORICARPOS ALBUS	SNOWBERRY	40	TREEBAND	SUPERTUBE	4' - 6'
EMERGENT SPECIES:					
CAREX SP.	SEDGE	100	TRANSPLANT	EMERGENT PLANT INSTALLATION	1' - 2'
JUNCUS SP.	RUSH	100	TRANSPLANT	EMERGENT PLANT INSTALLATION	1' - 2'
TOTAL:		1570			

NOTES:

1. Planting should be installed in the winter months of November–January, once rainfall has moistened the soil to a depth of 10 inches or greater. Planting should be completed by mid–February.
2. Planting technique shall be predominantly liner sized seedlings enclosed in protective hardware with weed control fabric. (see Liner Planting Details, Sheet 3). Seeds and other propagules should be collected from as close to the project site as possible, within the Navarro watershed.
3. Each planting spot shall be marked in the field by a restoration ecologist with a color coded (to species) surveyor flag. Flags should remain at each planting spot after plant installation. Individual planting sites shall be flagged based upon ecological criteria.
4. Plantings will require frequent irrigation during the first dry season after planting. Irrigation should begin in April and continue into October. Approximately two quarts of water should be applied directly to the plant. Watering interval should be 7 to 10 days depending on weather conditions.
5. Plants should have all weeds removed from around the stem three times each year for three years following installation. Weed removal should be performed once in February, April and December each year.
6. Protective hardware and weed control fabric should remain in place for 3 to 5 years following plant installation.
7. The exact planting locations of each species shall be determined in the field after construction. Those species requiring high soil moisture, (i.e. _Acer macrophyllum_, _Alnus rhombifolia_, _Carex sp._, _Juncus sp._, _Rosa californica_, _Rubus ursinus_, _Salix sp._) shall be planted in lower elevations of the planting zones.
8. Himalaya Berry (_Rubus discolor_), Harding Grass (_Phalaris aquatica_) and Yellow Star Thistle (_Centaurea solstitialis_) should be eradicated from the revegetation site, and monitored for re–emergence. Hand eradication methods are appropriate, provided that the physiology and reproductive strategy of each species is taken into account. If herbicide is used for invasive control, it should be applied in a sensitive fashion, by a licensed pesticide applicator with a with a background in native plant ecology.

ENTRIX

FIGURE 7 - 5

ANDERSON VALLEY HIGH SCHOOL
DEMONSTRATION REVEGETATION PROJECT

NAVARRO WATERSHED RESTORATION PLAN

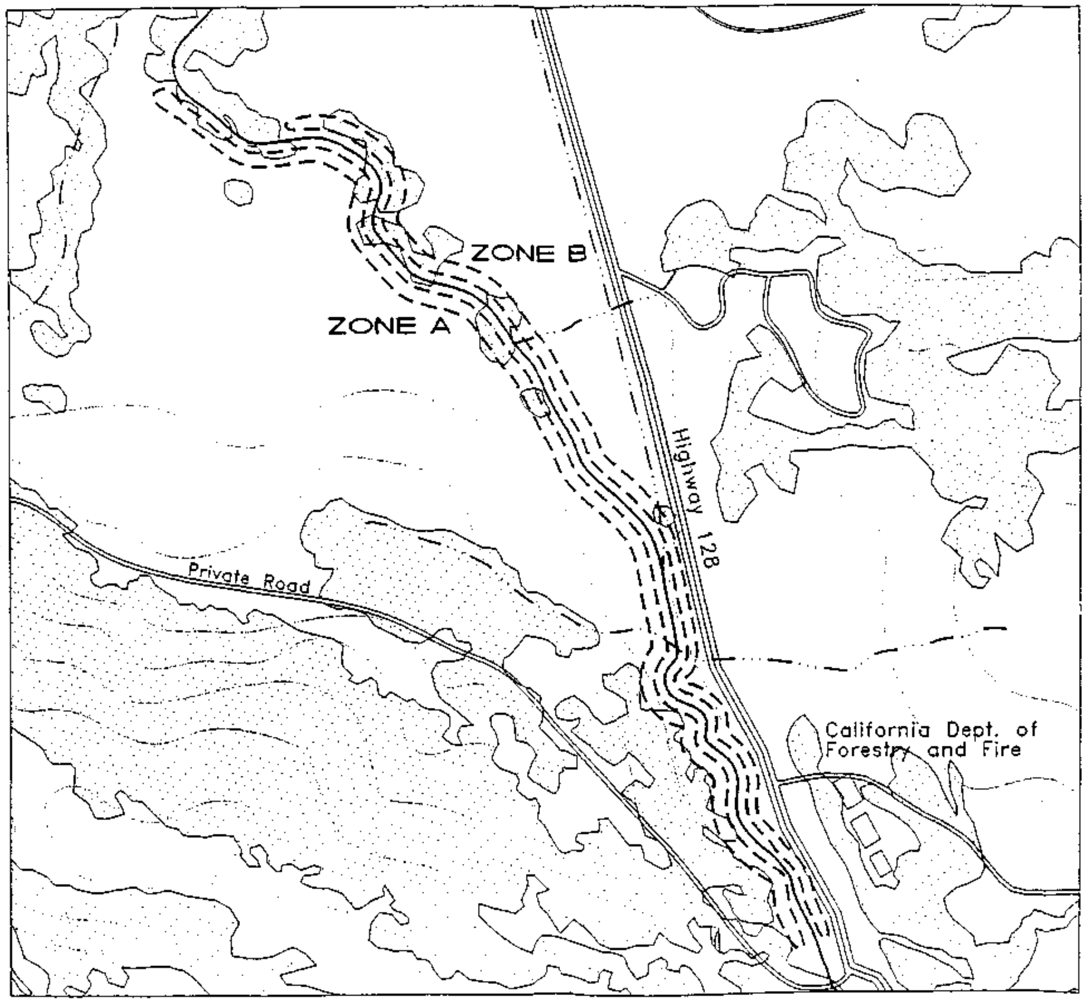
PREPARED BY: **CIRCUIT RIDER PRODUCTIONS, INC.**
DESIGN: K. GAFFNEY
DRAWN: K. GLEDHILL
SCALE: NO SCALE
DATE: 03-10-98

ZONE A

ACER MACROPHYLLUM	18
AESCULUS CALIFORNICA	25
ALNUS RHOMBIFOLIA	40
FRAXINUS LATIFOLIA	40
QUERCUS AGRIFOLIA	25
QUERCUS KELLOGII	18
UMBELLULARIA CALIFORNICA	30
HETEROMELES ARBUTIFOLIA	35
ROSA CALIFORNICA	75
RUBUS URSINUS	75
SALIX SP. (SPRIG)	50
SAMBUCUS MEXICANA	30
CAREX SP.	25
JUNCUS SP.	38
TOTAL	524

Map Data Source:
WAC Aerial Photograph, 1996
Site Visits, 02/98

Note: All locations are approximate.



ZONE B

ACER MACROPHYLLUM	17
AESCULUS CALIFORNICA	25
ALNUS RHOMBIFOLIA	40
FRAXINUS LATIFOLIA	40
QUERCUS AGRIFOLIA	25
QUERCUS KELLOGII	17
UMBELLULARIA CALIFORNICA	30
HETEROMELES ARBUTIFOLIA	35
ROSA CALIFORNICA	75
RUBUS URSINUS	75
SALIX SP. (SPRIG)	50
SAMBUCUS MEXICANA	30
CAREX SP.	25
JUNCUS SP.	37
TOTAL	521

300 0 300
1" = 300'
1 : 3600 SCALE

ENTRIX

FIGURE 7 - 6

BRADFORD RANCH DEMONSTRATION REVEGETATION PROJECT

NAVARRO WATERSHED RESTORATION PLAN

LEGEND
REVEGETATION ZONE
EXISTING VEGETATION
ROBINSON CREEK
INTERMITTENT STREAM
TOPOGRAPHIC CONTOUR

PREPARED BY: *CIRCUIT RIDER PRODUCTIONS, INC.*
DESIGN: K. GAFFNEY
DRAWN: K. GLEDHILL
SCALE: 1" = 300'
DATE: 03-10-98

PLANT LIST

SCIENTIFIC NAME	COMMON NAME	NUMBER OF LOCATIONS	CONTAINER SIZE	INSTALLATION METHOD	SPACING (F.O.C.)
TREE SPECIES:					
ACER MACROPHYLLUM	BIG LEAF MAPLE	35	SUPERCELL	SUPERTUBE	8' - 10'
AESCULUS CALIFORNICA	CALIFORNIA BUCKEYE	50	DIRECT SEED OR TREEPOT	DIRECT SEED OR SUPERTUBE	8' - 10'
ALNUS RHOMBIFOLIA	WHITE ALDER	80	SUPERCELL	SUPERTUBE	4' - 6'
FRAXINUS LATIFOLIA	OREGON ASH	80	SUPERCELL	SUPERTUBE	8' - 10'
QUERCUS AGRIFOLIA	COAST LIVE OAK	50	SUPERCELL	SUPERTUBE	8' - 10'
QUERCUS KELLOGII	BLACK OAK	35	SUPERCELL	SUPERTUBE	8' - 10'
UMBELLULARIA CALIFORNICA	CALIFORNIA BAY LAUREL	60	SUPERCELL	SUPERTUBE	8' - 10'
SHRUB SPECIES:					
HETEROMELES ARBUTIFOLIA	TOYON	70	SUPERCELL	SUPERTUBE	4' - 6'
ROSA CALIFORNICA	CALIFORNIA WILD ROSE	150	SUPERCELL	SUPERTUBE	4' - 6'
RUBUS URSINUS	CALIFORNIA BLACKBERRY	150	TREEBAND	SUPERTUBE	4' - 6'
SALIX SP.	WILLOW	100	DORMANT CUTTINGS	DORMANT SPRIG INSTALLATION	2' - 4'
SAMBUCUS MEXICANA	BLUE ELDERBERRY	60	DEEPOT	SUPERTUBE	4' - 6'
EMERGENT SPECIES:					
CAREX SP.	SEDGE	50	TRANSPLANT	EMERGENT PLANT INSTALLATION	2' - 4'
JUNCUS SP.	RUSH	75	TRANSPLANT	EMERGENT PLANT INSTALLATION	2' - 4'
TOTAL:		1045			

NOTES:

1. Planting should be installed in the winter months of November–January, once rainfall has moistened the soil to a depth of 10 inches or greater. Planting should be completed by mid–February.
2. Planting technique shall be predominantly liner sized seedlings enclosed in protective hardware with weed control fabric. (see Liner Planting Details, Sheet 3).
3. Each planting spot shall be marked in the field with a color coded (to species) surveyor flag. Flags should remain at each planting spot after plant installation.
4. Plantings will require frequent irrigation during the first dry season after planting. Irrigation should begin in April and continue into October. Approximately two quarts of water should be applied directly to the plant. Watering interval should be 7 to 10 days depending on weather conditions.
5. Plants should have all weeds removed from around the stem three times each year for three years following installation. Weed removal should be performed once in February, April and December each year.
6. Protective hardware and weed control fabric should remain in place for 3 to 5 years following plant installation.
7. The exact planting locations of each species shall be determined in the field after construction. Those species requiring high soil moisture, (i.e. Acer macrophyllum, Alnus rhombifolia, Carex sp., Juncus sp., Rosa californica, Rubus ursinus, Salix sp.) shall be planted in lower elevations of the planting zones.
8. The property owner will determine the exclusionary fencing setback that defines the width of the revegetation zones.

ENTRIX

FIGURE 7 - 7

BRADFORD RANCH DEMONSTRATION REVEGETATION PROJECT

NAVARRO WATERSHED RESTORATION PLAN

PREPARED BY: *CIRCUIT RIDER PRODUCTIONS, INC.*
DESIGN: K. GAFFNEY
DRAWN: K. GLEDHILL
SCALE: NO SCALE
DATE: 03-10-98

7.3 ROAD EROSION CONTROL AND PREVENTION DEMONSTRATION PROJECTS

The draft Navarro River Restoration Plan has identified erosion and sediment production associated with roads as a significant and preventable source of sediment yield to stream channels throughout the watershed. The goal of these four small demonstration projects is to present to landowners the typical costs and range of road drainage and spoil management techniques that can be implemented to reduce sediment yield to stream channels. Landowners throughout the Navarro River watershed are encouraged to view the described techniques as different ways or methods to drain roads, prevent culvert failure, reduce the risk of fillslope failures and reduce accelerated man-caused erosion and sediment yield to stream channels.

Most of the treatments described here are also expected to reduce long term maintenance requirements and costs. The proposed treatments represent one of the more "cost-effective" ways to address typical existing and potential erosion problems along roads. The solutions are designed to provide for effective, low maintenance erosion control and erosion prevention.

During the week of November 16 to 20, 1997 and on March 9, 1998 field mapping and inventory work was conducted in the Navarro River watershed. The field work and subsequent assessment resulted in the development of several demonstration projects for road erosion prevention and erosion control. Four road reaches were chosen, largely because individual landowners volunteered their roads as demonstration projects areas.

The demonstration projects consist of road logs, maps and cost tables which describe the proposed work at each site. The Butler and Ashton Road sites also has design profiles for each of the stream crossings proposed for upgrade or proper closure. Finally, draft descriptive specifications and miscellaneous sketches for the nine main work tasks that have been prescribed for one or more of the demonstration project areas are attached.

The four demonstration projects include the typical range of roads most landowners have to contend with in wildland sub-basins of the Navarro. All the routes originally were constructed as logging roads. Today, the routes are primarily used as access roads for rural residential living. The four projects are:

1. The David Butler Road in lower Dago Creek, a tributary in the Rancheria Creek watershed (Tables 7-1 and 7-2, Figures 7-8 through 7-16. Approximately 1.1 miles of unsurfaced, seasonal, low standard road was assessed. The road traverses steep inner gorge hillslopes and displays the typical range of drainage and slope stability problems. These same problems will be encountered by most ranch and timberland owners, including both low-use and abandoned roads. The demonstration project includes re-constructing 8 stream crossings, excavating potentially unstable sidecast spoil at four locations and improving road prism drainage and dispersing road runoff.
2. The upper portion of the Nash-Mill Road (Table 7-3 and Figure 7-17) located in Mill Creek, a tributary to the Navarro River located 3 miles downstream of Philo,

CA. Approximately 1.1 miles of intermittently rocked, year around use road was assessed. The road climbs steeply from the valley floor to the ridgetop and provides access to a half dozen or so rural sub-division parcels. The primary problems along the selected road reach are associated with road prism drainage and seasonal grading practices which have resulted in the construction of nearly continuous berms along the outside edge of the road. Several large gullies have formed below the road and resulted in large volumes of sediment being delivered to smaller tributary streams. Note that the costs (Table 7-4) for regrading roads following dozer work and the costs for re-rocking rolling dip sites on the Nash-Mill road have not been included.

3. The lower portions of the Holmes Ranch Road (Table 7-5 and Figure 7-18) also located in the Mill Creek watershed. Approximately 1.06 miles of rocked, year around, high use road was assessed. The road averages 25-30 feet wide. It traverses terraces immediately adjacent to Mill Creek and then climbs steeply across steep hillslopes. The road provides access to a major, rural sub-division, as well as several ranches. Erosional problems along the demonstration route are associated with high rates of fine sediment production and delivery from the road prism and ditch. The six stream crossings along the road appear to have properly sized culverts which are functioning well, however two stream crossings have high diversion potentials which need to be corrected. Note that the costs (Table 7-6) for regrading roads following dozer work and the costs for re-rocking rolling dip sites on the Holmes Ranch road have not been included.

4. A seasonal use road on the property of P. Evelyn Ashton (Tables 7-7 and 7-8 and Figures 7-19 through 7-25). The road starts along the upper portion of the Nash Mill Road and descends steadily downslope across hummocky and benchy earthflow topography. The road is unsurfaced, receives very low use levels and serves as a good example of a typical rural ranch driveway in the Navarro River watershed.

The road was re-visited in early March 1998 to finalize treatment prescriptions along the lower half (i.e. Stations 29+00 to 48+80) of the road. Heavy winter storms triggered the re-activation of two separate large earthflows, several smaller cutbank failures and the failure of a stream crossing culvert at site #3. The active portions of the earthflows range from 1 to 3 acres in size, each contain multiple blocks of moving hillslope and have offset the road at 4 locations from 1 to 7 feet vertically. The failed stream crossing occurred as a result of leakage at the couple between two sections of plastic pipe and triggered a debris slide which delivered sediment to a small class III stream.

Prior to the March site visit, the demonstration project was intending to emphasize small stream crossing construction practices and overall road prism drainage improvements. However, due to the observed deep-seated hillslope instability, we have laid out a project which emphasizes road upgrading between the start of the road at the Nash-Mill Road to Station 27+50, proper road closure between Stations 28+00 and 42+58, and road upgrading between Stations 42+75 and 48+80. We have proposed proper road closure for the middle portion of the road because it is likely that future wet winters will result in high road maintenance costs to the landowner. Future slide activity will make it difficult to perform annual and storm-event maintenance at the stream crossings and to eliminate the risk of accelerated sedimentation associated with the inability to maintain the stream crossings during the winter months.

For each draft demonstration project we have developed a:

1) **Road log listing all proposed work tasks and road drainage treatments.** The road log lists all tasks by standard engineering "station" method. A station is a 100-foot interval, measured along the centerline of the road bench. A station lath, or colorful flagging, is installed on the cutbanks along the road every 100 feet starting at the beginning of the demonstration road reach, and labeled with its station number. For example, the point on the road that is 4,000 feet from the beginning has a flag on the inside edge of the road labeled "40+00". Locations between station flags are identified such as "40+34". This is found 34 feet up-station of the 40+00 flag or 4034 feet from the beginning of the road. "Upstation" means in the direction of the higher station numbers; "downstation" means in the direction of lower station numbers.

In general, the tasks specified in this contract are presented so that work proceeds toward higher station numbers. The recommended work sequence is downstation, beginning at the end of the road and working out.

2) **Sketch map showing the location of all stream channels, stream crossing sites, ditch relief culverts, as well as the location of all proposed specific road drainage treatments intended to reduce erosion and sediment yield from the road.**

3) **Summary cost tables to improve road drainage and reduce road maintenance costs.** The total costs should be viewed as "not to exceed or the maximum costs" to perform the listed tasks, minus any additional road rocking costs. All tasks include a standard 25% contingency factor to accommodate unforeseen situations. However, most of the proposed work tasks are quite straight forward, and we are confident most of the contingency costs will not be needed. Finally, a limited amount of professional layout, supervision and reporting time has been included to ensure specific culvert installations, critical rolling dips and rolling dips in general are properly constructed.

All of the field data collected at specific sites mapped along the Road are also available in a database format (not included in this Plan), and are summarized in the road logs. The database information will be used during the implementation phase of the demonstration projects. If a sketch was made of the site area, it has been scanned and is shown on the back of each database form. The database form is used to understand the nature of the problems and the proposed solution(s) at all stream crossings along the Road.

The demonstration project plans consist of field designs that briefly describe the work that is recommended for implementation. The four project descriptions and the descriptive specifications are not "contract-ready." Rather, adjustments and improvements to the final work items may be developed as heavy equipment operations are conducted and as changing field conditions warrant. In developing these plans and cost-estimates, we have made the assumption that PWA, or a suitably qualified firm or individual with equivalent experience, will oversee field implementation of the four pilot projects.

7.3.1 Road Log Listing All Proposed Erosion Control and Erosion Prevention Treatments and Tasks for the Butler Road, Dago Creek Watershed

Table 7-1. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Butler Road, Dago Creek Watershed, Navarro River Basin.

PWA Site #	From	To: or At:	Treatment
RD25	1+45	1+95	RD axis = 1+70, dip dimensions: 50'Lx18'Wx 1'D. Gradient up road = 3%, gradient down road = -7%. Sidecast spoils.
RD24	3+05	3+55	RD axis = 3+30, dip dimensions: 50'Lx18'Wx 1'D. Gradient up road = 4%, gradient down road = -6%. Sidecast spoils.
RD23	4+50	5+00	RD axis = 4+75, dip dimensions: 50'Lx15'Wx 1'D. Gradient up road = 7%, gradient down road = -2%. Sidecast spoils.
RD22	5+75	6+25	RD axis = 6+00, dip dimensions: 50'Lx40'Wx 1'D. Gradient up road = 8%, gradient down road = -8%. Spoil materials up road to left of dip.
S#11		6+80	Install 24"X60' cmp with flared inlet with outlet emerging 30' down fillslope. Attach 30' of downspout extending down to natural channel. Install critical dip on right hinge line, before landing to eliminate diversion potential. Excavate any remaining unstable fill covered with bracken ferns to the right of the crossing axis.
RD21	7+75	8+25	RD axis = 8+00, dip dimensions: 50'Lx25'Wx 1'D. Gradient up road = 5%, gradient down road = -5%. Sidecast spoils.
	7+75	10+10	If road grade to left of crossing at site 10 is too steep after sill construction, could lower road through cut to lessen steepness.

Table 7-1. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Butler Road, Dago Creek Watershed, Navarro River Basin (continued).

PWA Site #	From	To: or At:	Treatment
S#10		10+10	Install sill by lowering road through site ~3' creating a broad & deep dip (60'Lx18'WX2'D). Excavate 4' highX3' deepX30' wide section of fill from the fill face at OBR. Install key way perpendicular to channel starting just above BOT flag. Key way should be 30' wide, 10' long & extend 2' below channel surface. Backfill with 60 yds of a mix of 1-2' diameter coarse boulders to form sill. Center of dip over key way should be 3' lower than edges. Excavate upstream from IBR to TOP providing 7' channel width. Excavate 60 yds (40'Wx2'Dx20'L) of unstable fill located to the right of proposed sill. Excavate fillslope downstream to large redwood.
RD20	11+25	11+75	RD axis = 11+50, dip dimensions: 50'Lx15'Wx 0.5'D. Gradient up road = 4%, gradient down road = -4%. Lower road, remove berm at axis, & build up road beyond or improve outslope at bedrock cutbank. Site needs permanent dip.
RD19	14+40	15+00	RD axis = 14+70, dip dimensions: 60'Lx18'Wx 1'D. Gradient up road = 11%, gradient down road = -11%. Sidecast spoils. Remove berm through length of dip. Make sure dip flow crosses 2 skids immediately below main road.
RD18	15+53	16+28	RD axis = 15+90, dip dimensions: 75'Lx18'Wx 1'D. Gradient up road = 18%, gradient down road = -15%. Site located at top of through cut. Take road down 2' at axis. Sidecast spoils or use to build up road if suitable.
RD17	17+95	18+55	RD axis = 18+25, dip dimensions: 60'Lx18'Wx 1'D. Gradient up road = 15%, gradient down road = -13%. Take road down 2' at axis. Remove berm with backhoe. Sidecast spoils, use to build up road if suitable, or endhaul up road to turn around.
RD16	19+20	19+80	RD axis = 19+50, dip dimensions: 60'Lx18'Wx 1'D. Gradient up road = 16%, gradient down road = -11%. Sidecast spoils or use to build up road if suitable.

Table 7-1. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Butler Road, Dago Creek Watershed, Navarro River Basin (continued).

PWA Site #	From	To: or At:	Treatment
RD15	20+25	20+75	RD axis = 20+50, dip dimensions: 50'Lx30'Wx 1'D. Gradient up road = 8%, gradient down road = -8%. Take road down 2' in axis. Sidecast spoils up road from dip (down station).
RD14	21+75	22+45	RD axis = 22+10, dip dimensions: 70'Lx24'Wx 1'D. Gradient up road = 16%, gradient down road = -15%. Remove berm with backhoe. Use spoils on road to enhance dip if suitable or endhaul to landing at station 24+00.
RD13	23+20	23+80	RD axis = 23+50, dip dimensions: 60'Lx15'Wx 1'D. Gradient up road = 10%, Gradient down road = -8%.
S#9		24+80	Install 24" x50' culvert with flared inlet where outlet emerges 25' down fillslope from OBR. Install 20' downspout to natural channel below. Install critical dip on right hinge line by raising road bed several feet over 50' length of road. Excavate 5' up channel from IBR to create stilling basin.
RD12	25+90	26+40	RD axis =26+15, dp dimensions: 70'Lx15'Wx 1'D. Gradient up road = 14%, gradient down road = -10%.
RD11	27+10	27+60	RD axis = 27+35, dip dimensions: 50'Lx15'Wx 1'D. Gradient up road = 4%, gradient down road = -2%. Remove berm with backhoe. Use spoils on road to enhance dip if suitable.
RD10	28+10	28+60	RD axis = 28+35, dip dimensions: 50'Lx15'Wx 1'D. Gradient up road = 7%, gradient down road = -6%. Remove berm with backhoe. Use spoils on road to enhance dip if suitable. If spoils are competent then place against base of cutbank slide.
	28+40	29+30	Cutbank slide.

Table 7-1. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Butler Road, Dago Creek Watershed, Navarro River Basin (continued).

PWA Site #	From	To: or At:	Treatment
S#8		29+60	Install 24"X60' culvert with flared inlet. Outlet should emerge at large fir below OBR. Attach 20' downspout to the natural channel. Excavate large stilling basin by excavating 5' upstream of proposed inlet area. Install critical dip at crossing by lowering road 1-2' in axis of dip & building up road at station 30+00 over a distance of 30-40'.
RD9	31+80	32+30	RD axis =32+05, dip dimensions: 60'Lx18'Wx 1'D. Gradient up road = 11%, gradient down road = -15%. Take road down 2' in axis of dip.
S#7	31+40	31+75	Excavate potential fill failure between stations 31+40 & 31+75. Use failures to left & right as template for belly in excavation. Excavate 35'Wx2'Dx25'L = 65 yds. Endhaul spoils to landing to right past site 6 & use spoil to raise road & eliminate diversion potential at site 5. No future sidecasting along this section of road. Remove berm for 150' around bend & use berm spoils on road enhancing very mild outslope or push beyond site 5 to raise road bed & eliminate diversion potential.
S#6			Excavate unstable fill along 60' of the right bank above class 2 stream. Extend excavation 10' back from fill edge & 25' downslope. Excavate 7' channel width below right bank. Move current slash pile behind site & place spoils above on upper landing & on road bed to raise road & eliminate diversion potential at site 5. Keep spoils away from unstable landing edge located immediately to right of site and above Dago Creek.
RD8	34+60	35+10	RD axis =34+85, dip dimensions: 50'Lx18'Wx 1'D. Gradient up road = 4%, gradient down road = -1%. Take road down 2' in axis of dip.

Table 7-1. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Butler Road, Dago Creek Watershed, Navarro River Basin (continued).

PWA Site #	From	To: or At:	Treatment
S#5		32+80	Install 54"X60' culvert with flared inlet with pipe outlet at BOT. Install pipe deep in fill in centerline of profile with 12% gradient. Flared inlet needed to facilitate transport of coarse sediment. Road over crossing should be lowered 3' & centerline of road should be moved 26' downstream from orange site flag. Remove fresh fan deposits from TOP to proposed cmp inlet constructing long & deep stilling basin. Large leaning tree above BOT will need to be removed. Use materials excavated from upstream fan & lowering road to raise road significantly to right (up station) of crossing to eliminate diversion potential.
RD7	35+30	35+80	RD axis =35+55, dip dimensions: 50'Lx18'Wx 1'D. Gradient up road = 3%, gradient down road = -1%.
RD6	36+75	37+25	RD axis =37+00, dip dimensions: 50'Lx18'Wx 1'D. Gradient up road = 4%, gradient down road = -1%.
RD5	38+15	38+65	RD axis =38+40, dip dimensions: 50'Lx18'Wx 1'D. Gradient up road = 4%, gradient down road = -1%. Pull perched fill at outlet of dip. Place spoils on road to enhance dip & outslope.
S#4		40+00	Install 30"x50' culvert at base of fill in natural channel with large stilling basin excavated between IBR & TOP. Install critical dip on right hinge line.
S#12		40+65	Install sill by lowering road ~5' in axis creating a broad & deep dip (80'Lx18'WX3'D). Excavate 15' longX3' deepX25' wide section of fill from the fill face at OBR. Install key way perpendicular to channel 20' wide & 2' down below channel surface. Sill dimensions = 15' long X 5' high X 20' wide. Backfill with 20 yds of a mix of 1- 2' diameter coarse boulders to form sill between key way & OBR. Make sure that road is built up at least 3' over 50' length of road to the right of the stream so that flow cannot divert down road. Make sure highest amount of down road raising occurs near the base of the cutbank.

Table 7-1. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Butler Road, Dago Creek Watershed, Navarro River Basin (concluded).

PWA Site #	From	To: or At:	Treatment
RD3	42+80	43+30	RD axis =43+05, dip dimensions: 50'Lx18'Wx 1'D. Gradient up road = 8%, gradient down road = -2%. Place spoils on road to enhance outslope if suitable.
RD2	44+10	44+70	RD axis =44+40, dip dimensions: 60'Lx18'Wx 1'D. Gradient up road = 8%, gradient down road = -2%. Place spoils on road to enhance outslope if suitable.
S#3	47+40	47+80	Excavate oversteepened fill along 40' of road between 2 firs on right bank of Dago Ck. Stockpile spoils on road near cutbank to improve outslope.
S#2		51+35	Install sill by lowering road through site ~3' creating a broad & deep dip (60'Lx18'WX2'D). Excavate 4' highX3' deepX15' wide section of fill from the fill face at OBR. Install key way perpendicular to channel & parallel to redwood & willow clump. Key way should extend 2' below channel surface. Backfill with 20 yds of a mix of 1- 2' diameter coarse boulders to form sill between key way & OBR. Center of dip over key way should be 3' lower than edges. Store spoils on road building up the road to left between stations 50+00 & 51+10.
RD1	52+75	53+25	RD axis =53+00, dip dimensions: 50'Lx17'Wx 1'D. Gradient up road = 8%, gradient down road = -2%. Take road down 1' in axis of dip.
S#1	54+83	55+20	Excavate oversteepened fill along 35' of road with 3' average depth. Extend excavation 20' down slope & leave willow at base of unstable lobe. Endhaul spoils 400' to south (right) to large terrace at confluence of Dago & Rancheria Creeks. Straw mulch/plant slope (40'Wx20'L= 800 ft^2).

Treatment Explanations:

RD: Construct a rolling dip to drain road runoff
CRD: Construct a critical rolling dip to prevent stream diversions
IBR: Inboard edge of the road
OBR: Outboard edge of the road
CLP: Center line of the profile
TOP: Top of excavation
BOT: Bottom of excavation
OS: Outslope road
RBS: Remove berm & sidecast spoil
S#: Site #

Table 7-2. Total Estimated Costs to "Storm Proof" the Butler Road, Dago Creek Watershed, Navarro River Basin.

Cost Category	Stream/Slide Sites	Road Drainage	Sub-Total
Equipment Move in and out[1]	$1,500.		**$1,500.**
Heavy Equipment[2]	$10,125.	$1,900.	**$12,025.**
Culvert Costs[3]	$9,025.	NA	**$9,025.**
Purchase Rip-Rap Rock	Estimate 90 yards available on site		**0.**
Laborers	$520.	NA	**$520.**
Project Supervision[4]	$2,500.	$500.	**$3,000.**
Sub-Total	**$23,670.**	**$2,400.**	**-----**
		Total[5]	**$26,070.**

[1]Costs to low-boy equipment into and back out of the watershed.

[2]Heavy equipment costs include 25% contingency hours to accommodate unforeseen circumstances.

[3]Costs for high, moderate and low treatment immediacy sites are culvert costs, costs for road treatments are to import rock.

[4]Consultation for a PWA professional to ensure proper project layout and supervision of proposed treatments.

[5]Should be viewed as not to exceed costs to implement all proposed itemized road treatments.

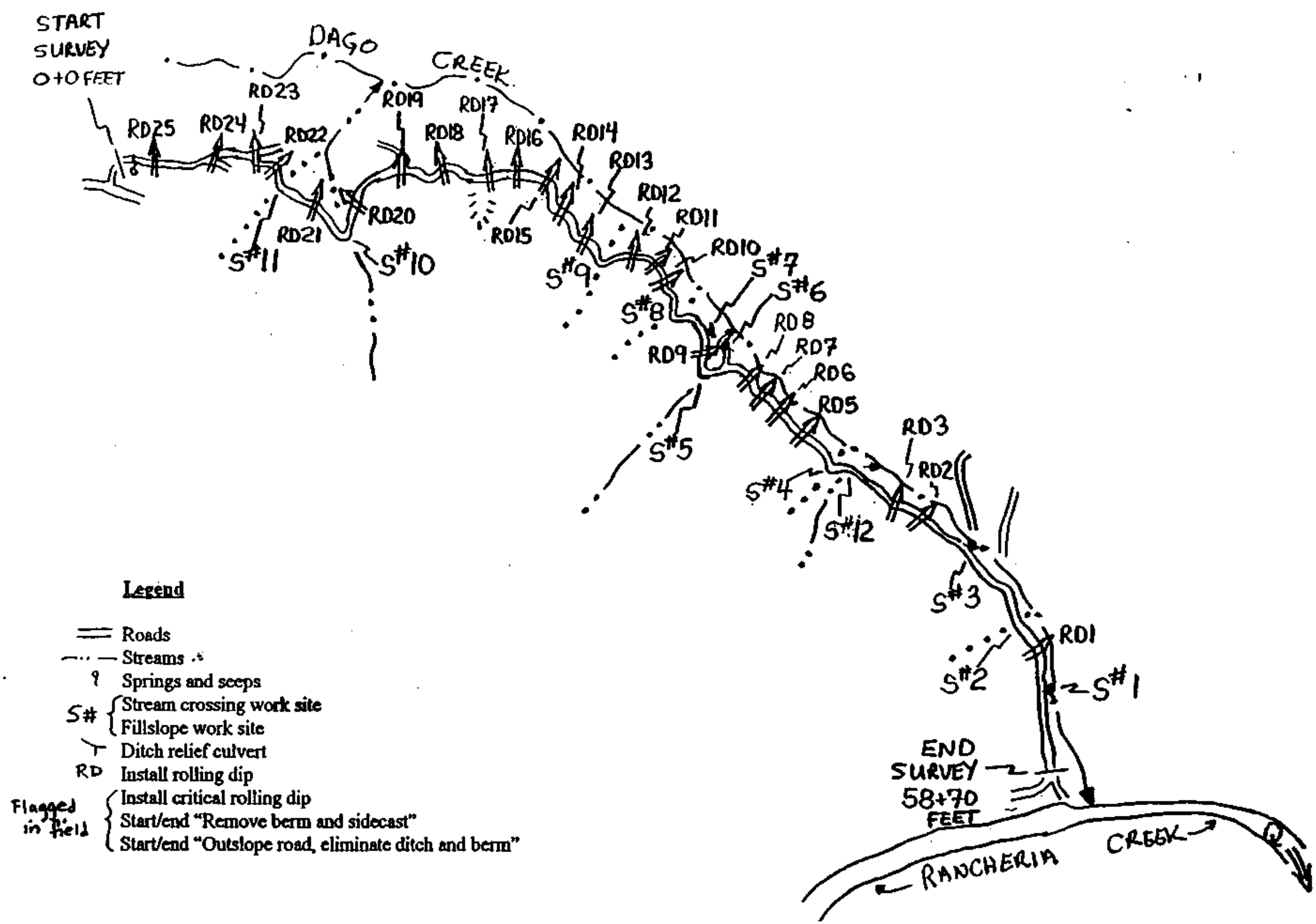


Figure 7-8. Location Map for Butler Road Demonstration Project, Dago Creek Watershed.

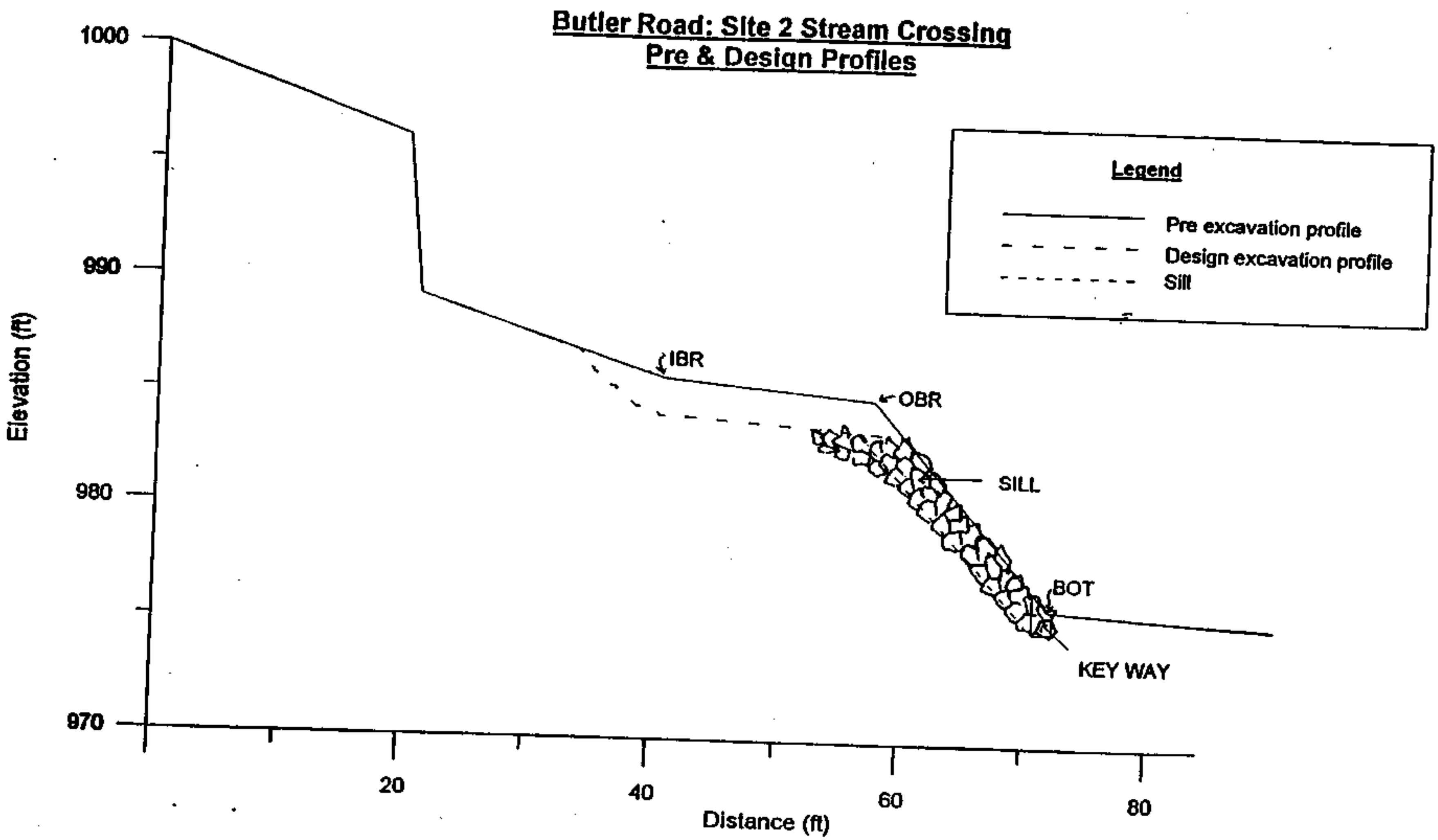


Figure 7-9. Butler Road: Site 2 Stream Crossing Pre & Design Excavation Profiles.

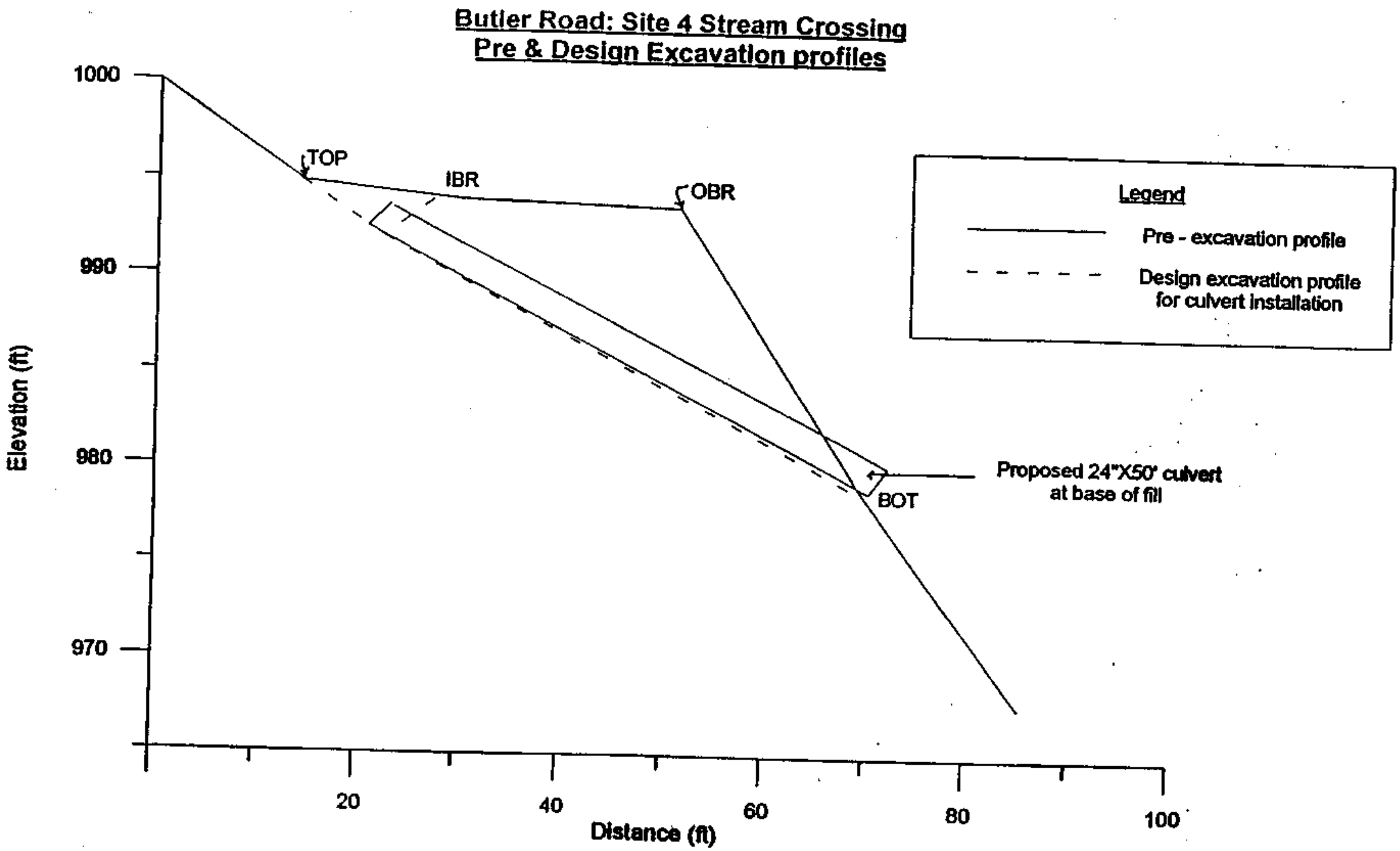


Figure 7-10. Butler Road: Site 4 Stream Crossing Pre & Design Excavation Profiles.

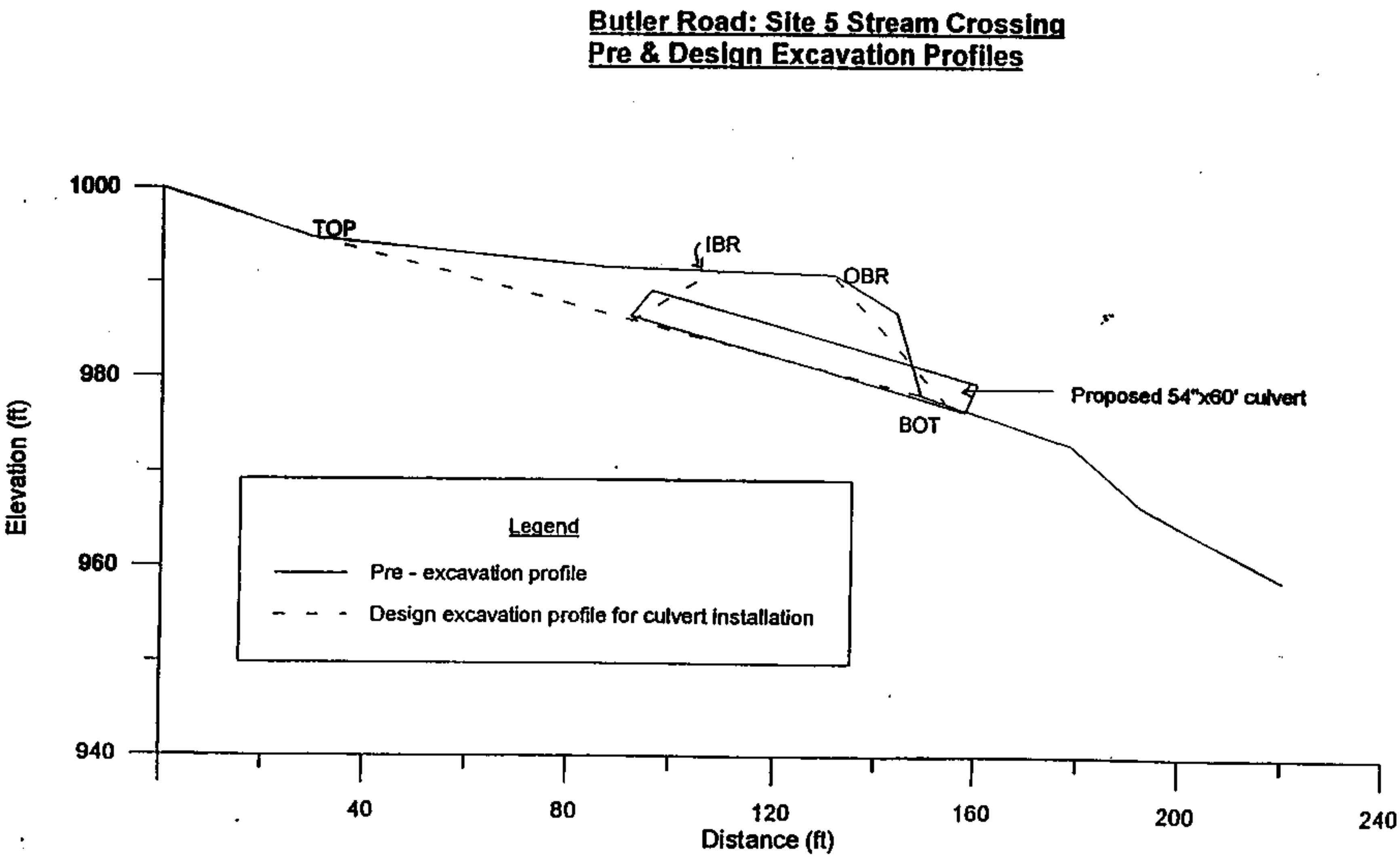


Figure 7-11. Butler Road: Site 5 Stream Crossing Pre & Design Excavation Profiles.

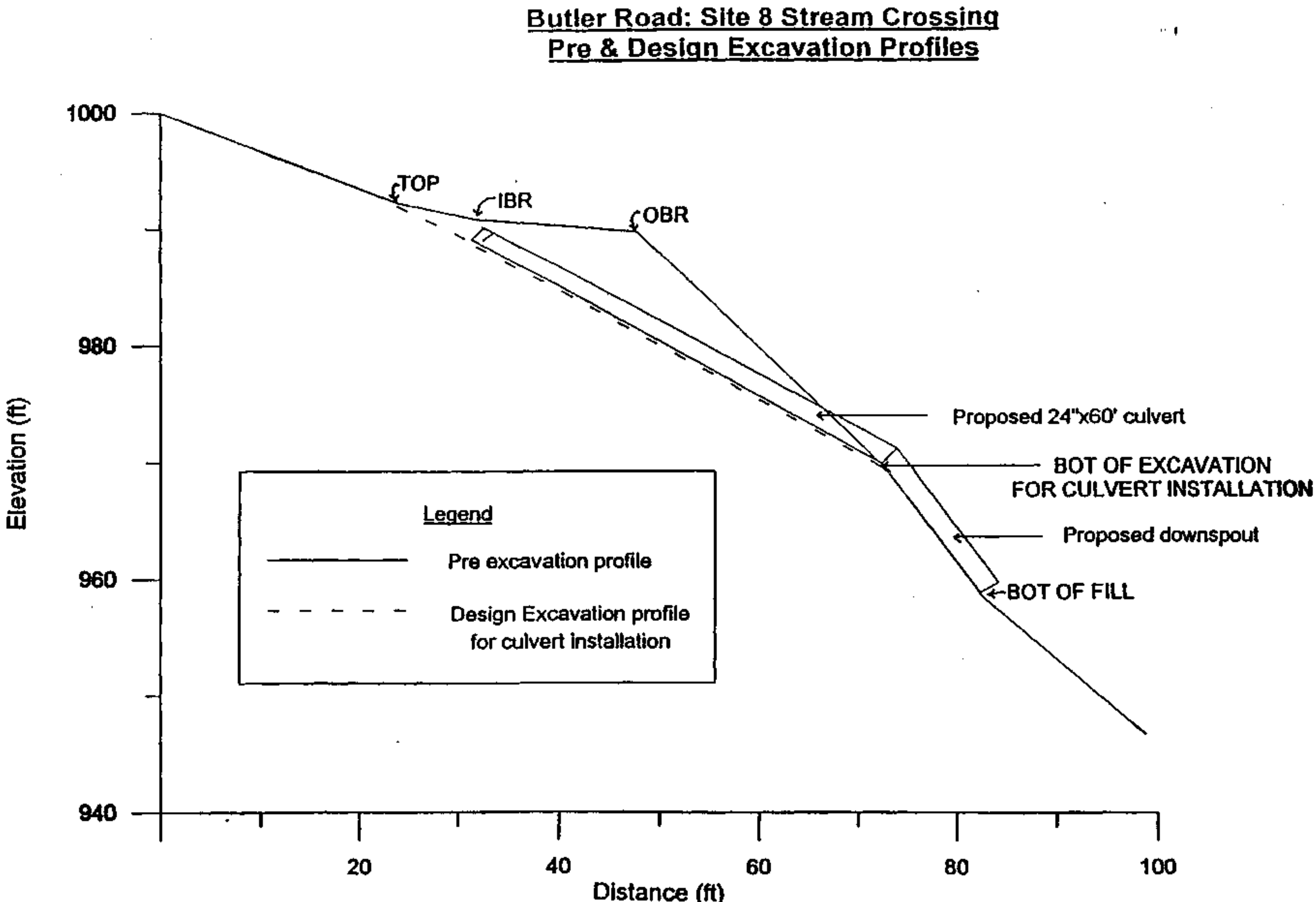


Figure 7-12. Butler Road: Site 8 Stream Crossing Pre & Design Excavation Profiles.

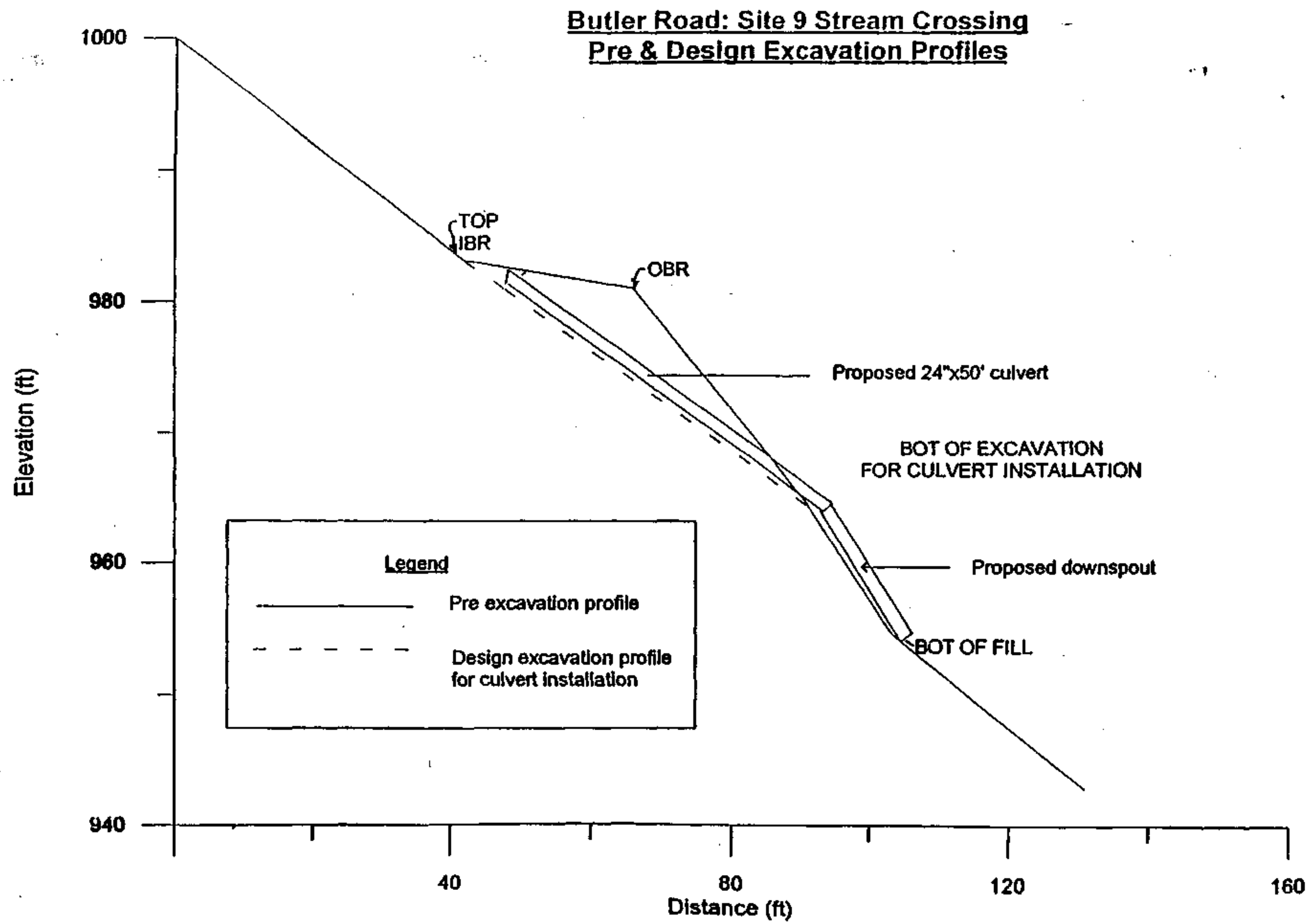


Figure 7-13. Butler Road: Site 9 Stream Crossing Pre & Design Excavation Profiles.

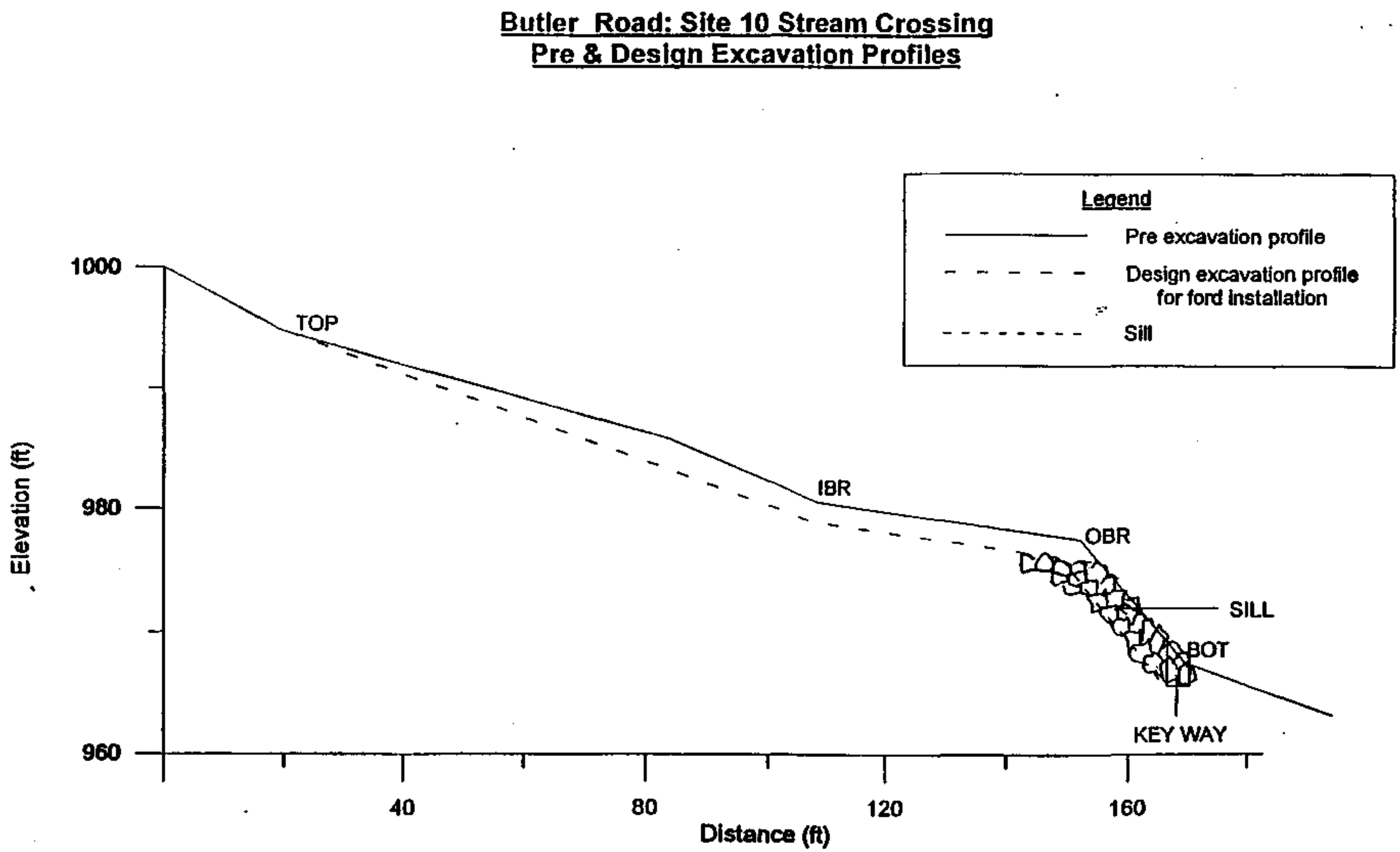


Figure 7-14. Butler Road: Site 10 Stream Crossing Pre & Design Excavation Profiles.

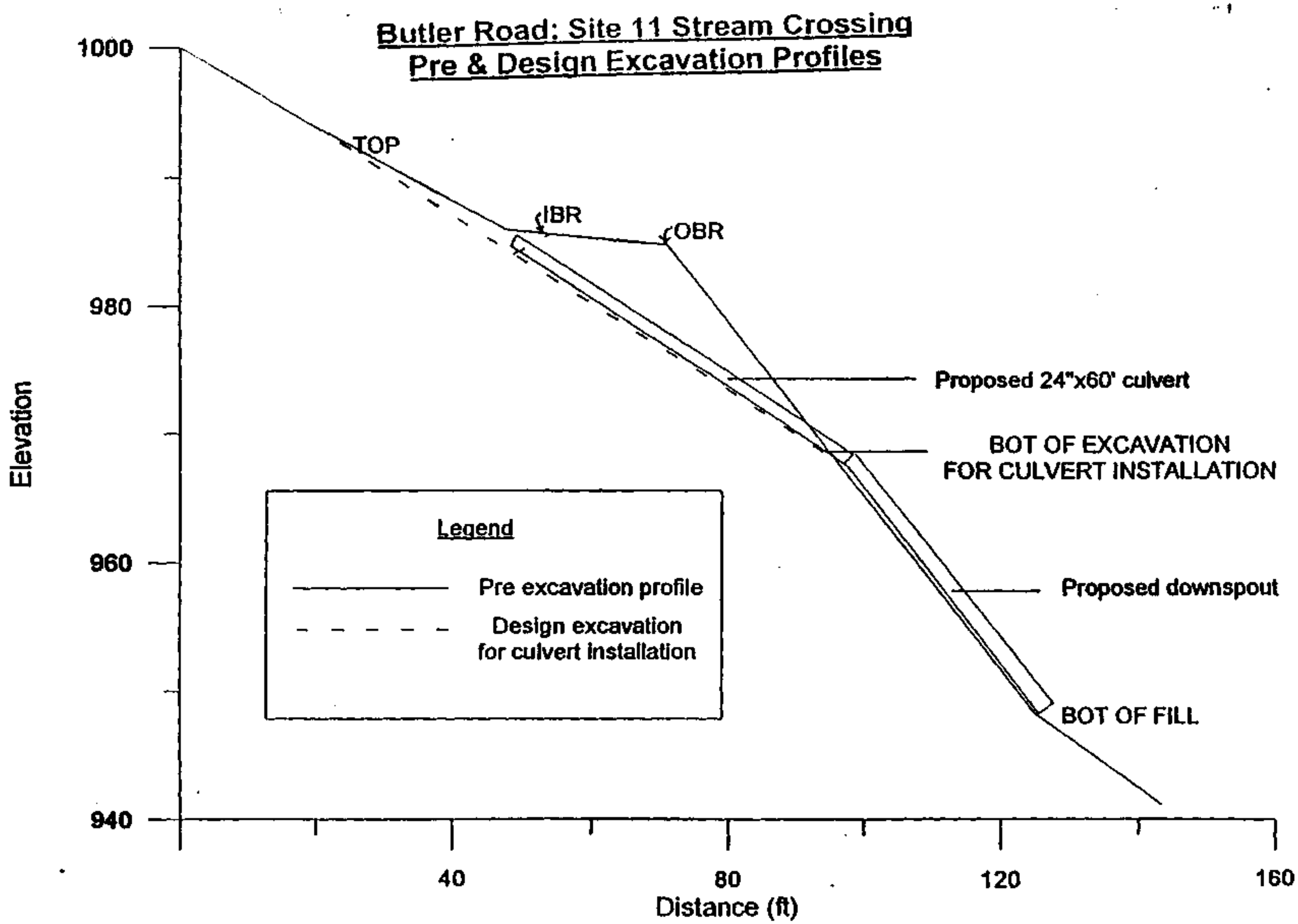


Figure 7-15. Butler Road: Site 11 Stream Crossing Pre & Design Excavation Profiles.

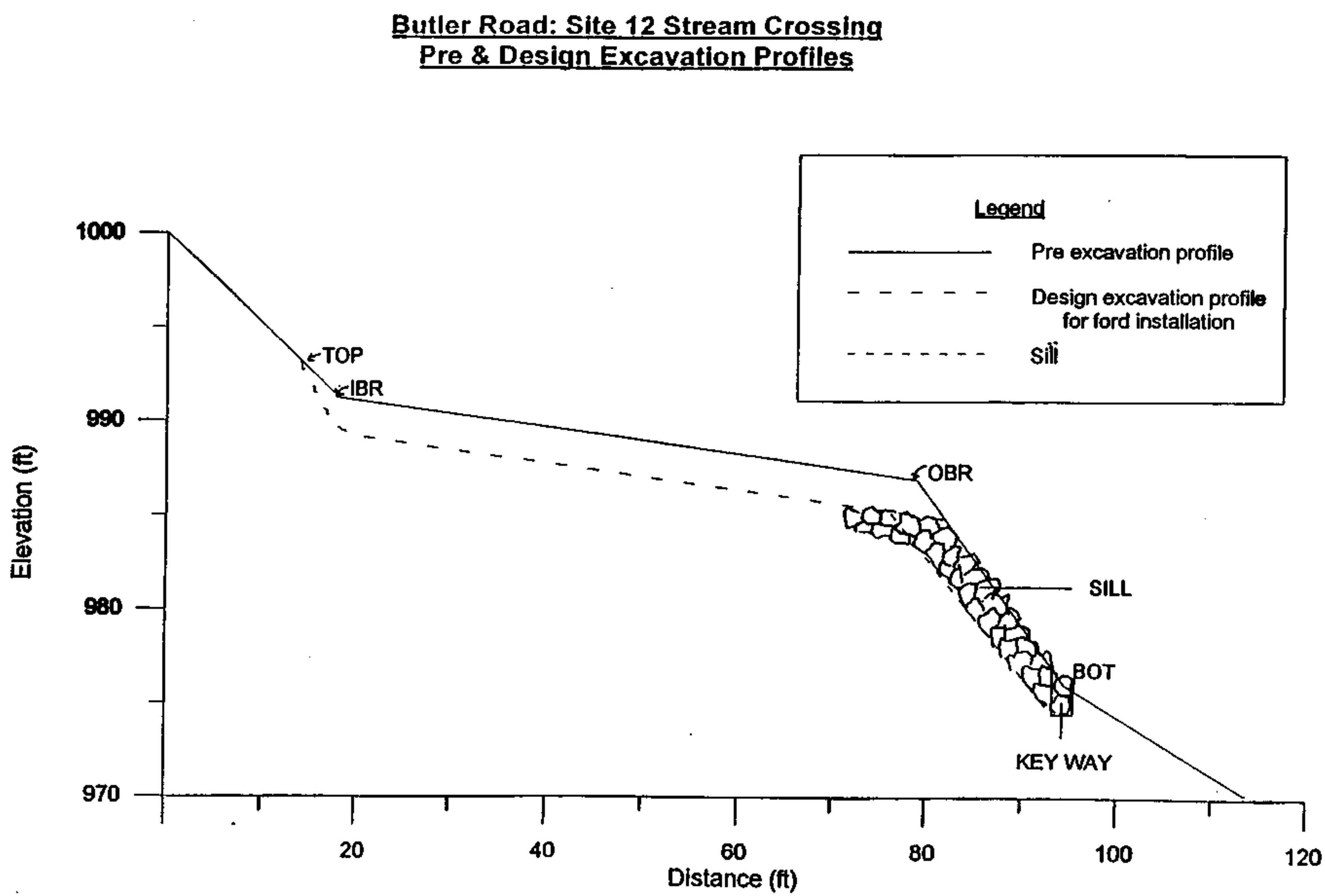


Figure 7-16. Butler Road: Site 12 Stream Crossing Pre & Design Excavation Profiles.

7.3.2 ROAD LOG LISTING ALL PROPOSED EROSION CONTROL AND EROSION PREVENTION TREATMENTS AND TASKS FOR THE NASH MILL ROAD, MILL CREEK WATERSHED

Table 7-3. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Nash Mill Road, Mill Creek Watershed.

PWA site #	To	From: or At:	Treatment
RD1	1+00	1+50	RD axis = 1+25, Dip dimensions: 50'Lx20'Wx 1'D, Gradient up road = 5%, Gradient down road = -3%. Use spoils to plug ditch.
RD2	2+50	3+00	RD axis = 2+75, Dip dimensions: 50'Lx18'Wx 1'D, Gradient up road = 3%, Gradient down road = -4%. Use spoils to plug ditch.
RD3	3+75	4+25	RD axis = 4+00, Dip dimensions: 50'Lx18'Wx 1'D, Gradient up road = 8%, Gradient down road = -8%. Use spoils to plug ditch.
RD4	5+20	5+70	RD axis = 5+45, Dip dimensions: 50'Lx18'Wx 1'D, Gradient up road = 7%, Gradient down road = -5%. Remove berm & use spoils to plug ditch.
RD5	6+95	7+45	RD axis = 7+20, Dip dimensions: 50'Lx18'Wx 1'D, Gradient up road = 5%, Gradient down road = -5%. Remove berm & use spoils to plug ditch.
RD6	8+50	9+00	RD axis = 8+75, Dip dimensions: 60'Lx20'Wx 1'D, Gradient up road = 10%, Gradient down road = -9%. Remove berm & use spoils to plug ditch.
RD7	9+60	10+10	RD axis =9+85, Dip dimensions: 60'Lx20'Wx 1'D, Gradient up road = 10%, Gradient down road = -7%. Remove berm & use spoils to plug ditch.

Table 7-3. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Nash Mill Road, Mill Creek Watershed (continued).

PWA site #	To	From: or At:	Treatment
RD8	11+50	11+75	RD axis =11+50, Dip dimensions: 50'Lx15'Wx 1'D, Gradient up road = 8%, Gradient down road = -5%. Remove berm & use spoils to plug ditch.
RD9	13+35	13+85	RD axis =13+60, Dip dimensions: 60'Lx18'Wx 1'D, Gradient up road = 10%, Gradient down road = -9%. Remove berm & use spoils to plug ditch. Berm is 6' wide.
RD10	15+10	15+60	RD axis =15+35, Dip dimensions: 50'Lx16'Wx 1'D, Gradient up road = 5%, Gradient down road = -5%. Remove berm & use spoils to plug ditch. Berm is 3' wide.
RD11	16+75	17+25	RD axis =17+00, Dip dimensions: 50'Lx18'Wx 1'D, Gradient up road = 10%, Gradient down road = -5%. Remove berm & use spoils to plug ditch. Berm is 4' wide.
RD12	18+10	18+60	RD axis =18+35, Dip dimensions: 50'Lx18'Wx 1'D, Gradient up road = 3%, Gradient down road = -3%. Remove berm & use spoils to plug ditch. Berm is 2' wide.
OS Road	18+60	20+20	Remove berm, maintain outsloped road and fill ditch. Berm is 4' wide, 1' deep. Mulch & plant slope = 160' wide x 10' long = 1600 ft^2.
OS Road	21+40	22+70	Remove berm, outslope road and fill ditch. Sidecast spoils. Mulch & plant slope = 130' wide x 20' long = 2600 ft^2.
RD13	22+45	22+95	RD axis =22+70 dimensions: 50'Lx32x 2'D, Gradient up road = 5%, Gradient down road = -5%. Remove berm & use spoils to plug ditch. Berm is 16' wide to the OBF. Can also use spoils to enhance outslope or reshape swale.
RD14	26+55	27+05	RD axis =26+80, Dip dimensions: 60'Lx25'Wx 1'D, Gradient up road =13%, Gradient down road = -5%. Remove berm & use spoils to plug ditch. Berm is 2' wide. Excess spoils can be sidecast.

Table 7-3. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Nash Mill Road, Mill Creek Watershed (continued).

PWA site #	To	From: or At:	Treatment
RD15	28+00	28+60	RD axis =28+30, Dip dimensions: 60'Lx40'Wx 1'D, Gradient up road =10%, Gradient down road = -8%. Plug ditch with spoils & if suitable use spoils to enhance dip. No sidecast on slide to right (down station).
RD16	31+10	31+70	RD axis =31+40, Dip dimensions: 70'Lx25'Wx 1'D, Gradient up road =15%, Gradient down road = -13%. Plug ditch with spoils & if suitable use spoils to enhance dip. Berm is 2' wide.
BD1		32+39	Breach berm for 10 feet, sidecast spoil.
BD2		35+00	Breach berm for 10 feet, sidecast spoil.
RD17	35+70	36+30	RD axis =36+00, Dip dimensions: 70'Lx25'Wx 1'D, Gradient up road =15%, Gradient down road = -13%. Plug ditch with spoils & if suitable use spoils to enhance dip.
RD18	38+20	39+00	RD axis =38+60, Dip dimensions: 80'Lx22'Wx 1'D, Gradient up road =16%, Gradient down road = -14%. Plug ditch with spoils & if suitable use spoils to enhance dip.
BD3		39+04	Breach berm for 10 feet, sidecast spoil.
BD4		41+00	Breach berm for 10 feet, sidecast spoil.
RD19	42+25	42+75	RD axis =42+50, Dip dimensions: 70'Lx27'Wx 1'D, Gradient up road =16%, Gradient down road = -14%. Plug ditch with spoils & if suitable use spoils to enhance dip.
RD20	44+00	44+50	RD axis =44+25, Dip dimensions: 50'Lx24'Wx 1'D, Gradient up road =10%, Gradient down road = -7%. Plug ditch with spoils & if suitable use spoils to enhance dip.

Table 7-3. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Nash Mill Road, Mill Creek Watershed (concluded).

PWA site #	To	From: or At:	Treatment
RD21	46+55	47+05	RD axis =46+80, Dip dimensions: 50'Lx18'Wx 1'D, Gradient up road =10%, Gradient down road = -4%. Plug ditch with spoils & if suitable use spoils to enhance dip.
BD5		47+57	Breach berm for 10 feet, sidecast spoil.
RD22	48+75	49+25	RD axis =49+00, Dip dimensions: 50'Lx30'Wx 1'D, Gradient up road =6%, Gradient down road = -5%. Plug ditch with spoils & if suitable use spoils to enhance dip.
Remove Berm	50+30	59+25	Remove berms at IBR & OBR between stations 50+30 & 51+55. Continue to remove berm at OBR from 51+55 to 59+25. Site located in saddle. Sidecast spoils.
RD23	52+90	53+40	RD axis =53+15, Dip dimensions: 50'Lx18'Wx 1'D, Gradient up road =2%, Gradient down road = -3%. Plug ditch with spoils & if suitable use spoils to enhance dip. Berm is 2' wide.
RD24	55+75	56+25	RD axis =56+00, Dip dimensions: 50'Lx18'Wx 1'D, Gradient up road =5%, Gradient down road = -4%. Plug ditch with spoils & if suitable use spoils to enhance dip. Berm is 2' wide.
RD25	58+75	59+25	RD axis =59+00, Dip dimensions: 50'Lx30'Wx 1'D, Gradient up road =10%, Gradient down road = -7%. Plug ditch with spoils & if suitable use spoils to enhance dip. Berm is 10' wide.

Treatment Explanations:

RD: Construct a rolling dip to drain road runoff
CRD: Construct a critical rolling dip to prevent stream diversions
IBR: Inboard edge of the road
OBR: Outboard edge of the road
CLP: Center line of the profile
TOP: Top of excavation
BOT: Bottom of excavation
OS: Outslope road
RBS: Remove berm & sidecast spoil
S#: Site #

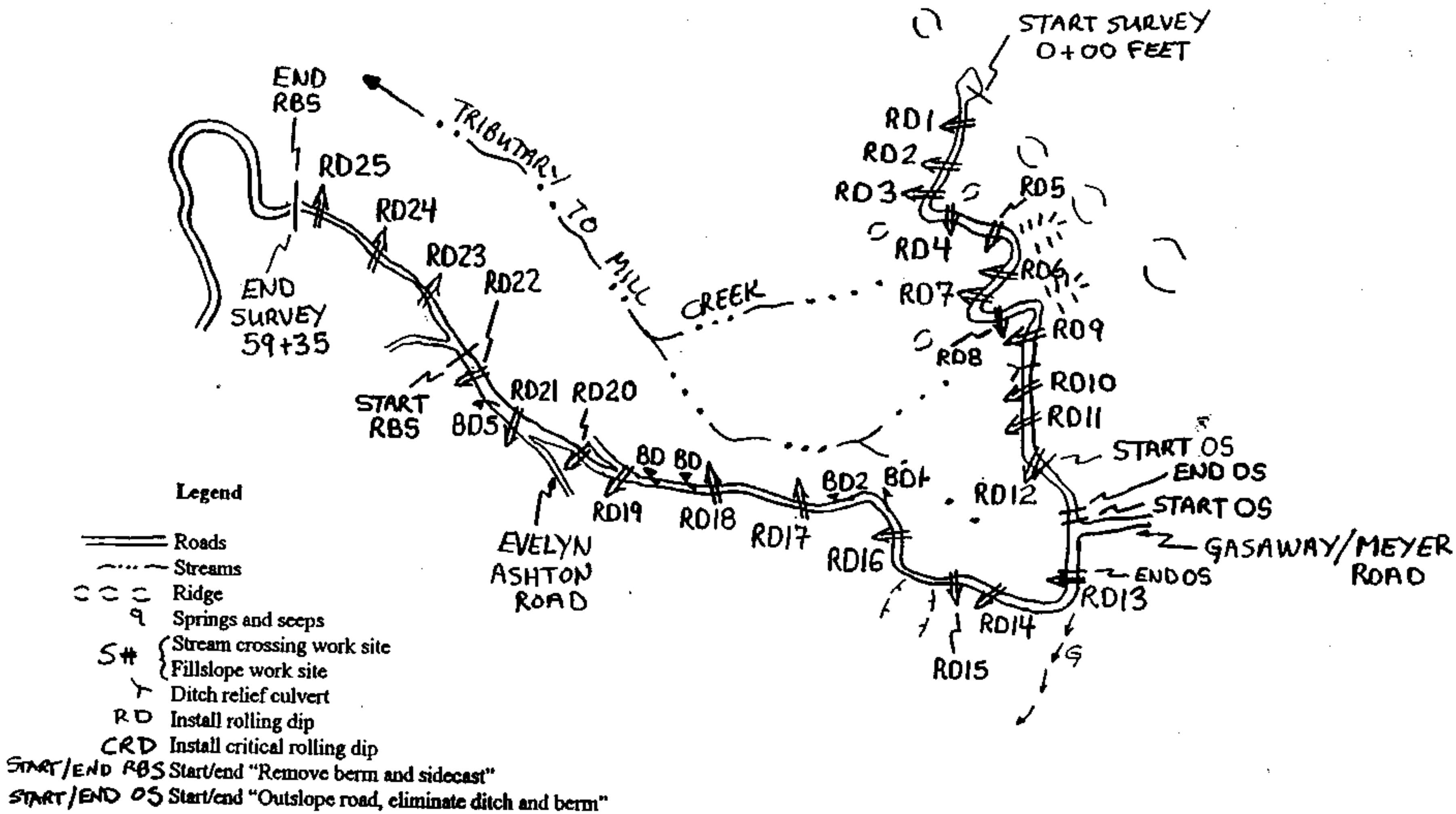


Figure 7-17. Location Map for Nash Mill Road Demonstration Project, Mill Creek Watershed.

Table 7-4. Total Projected Costs to "Storm Proof" the Nash Mill Road, Mill Creek Watershed, Navarro River Basin.

Cost Category	Stream/Slide Sites	Road Drainage	Sub-Total
Equipment Move in and out[1]	NA	$350.	**$350.**
Heavy Equipment[2]	NA	$2,200.	**$2,200.**
Culvert Costs	NA	NA	**0.**
Purchase Rip-Rap Rock	NA	NA	**0.**
Laborers	NA	NA	**0.**
Project Supervision[3]	NA	$500.	**$500.**
Sub-Total	**NA**	**$3,050.**	**-----**
		Total [4]	**$3,050.**

[1]Costs to low-boy equipment into and back out of the watershed.

[2]Heavy equipment costs include 25% contingency hours to accommodate unforeseen circumstances.

[3]Consultation for a PWA professional to ensure proper project layout and supervision of proposed treatments.

[4]Should be viewed as not to exceed costs to implement all proposed itemized road treatments.

7.3.3 ROAD LOG LISTING ALL PROPOSED EROSION CONTROL AND EROSION PREVENTION TREATMENTS AND TASKS FOR THE HOLMES RANCH ROAD, MILL CREEK WATERSHED

Table 7-5. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Holmes Ranch Road, Mill Creek Watershed.

PWA site #	To	From: or At:	Treatment
RD10	5+35	5+95	RD axis = 5+65, Dip dimensions: 75'Lx30'Wx 1'D, Gradient up road = 10%, Gradient down road = -2%. Use spoils to plug ditch. Excess spoils can be used to enhance dip.
RD9	7+60	8+45	RD axis = 8+10, Dip dimensions: 70'Lx25'Wx 1'D, Gradient up road = 3%, Gradient down road = -1%. Use spoils to plug ditch. Tie dip into ditch. Excess spoils can be used to enhance dip.
RD8	10+15	10+75	RD axis = 10+45, Dip dimensions: 60'Lx30'Wx 1'D, Gradient up road = 5%, Gradient down road = -3%. Use spoils to plug ditch. Tie dip into ditch. Excess spoils can be used to enhance dip.
RD7	13+50	14+10	RD axis = 13+80, Dip dimensions: 60'Lx30'Wx 1'D, Gradient up road = 3%, Gradient down road = -3%. Use spoils to plug ditch. Tie dip into ditch. Excess spoils can be used to enhance dip.
RD6	15+70	16+30	RD axis = 16+00, Dip dimensions: 60'Lx30'Wx 1'D, Gradient up road = 2%, Gradient down road = -2%. Use spoils to plug ditch. Tie dip into ditch. Excess spoils can be used to enhance dip.
RD5	17+62	18+37	RD axis = 18+00, Dip dimensions: 75'Lx27'Wx 1'D, Gradient up road = 7%, Gradient down road = -5%. Use spoils to plug ditch. Tie dip into ditch. Excess spoils can be used to enhance dip.
S#4		19+60	Clean cmp inlet area & enlarge stilling basin to prevent future plugging.
RD4	26+50	27+10	RD axis = 26+80, Dip dimensions: 60'Lx30'Wx 1'D, Gradient up road = 2%, Gradient down road = -2%. Use spoils to plug ditch. Tie dip into ditch. Excess spoils can be used to enhance dip. Plug ditch relief.

Table 7-5. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing) Treatments and Tasks by Location for Holmes Ranch Road, Mill Creek Watershed (concluded).

PWA site #	To	From: or At:	Treatment
RD3	28+45	28+95	RD axis = 28+70, Dip dimensions: 60'Lx27'Wx 1'D, Gradient up road = 1%, Gradient down road = -3%. Use spoils to plug ditch. Tie dip into ditch. Excess spoils can be used to enhance dip.
RD2	30+25	30+75	RD axis = 30+50, Dip dimensions: 60'Lx30'Wx 1'D, Gradient up road = 3%, Gradient down road = -3%. Use spoils to plug ditch. Tie dip into ditch. Excess spoils can be used to enhance dip.
S#3		41+60	No treatment. Meyer Gulch.
RBS		42+00	End remove berm and sidecast spoil.
S#2		47+40	Install critical dip on right hingeline at station 47+10 oblique to road to eliminate diversion potential.
RD1	48+92	49+67	RD axis = 49+30, Dip dimensions: 85'Lx21'Wx 0.5'D, Gradient up road = 15%, Gradient down road = -14%. Do not tie dip into inboard ditch. Dip serves to drain road surface only, not the ditch. Use spoils to enhance dip or sidecast.
RBS	54+05		Start remove berm & sidecast spoil.
S#1		53+20	Install critical dip on right hingeline at station 52+50. Install oblique to road to eliminate diversion potential and connect to inboard ditch.

Treatment Explanations:

RD: Construct a rolling dip to drain road runoff
CRD: Construct a critical rolling dip to prevent stream diversions
IBR: Inboard edge of the road
OBR: Outboard edge of the road
CLP: Center line of the profile
TOP: Top of excavation
BOT: Bottom of excavation
OS: Outslope road
RBS: Remove berm & sidecast spoil
S#: Site #

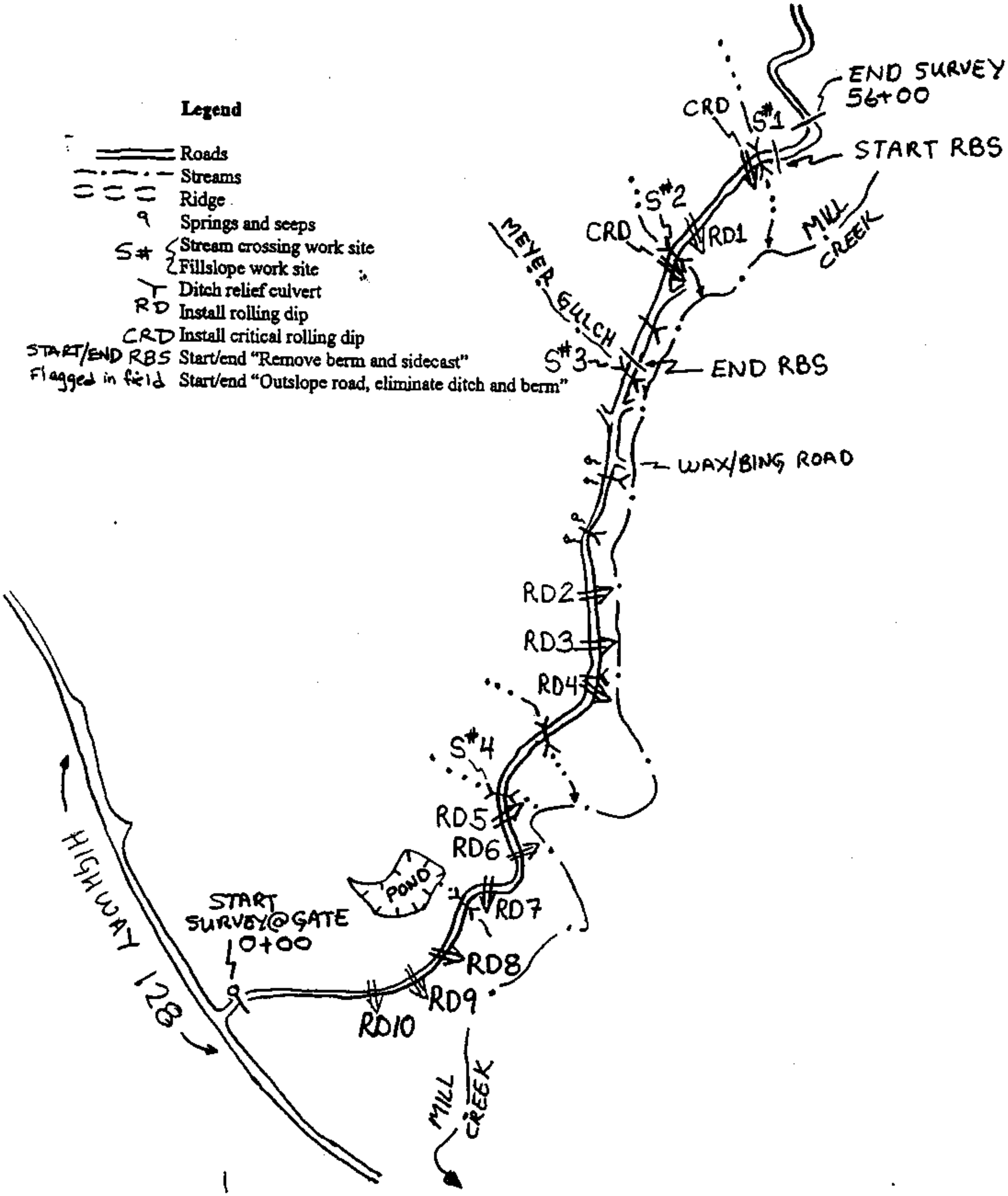


Figure 7-18. Location Map for Holmes Ranch Road Demonstration Project, Mill Creek Watershed.

Table 7-6. Total Projected Costs to Storm Proof the Holmes Ranch Road, Mill Creek Watershed Navarro River Basin.

Cost Category	Stream/Slide Sites	Road Drainage	Sub-Total
Equipment Move in and out[1]	$700.		**$700.**
Heavy Equipment[2]	$900.	$1,500.	**$2,400.**
Culvert Costs	NA	NA	**0.**
Purchase Rip-Rap Rock	NA	NA	**0.**
Laborers	NA	NA	**0.**
Project Supervision[3]	$200.	$300.	**$500.**
Sub-Total	**$1,100.**	**$2,500.**	**-----**
		Total [4]	**$3,600.**

[1]Costs to low-boy equipment into and back out of the watershed.

[2]Heavy equipment costs include 25% contingency hours to accommodate unforeseen circumstances.

[3]Consultation for a PWA professional to ensure proper project layout and supervision of proposed treatments.

[4]Should be viewed as not to exceed costs to implement all proposed itemized road treatments.

7.3.4 Road Log Listing All Proposed Erosion Control and Erosion Prevention Treatments and Tasks for the Ashton Road, Mill Creek Watershed

Table 7-7. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing and road closure) Treatments and Tasks by Location for the Ashton Road, Mill Creek Watershed, Navarro River Basin.

PWA Site #	From	To: or At:	Treatment
		0+00	Start road log at junction with Nash-Mill Road.
RD1	1+10	1+60	RD axis = 1+35, dip dimensions: 50'Lx12'Wx 1'D. Gradient up road = 7%, gradient down road = -7%. Sidecast spoils.
RD2	2+95	3+45	RD axis = 3+20, dip dimensions: 50'Lx15'Wx 1'D. Gradient up road = 6%, gradient down road = -2%. Sidecast spoils.
DRC#1		4+40	Existing 12" ditch relief culvert, undersized but OK..
RD3	9+55	10+25	RD axis = 9+90, dip dimensions: 70'Lx18'Wx 2'D. Gradient up road = 5%, gradient down road = -2%. Lower road in axis of dry swale 2.5 feet and sidecast spoils either up-road or down-road from axis of swale.
RD4	13+85	14+45	RD axis = 14+15, dip dimensions: 60'Lx18'Wx 1'D. Gradient up road = 7%, gradient down road = -6%. Lower road in axis of dry swale 1.5 feet and sidecast spoils either up-road or down-road from axis of swale.
RD5	15+35	15+85	RD axis = 15+60, dip dimensions: 50'Lx15'Wx 1'D. Gradient up road = 4%, gradient down road = -4%. Sidecast spoils.
S#1		17+50	Remove existing 12" CMP and install 24"x 40' CMP in the axis of the natural channel and at a steeper angle than the current culvert. Install critical rolling dip (CRD) at left hingeline of crossing fill and use excavated fill to plug the down road ditch and improve road outslope.
DRC#2		18+85	Existing 6" ditch relief culvert, undersized but OK.
RD6	19+40	19+90	RD axis = 19+65, dip dimensions: 50'Lx18'Wx 1'D. Gradient up road = 1%, gradient down road = -2%. Sidecast spoils.

Table 7-7. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing and road closure) Treatments and Tasks by Location for the Ashton Road, Mill Creek Watershed, Navarro River Basin (continued).

PWA Site #	From	To: or At:	Treatment
S#2		21+50	Remove 12" CMP and install a ford or wet crossing utilizing a rock rip-rap sill. Lower the road through crossing ~4' in axis of stream by creating a broad & deep rolling dip (70'Lx18'Wxavg. 2'D). Excavate 20' long x 3' deep x 24' wide section of fill from the fill face beyond the OBR. Excavate a key way perpendicular to stream channel starting just above BOT flag and between tanoak (right) and Doug fir (left). Key way should be 20' wide, 7' long & extend 2' below channel surface. Backfill with 25 yds of a mix of 1-2' diameter coarse boulders to form sill up road fill face. Construct rock sill in broad U shape with the center of the keyway approximately 2-3' lower than edges. Use excess spoil to fill gully to left of crossing. Finally, make sure road rolling dip is graded neatly into top of rock sill.
RD7	23+05	23+55	RD axis = 23+30, dip dimensions: 50'Lx15'Wx 1'D. Gradient up road = 3%, gradient down road = -3%. Sidecast spoil.
		25+40	Junction with spur road to east.
RD8	25+85	26+55	RD axis = 26+20, dip dimensions: 70'Lx15'Wx 1.5'D. Gradient up road = 12%, gradient down road = -12%. Use spoil to plug ditch down road and sidecast excess material.
RD9	27+48	28+23	RD axis = 27+85, dip dimensions: 75'Lx24'Wx 1.5'D. Gradient up road = 14%, gradient down road = -13%. Use spoil to plug ditch down road and sidecast excess material.
		28+23	Begin proper road closure, i.e. abandonment, by removing stream crossing fills and creating a mild outslope along the road prism.

Table 7-7. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing and road closure) Treatments and Tasks by Location for the Ashton Road, Mill Creek Watershed, Navarro River Basin (continued).

PWA Site #	From	To: or At:	Treatment
S#3		28+50	Excavate the stream crossing of all introduced fill and culverts (est. 400 yds). Construct a free flowing stream channel with a 5' wide stream bed, a straight line gradient between the TOP and BOT flags (a distance of 81'), and lay back the stream crossing sideslopes to approximately 50% in steepness. Push the spoil material down road creating an outsloped road over the next 100-150' of road.
OS	30+00	42+20	Outslope the road prism by lowering the outside edge of road approximately 1 foot and move excavated material to bury any remnant inboard ditch. Make sure no berms are left along the outside edge of the road.
S#4		33+20	Excavate the stream crossing of all introduced fill and culverts (est. 110 yds). Construct a free flowing stream channel with a 6' wide stream bed, a straight line gradient between the TOP and BOT flags (a distance of 40'), and lay back the stream crossing sideslopes to approximately 50% in steepness. Push the spoil material down road creating an outsloped road over the next 75' of road.
S#5		42+60	Excavate the stream crossing of all introduced fill and culverts (est. 165 yds). Construct a free flowing stream channel with a 4' wide stream bed, a straight line gradient between the TOP and BOT flags (a distance of 40'), and lay back the stream crossing sideslopes to approximately 50% in steepness. Push the spoil material down road creating an outsloped road over the next 100' of road.
		43+80	End proper road closure, i.e. abandonment, by removing stream crossing fills and creating a mild outslope along the road prism.

Table 7-7. Road Log Listing All Proposed Erosion Control and Erosion Prevention (storm proofing and road closure) Treatments and Tasks by Location for the Ashton Road, Mill Creek Watershed, Navarro River Basin (concluded).

PWA Site #	From	To: or At:	Treatment
RD10	45+10	46+90	RD axis = 46+40, dip dimensions: 100'Lx16'Wx 1'D. Gradient up road = 17%, gradient down road = -16%. Sidecast spoils, do not use on road to enhance rolling dip.
DRC#3		47+00	Existing ditch relief culvert, undersized but OK.
S#6		48+80	Remove existing 24" CMP and then install 24"x 40' CMP in the axis of the natural channel and at a steeper angle than the current culvert. Install critical rolling dip (CRD) at right hingeline of crossing fill. Excavate and endhaul with a dump truck approximately 60 yds. of fill from both sides of the gully below current CMP outlet. Lay back gully sideslopes to approximately 50%. Endhauled spoils should be taken to the large terraces located downstream of home.
		49+30	End of demonstration project..

Treatment Explanations:

RD: Construct a rolling dip to drain road runoff
CRD: Construct a critical rolling dip to prevent stream diversions
IBR: Inboard edge of the road
OBR: Outboard edge of the road
CLP: Center line of the profile
TOP: Top of excavation
BOT: Bottom of excavation
OS: Outslope road
RBS: Remove berm & sidecast spoil
S#: Site #

Table 7-8. Total Estimated Costs to "Storm Proof" and "Properly Close" Portions of the Ashton Road, Mill Creek watershed, Navarro River Basin.

Cost Category	Upgrade Stream Sites	Upgrade Road Drainage	Road Closure Stream Sites	Road Closure Drainage	Sub-Total
Equipment Move in and out[1]	$1,500.				**$1,500.**
Heavy Equipment[2]	$2,900.	$1,250.	$3,000.	$1,250.	**$8,400.**
Purchase Rock Rip-Rap/ Culverts[3]	$1,400.	NA	NA	NA	**$1,400.**
Laborers	$200.	NA	NA	NA	**$200.**
Project Supervision[4]	$500.	$500.	$500.	$500.	**$2,000.**
Sub-Total	**$5,000.**	**$3,250.**	**$3,500.**	**$1,750.**	**$13,500.**
				Total [5]	**$13,500.**

[1]Costs to low-boy equipment into and back out of the watershed.

[2]Heavy equipment costs include 25% contingency hours to accommodate unforeseen circumstances.

[3]Costs for high, moderate and low treatment immediacy sites are culvert costs, costs for road treatments are to import rock.

[4]Consultation for a PWA professional to ensure proper project layout and supervision of proposed treatments.

[5]Should be viewed as not to exceed costs to implement all proposed itemized road treatments.

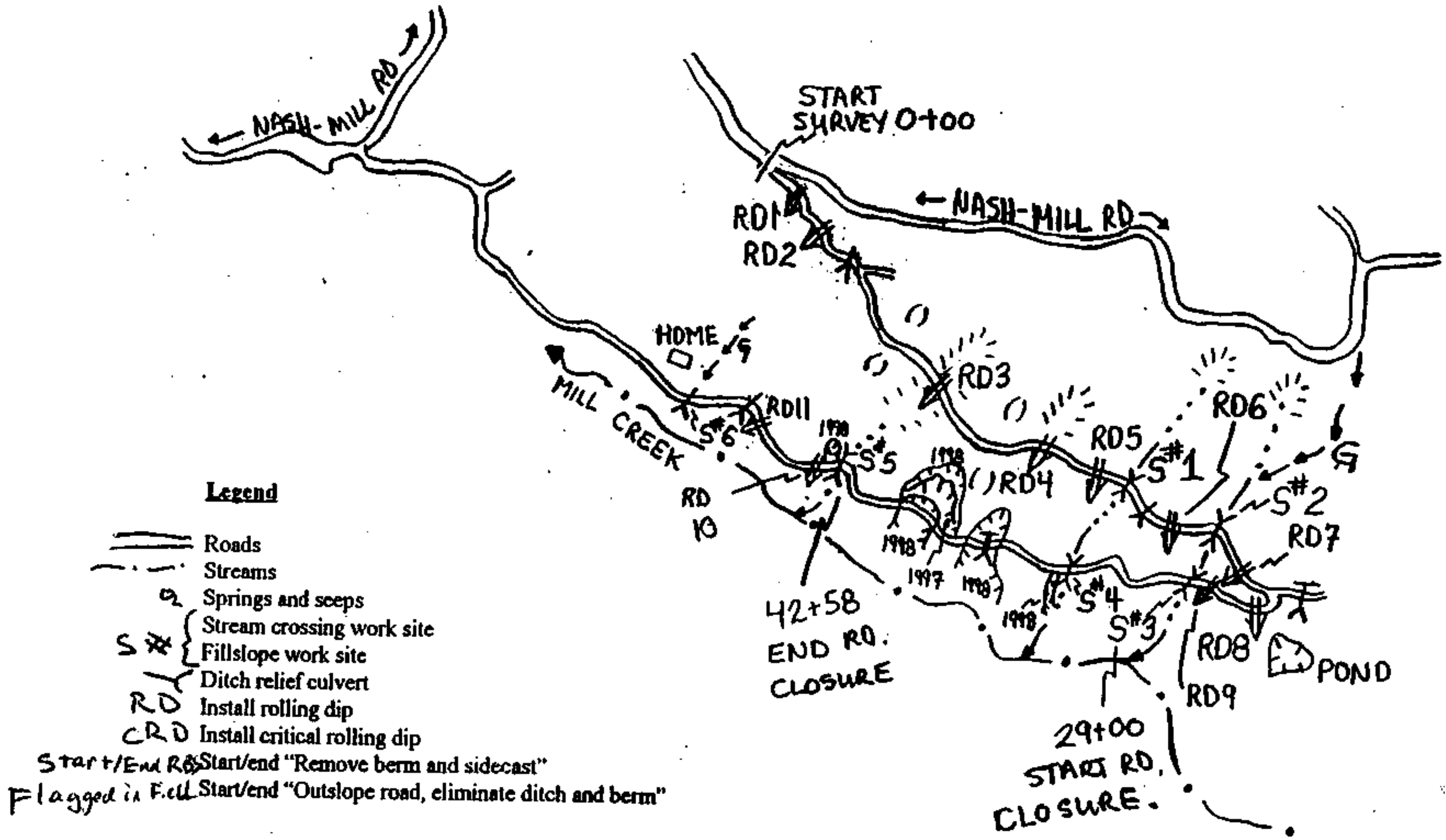


Figure 7-19. Location Map for Ashton Road Demonstration Project, Mill Creek Watershed.

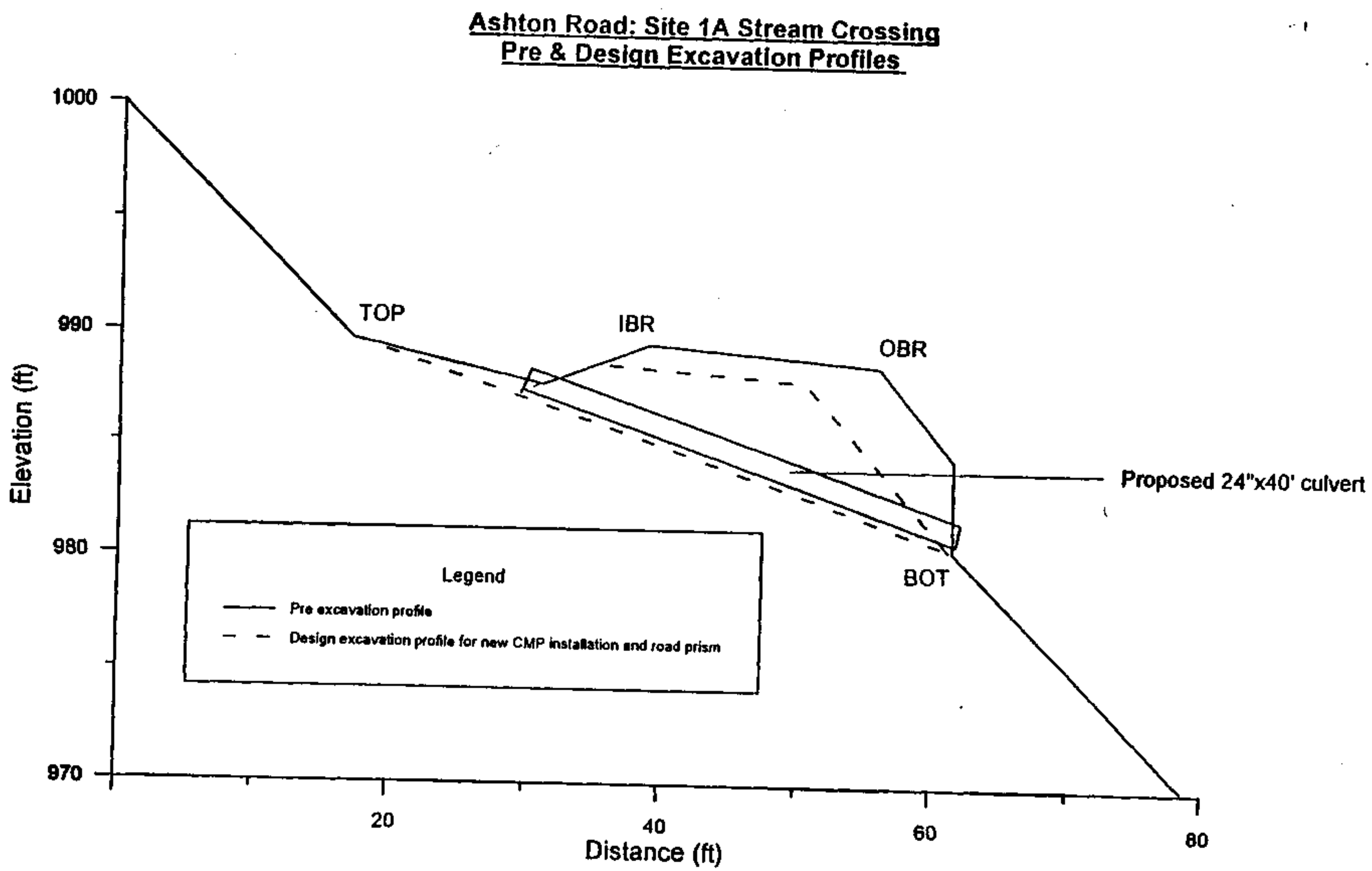


Figure 7-20. Ashton Road: Site 1A Stream Crossing Pre & Design Excavation Profiles.

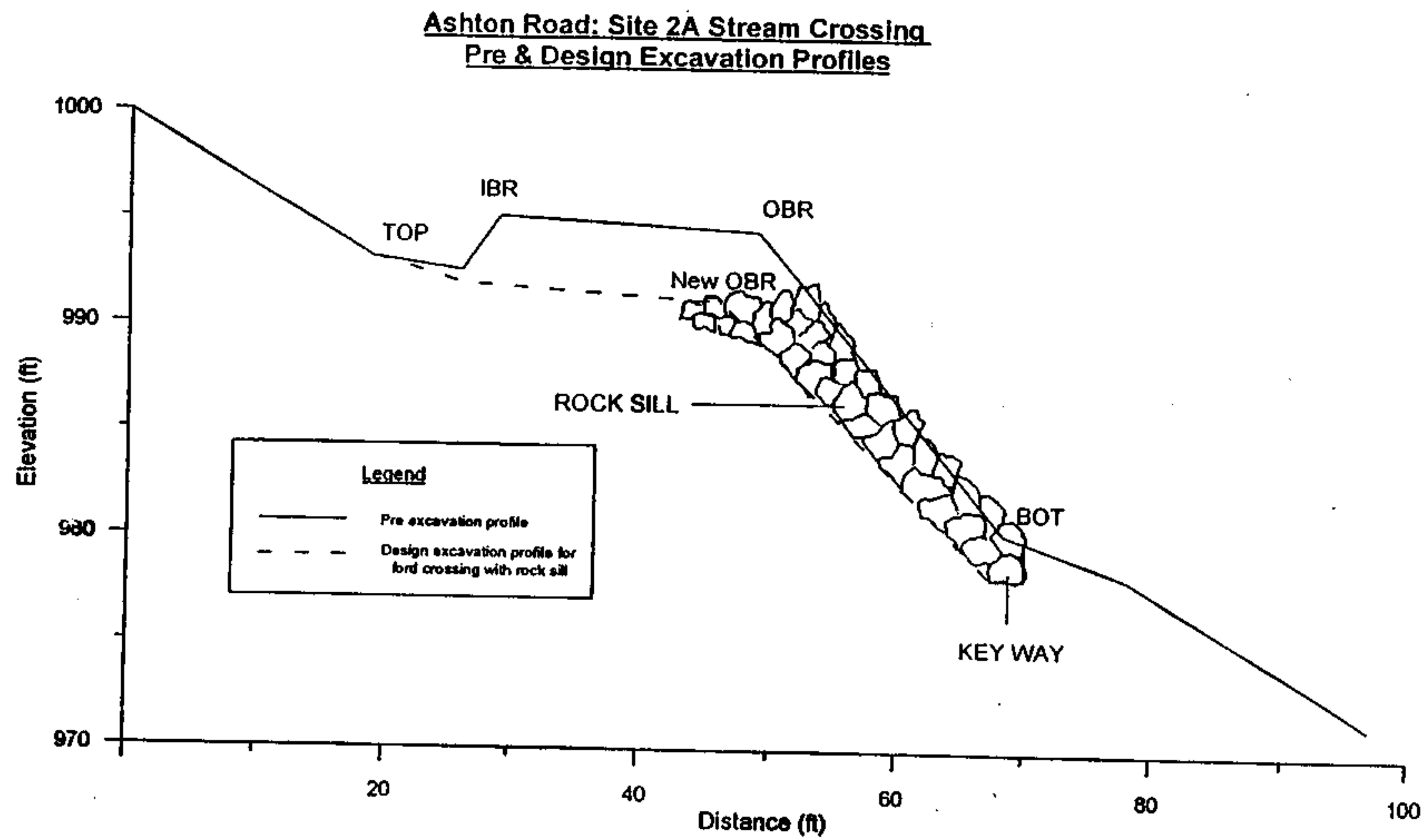


Figure 7-21. Ashton Road: Site 2A Stream Crossing Pre & Design Excavation Profiles.

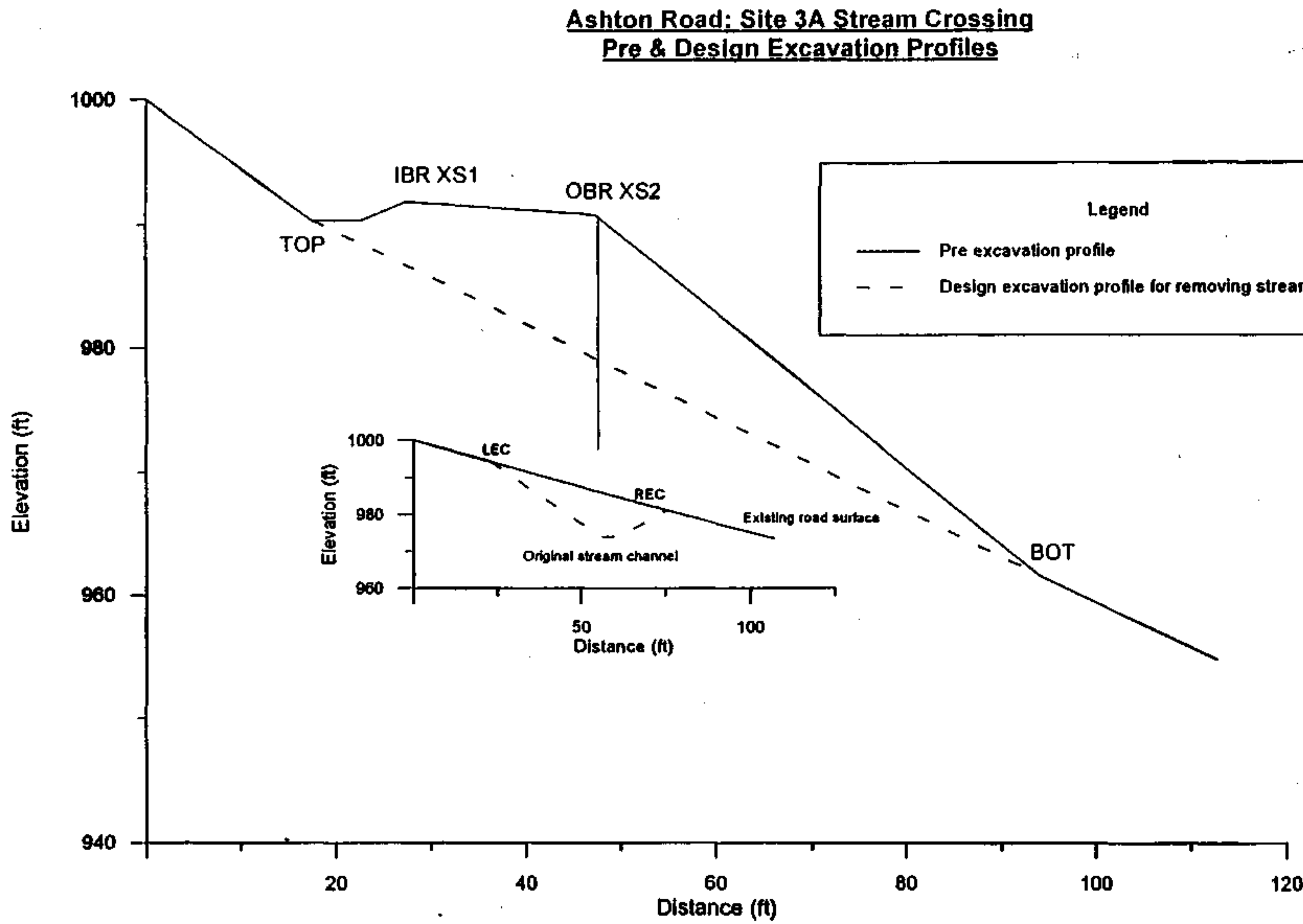


Figure 7-22. Ashton Road: Site 3A Stream Crossing Pre & Design Excavation Profiles.

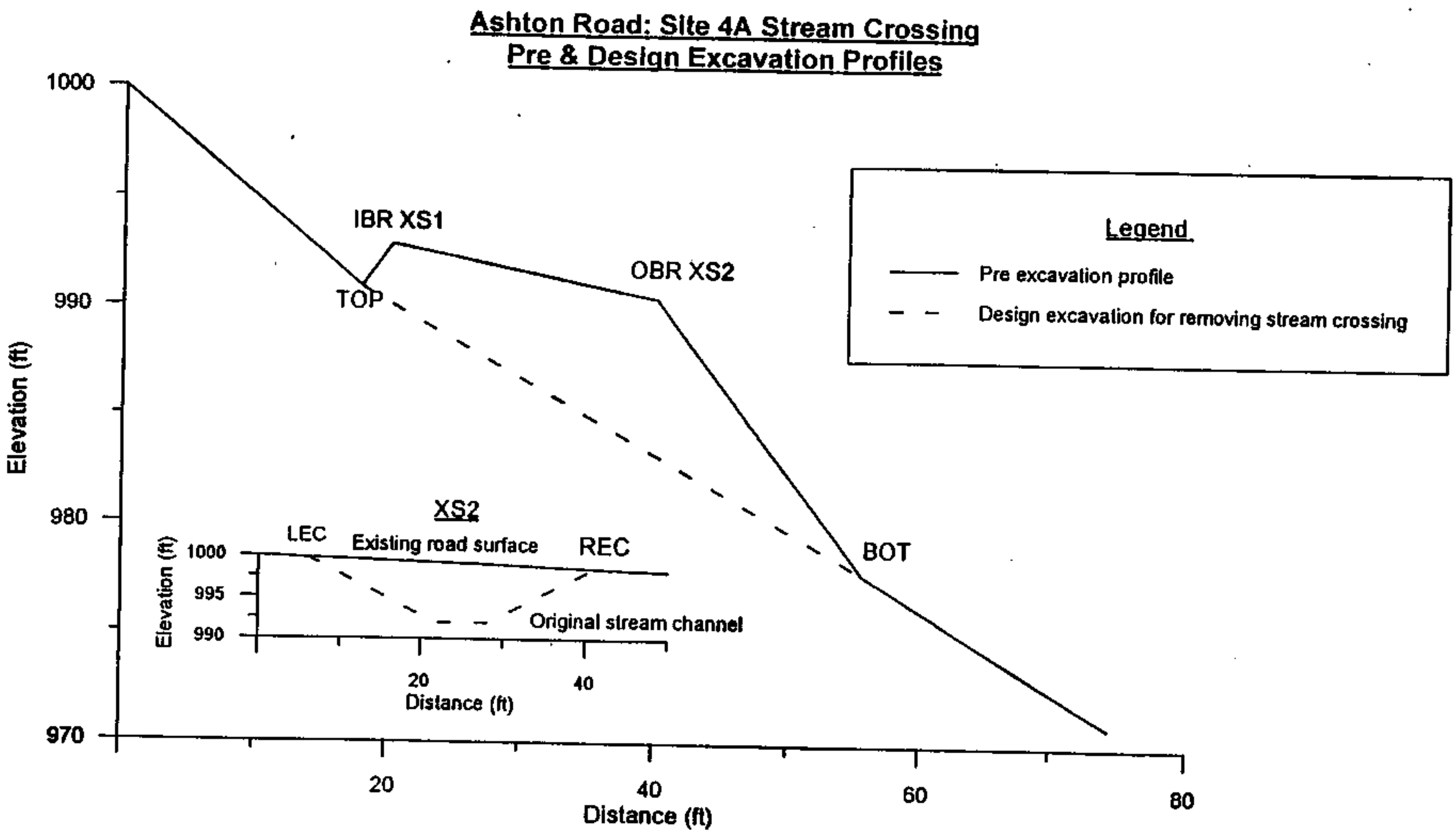


Figure 7-23. Ashton Road: Site 4A Stream Crossing Pre & Design Excavation Profiles.

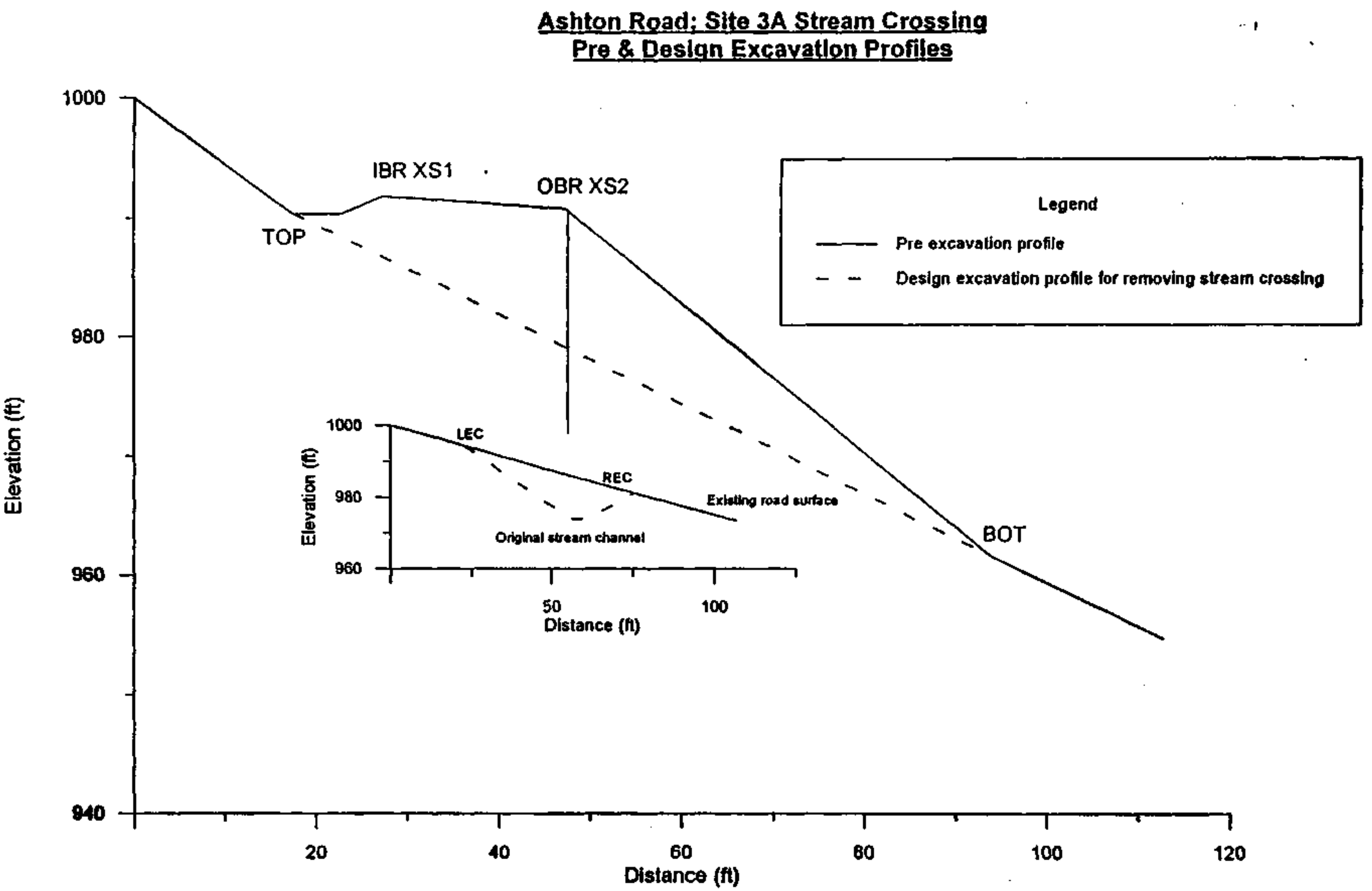


Figure 7-24. Ashton Road: Site 5A Stream Crossing Pre & Design Excavation Profiles.

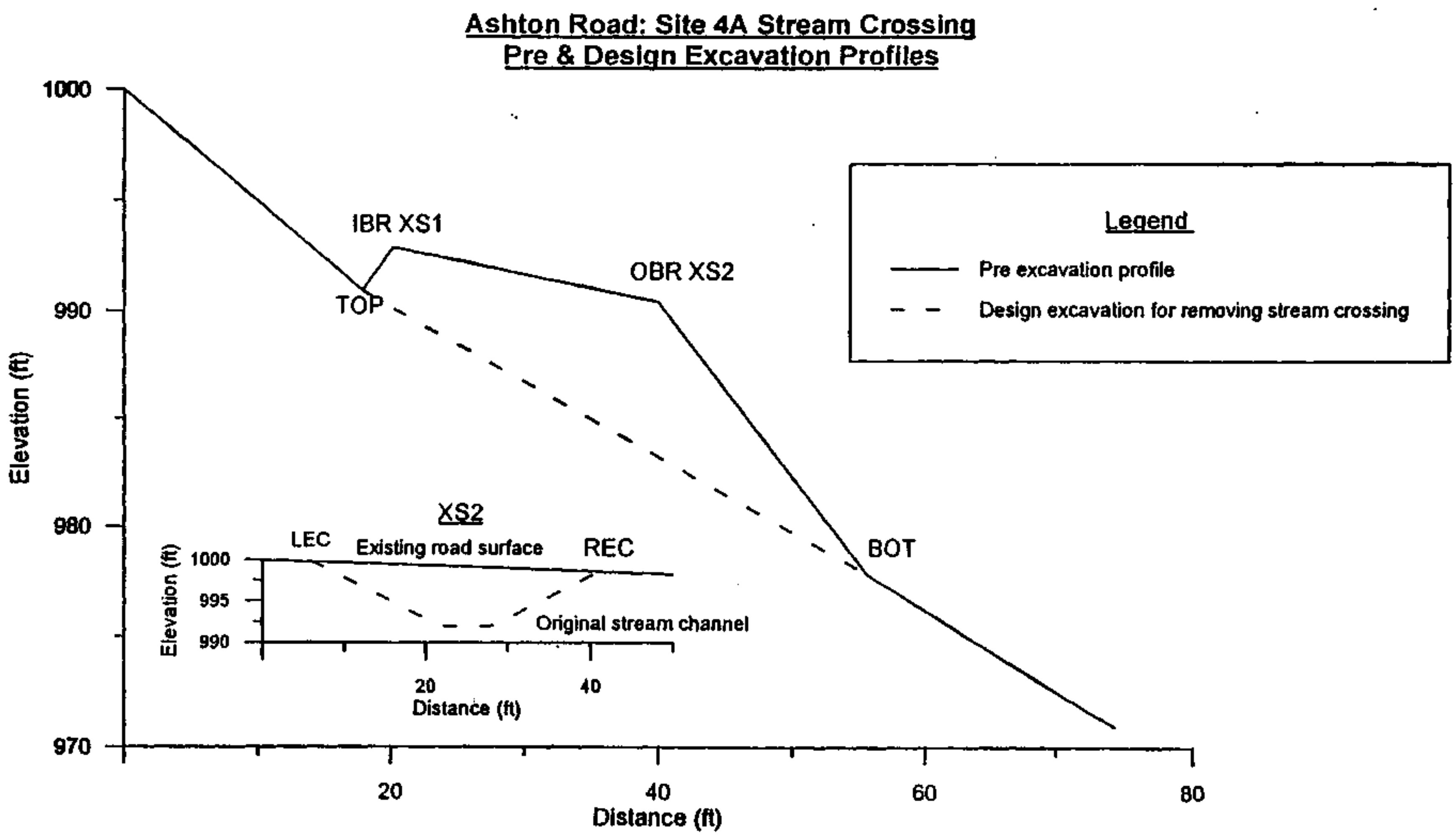


Figure 7-25. Ashton Road: Site 6A Stream Crossing Pre & Design Excavation Profiles.

7.3.5 General Descriptions and Specifications for the Demonstration Road Treatment Projects

These demonstration pilot projects involve erosion control and watershed restoration work at four sites in the Navarro River basin (see description, above). It includes the stabilization and upgrading of permanent (all-weather) and seasonal access roads. The Road Logs describe the basic treatment which have been prescribed at each work site along the roads. Work sites have been flagged in the field, and treatment maps show the approximate location of each site.

Work items include: culvert installation, ford or wet crossing installation (employing sill construction), construction of rolling dips and "critical" rolling dips, sidecast excavation, berm removal, spoil disposal and stream crossing excavation. These work items are described in the following sections. The suite of treatments to be applied at stream crossings and other sites includes both culvert installations as well as construction of various fords. We have not routinely recommended the use of culverted stream crossings, except on the highest standard roads and the largest streams. Culverted stream crossings have high maintenance requirements, and channels with high rates of sediment transport have a high likelihood of eventual culvert plugging. Instead, we have recommended the installation of various fords (concrete, rock, rock and sill, and earth) at several stream crossings in the pilot project area.

Stations

All work is laid out in the field using the standard engineering "station" method. A station is a 300-foot (Butler Road) or 400-foot (all other roads) interval, measured along the centerline of the road bench. A station flag, is hung on the cutbank along the road every 300 or 400 feet starting at the beginning of the road, and labeled with its station number. For example, the point on the road that is 1,000 feet from the beginning has a flag on the inside or outside edge of the road labeled "10+00". Locations between station laths are identified such as "10+34". This is found 34 feet up-station of the 10+00 lath or 1,034 feet from the beginning of the road. "Upstation" means in the direction of the higher station numbers; "downstation" means in the direction of lower station numbers. In general, the work specified in these pilot projects is presented so that work proceeds toward higher station numbers. The order of actual implementation is not important for these projects.

Work Site Descriptions

Work sites are described on the road log for each road segment proposed for treatment. Treatments are proposed at designated sites which have received specific field measurement and analysis, as well as generic treatment locations (e.g., rolling dips). All work locations (including both sites and generic treatment locations) have been flagged and marked in the field. At a minimum, general specifications for performing work at individual sites apply to all work sites, but Treatment Descriptions (listed in the road log listing for each road) may call for additional procedures at selected sites.

Work Items

Eight types of road rehabilitation and upgrading procedures have been prescribed for road segments in the four pilot road project areas. All are described below and in the "Handbook for Forest and Ranch Roads" (June 1994) available through the Mendocino County Resource Conservation District in Ukiah, CA. The proposed treatments include:

1. Culvert installation, including installation of flared inlets and downspouts, in which new (typically larger diameter) culverts are installed at existing stream crossings where drainage pipes are currently non-existent or are undersized for the 50-year design flow.

2. Ford construction (including sills), in which the road surface is strongly dipped across the stream to allow stream flow to flow over the road bed without resulting in excessive erosion. Design measures are included to prevent erosion and to allow for vehicle traffic.

3. Rolling dip construction, where a rolling dip is excavated into the road bed to direct surface runoff off the road and on to adjacent vegetated slopes. Rolling dips can be employed on all types of roads including outsloped roads and insloped roads with ditches.

4. Critical rolling dip construction, in which the road surface is "dipped" immediately adjacent to a stream crossing to prevent stream flow from diverting down the road or ditch when the culvert plugs during a winter storm. Specific locations for critical rolling dips have been flagged in the field for construction.

5. Berm removal, in which the earth berm along the outside edge of the road bed is excavated or removed by grading to allow for better road surface drainage.

6. Sidecast excavation, in which potentially unstable sidecast material along the outside edge of the road prism are excavated to prevent future failure. The excavated materials (spoil) are either stored locally, or hauled off to a nearby, stable storage site.

7. Stream crossing excavations, where the road was built across former stream channels, in which the fill (including culvert) is to be excavated and moved to a stable storage location,

8. Storage areas and fillsite treatments, are the locations where spoil removed from stream crossing excavations, road outsloping and one log jam treatment is to be permanently stored and stabilized.

9. Straw mulching, seeding and planting is employed in certain locations to protect bare soil areas and prevent erosion until sites can be revegetated.

Legal Requirements for Stream Crossing Work

All private landowners considering temporary or permanent stream crossings need to obtain proper permits and follow applicable laws and regulations of state and federal agencies. Prior to conducting road building or timber operations, or to modifying the bed or banks of a stream channel for *any* purpose, it is important to determine the legal requirements of your work.

Under the provisions of section 1603 of the Fish and Game Code, ***any activity that would result in the diversion or obstruction of natural streamflow, or in physical modification of the bed or banks of a stream or lake, is unlawful to perform without first formally notifying the Department of Fish and Game.*** The Department of Fish and Game will act on your 1603 proposal within 30 days (or sooner), and may request a field visit to the site and/or propose measures deemed necessary to protect fish and wildlife. Permanent or temporary stream crossing structures, fords, rip-rapping or other bank stabilization measures, culvert installations, bridges, or skidding across temporary crossings are some of the projects which are subject to the 1603 notification process (Appendix C).

Forestry operations and road activities near watercourses are also subject to the California Forest Practices Act and to rules and regulations developed by the State Board of Forestry and administered by the California Department of Forestry and Fire Protection (Appendix D). These apply to any forest operation involving commercial wood products. The rules include culvert sizing requirements, requirements for removal of temporary stream crossings, limits on equipment operations near stream channels, road construction standards, and a variety of other road building and erosion control requirements. Information on the Forest Practice Act and Rules can be obtained from Ranger Unit offices of the California Department of Forestry and Fire Protection.

Federal and state water pollution regulations are administered and enforced by the California Water Resources Control Board, through their Regional Water Quality Control Boards. Information about requirements pertaining to road building work can be obtained from the Regional Water Quality Control Board with jurisdiction for your area. A wrong choice in stream crossing method can result in major damage to both the immediate site and to downstream water quality. There are strict legal requirements for protecting water quality. ***Stop-work orders, clean up and repair orders, and penalties for pollution can delay the project and be very expensive. It pays to do it right the first time.***

Ask for assistance from the local California Department of Fish and Game warden, a forester from the California Department of Forestry and Fire Protection, and the Regional Water Quality Control Board inspector for assistance and information about requirements for the project. Prevention is always the best course of action.

Descriptive Specifications

Culvert Installation

Where a road crosses a natural watercourse, provision should be made to carry the water under the road. Streams can be crossed with bridges, culverts or fords. This pilot project calls for the installation of culverted stream crossings as well as several fords. Culverts are the most common stream crossing structure. To function properly, culverts should be installed at a stable grade (preferably at or slightly below the bed of the original stream channel). It is best for the road to cross at right angles to the stream channel, but regardless of the road alignment, the culvert should be placed parallel to the natural channel so that the inlet will not plug and flow from the outlet will not erode either of the channel banks.

Except for the very smallest of crossings, it is generally not sufficient or adequate to estimate (guess) culvert sizes for stream crossings along forest and ranch roads. Culvert capacity design for the 50-year flood flow should include both field estimates (based on channel dimensions) and quantitative discharge calculations. Culvert length should be estimated so that correct quantities of pipe will be available on the job site when crossings are installed.

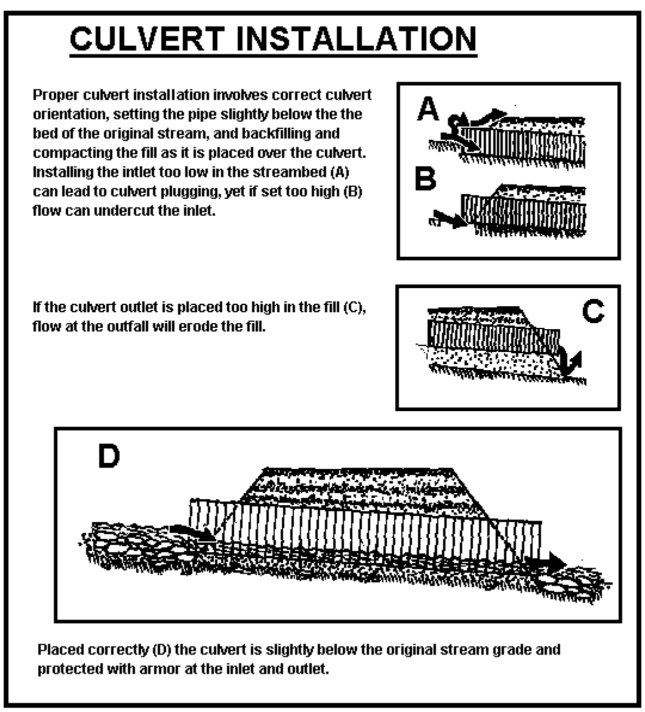
Culverts should be properly aligned, bedded, backfilled and covered, or they will be subject to eventual failure. In all cases, disturbance to the stream banks and streambed should be minimized during stream crossing construction. If the stream is flowing at the culvert installation site, the crossing should be dewatered by constructing a small diversion dam just upstream and pumping or diverting flow around the project area. The dewatered stream channel is then cleared for the culvert. Large rocks and woody debris should be removed. Both the culvert foundation and trench walls must be free of logs, stumps, limbs or rocks that could damage the pipe, or subsequently cause seepage of flow around the outside of the culvert.

The culvert should be aligned with the natural stream channel. Correct alignment is critical for the culvert to function properly. Misalignment can result in bank erosion and debris plugging problems. Stream crossing culverts should be placed at the base of the fill, and at the grade of the original streambed. The culvert should be inset slightly into the natural streambed so that water drops several inches as it enters the pipe. Culvert inlets set too low can plug with debris and those set too high can allow water to undercut the culvert. Culverts placed midway up the outside of the fill are more likely to plug with sediment or organic debris, because their ability to pass materials is reduced, or to cause erosion of the fill below the culvert outlet.

The culvert bed may be composed of either compacted rock-free soil, or gravel. If gravel is used for the bed, filter fabric will be needed to separate the gravel from the soil to minimize the potential for soil piping. Bedding beneath the culvert should provide for even distribution of the load over the length of the pipe. Nearly every culvert will sag after it is buried. To allow for this, all culverts should be installed with a "camber" or slight hump in the bed centered under the middle of the pipe. The amount of camber should be between 1.5 to 3 inches per 10 feet of culvert pipe length. Natural settling and compaction which occurs after backfilling will then allow the pipe to settle into a straight profile.

Backfilling can begin once the culvert is in-place in its bed. Backfill material should be free of rocks, limbs or other debris that could dent the pipe or allow water to seep around the pipe. One end of the culvert should be covered, and then the other end. Once the ends are secured, the center is covered. Careful pouring or sifting of backfill material over the top of the pipe using a backhoe or excavator bucket will allow finer particles to flow around and under the culvert sides. Larger particles will roll to the outside. The fine soil particles will compact more easily and provide a good seal against leaks along the length of the pipe.

The backfill material should be tamped and compacted throughout the entire installation process. The base and sidewall material should be compacted before the pipe is placed in its bed. A minimum amount of fill material should be used for the bed of the culvert to reduce seepage into and along the fill. Backfill material should then be compacted at regular intervals (in approximately 0.5-1 foot lifts) until at least 1/3 of the diameter of the culvert has been covered. This will prevent leaking. A vibrating, gas-powered hand-compactor can be used. Once backfilling has been completed, the inlet and outlet of the culvert should be armored. A metal, concrete, sandbag or rock head-wall can be constructed to prevent inlet erosion.



Stream crossing design should account for the possibility of culvert failure from both overflow and from plugging. Woody debris and sediment transported down a stream channel can substantially increase the risk and likelihood of culvert plugging and failure. Debris control structures (trash racks) at culvert inlets and energy dissipators (such as downspouts) at culvert outlets, are key components of stable culvert design. The design of these protective structures has been varied, and there are as many successful designs as there have been failures. Debris control is best obtained by some type of grate or "filtering" structure of inclined poles built across the channel just upstream from the culvert inlet. If the culvert outlet emerges mid-fill, a downspout or flume will be needed to carry streamflow down past the base of the fill and to the natural channel. This will prevent outlet erosion.

As a final precaution against sedimentation in the stream, a slash windrow can be constructed at the base of the road fill around and adjacent to the culvert outlet so that soil is not sidecast into the stream channel or onto the inlet during final grading of the road bed. Mulching and grass seeding can also be used on the bare fillslope to reduce erosion.

Final filling of the stream crossing can now be performed. Layers of fill are pushed over the crossing in 1 foot "lifts" or layers until the final, design road grade is achieved. Fill should be placed over the top of the culvert to a depth of at least 1 foot, for 18" to 36" culverts, or a minimum of 1/3 to ½ the culvert diameter for larger pipes. If adequate cover cannot be achieved, then a pipe-arch or two smaller culverts should be installed.

Ford or Wet Crossing Construction

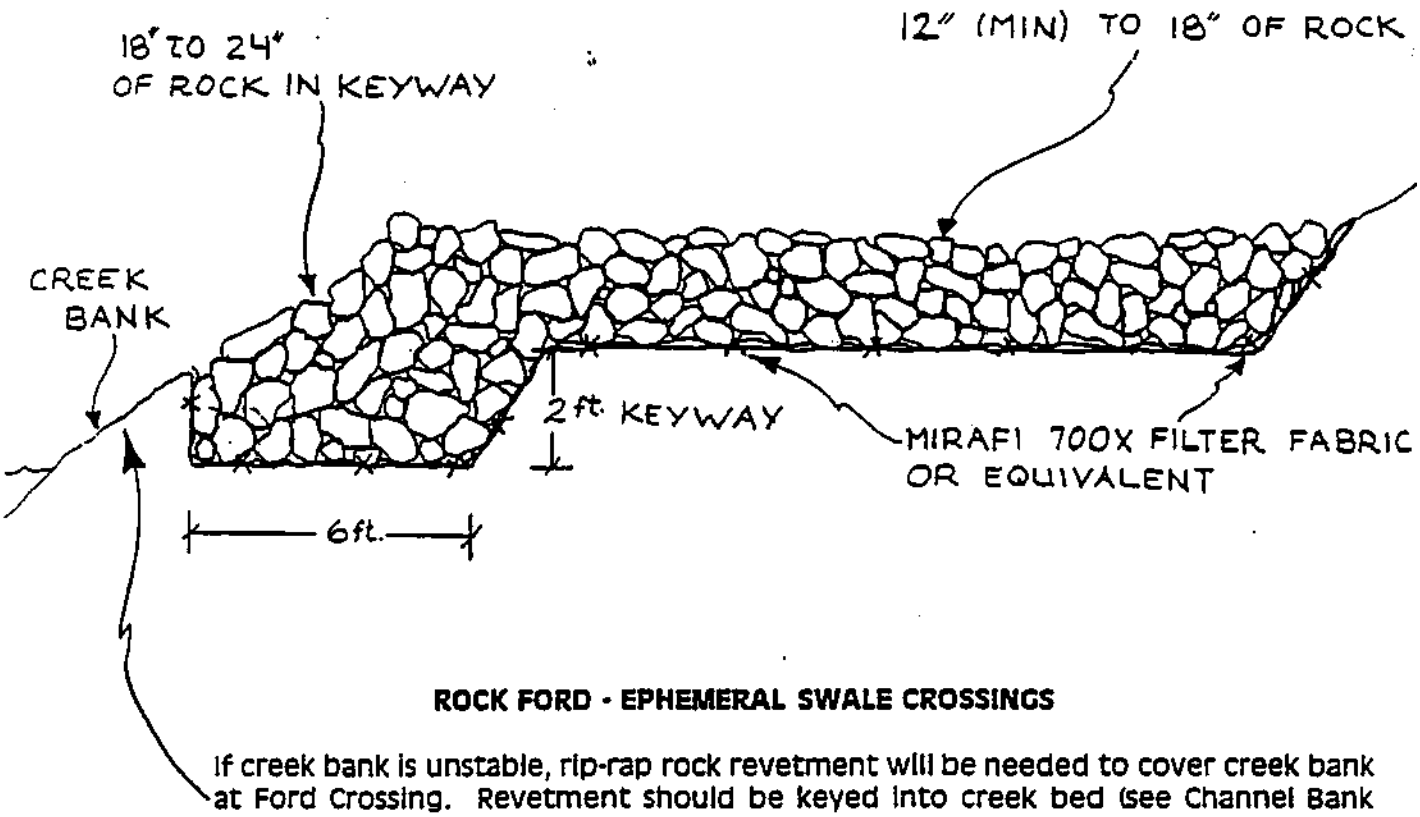
Construction of ford crossings typically involves excavating a prominent broad dip through the stream crossing fill, in many cases down to or near the original channel bed, and then installing the designated type of ford making sure adequate energy dissipation is naturally present or is installed below the crossing. Hardened sills will be constructed at the lower end of the fords to prevent erosion of the remaining road fill[17]. Typical components of the construction are shown on the attached drawings.

Fords on live streams, called "wet fords," are typically composed of streambed gravels, fill, or concrete structures built in contact with the streambed so that vehicles can cross the channel. If possible, a stable, rocky (or bedrock) portion of the channel should be selected for the ford. Fords can be made of permeable trench drains of coarse cobbles and boulders. Low summer flows seep through the fill, and high water discharges flow over the top. During extreme events, however, the ford may not be usable for a period of time (permeable fords of fish-bearing streams may be a barrier to migrating fish and installation will require approval by the Department of Fish and Game).

Fords work well on small to medium sized streams where there is a stable stream bottom and vehicle traffic is light. Compared to a culverted fill, they have the advantage of little fill to wash out during flood flows. Unless wet fords are constructed of poured concrete, they are less desirable in high traffic areas because continued disturbance to the streambed can cause persistent downstream turbidity and fine sediment pollution problems. Dry fords on seasonal roads can often be installed and used with minimal impact to the channel system.

Paving or rock armoring fords (Figures 7-26 and 7-27) across live streams may be necessary to maintain water quality if there is to be regular traffic. Paving often consists

[17] Sill construction is described in additional detail in the workplans.



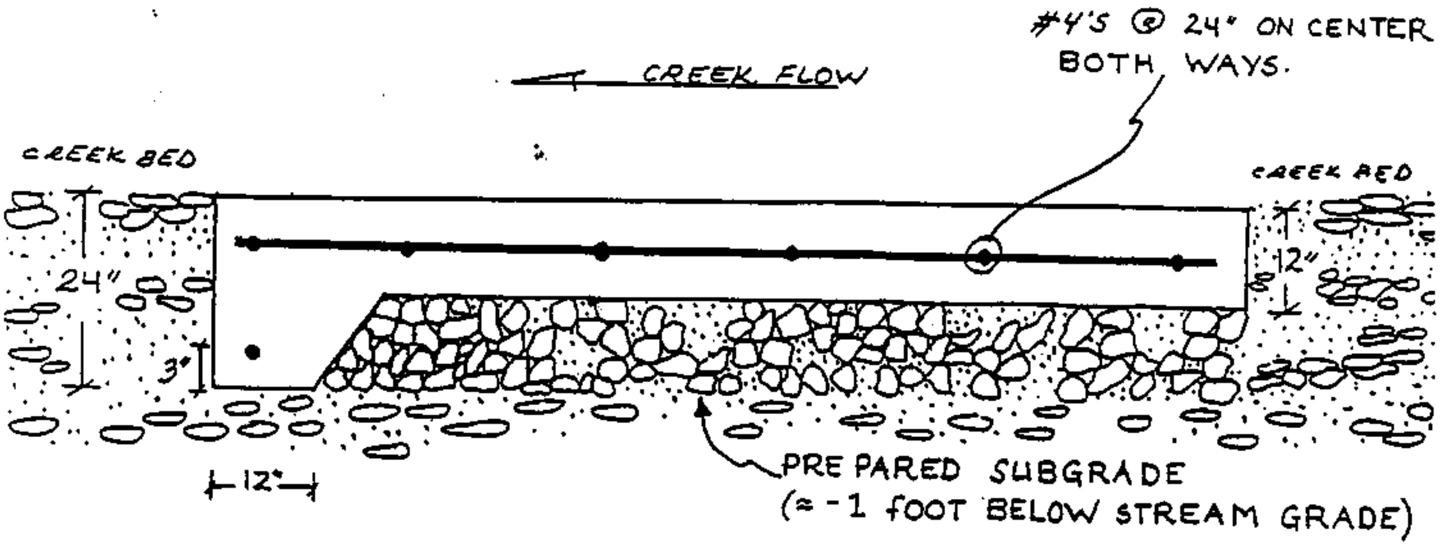
ROCK FORD - EPHEMERAL SWALE CROSSINGS

If creek bank is unstable, rip-rap rock revetment will be needed to cover creek bank at Ford Crossing. Revetment should be keyed into creek bed (see Channel Bank Stabilization Section).

ROCK FORDS

1. Subexcavate roadbed to form exaggerated dip through crossing.
2. Proof roll exposed subgrade with rubber tire or track crawler to provide a smooth uniform appearance.
3. Place geotextile fabric over prepared subgrade (Mirafi 700X or equivalent). Overlap a minimum of 3 feet, if necessary (upstream lap covers downstream lap).
4. Cover fabric with minimum two layers of rock, rock 8 to 18 inches in nominal dimension.
5. Outboard road edge sill (keyway) should consist of larger rock (12 to 24 inches in nominal dimension) along a deepen edge keyway underlain with continuous fabric.

Figure 7-26. Rock Ford - Ephemeral Swale Crossings.



CONCRETE FORDS

1. Prepare subgrade for concrete pour. Subexcavate 12 inches below finished road surface crossing grade. Subgrade surface should be reasonable planer and consist of gravelly sand or cobbles derived from the adjacent stream bed. Proof roll subgrade surface with rubber tire or track crawler to provide a smooth, uniform surface.

2. Excavate downstream thicken edge 24" X 12".

3. Place forms and set dobries to support reinforcing bar.

4. Place steel reinforcing schedule, #4 rebar at 24 inches on center, in two directions perpendicular to each other in center of concrete slab. #4 rebar, top and bottom, longitudinally in downstream thicken edge. Minimum 3-inch concrete cover over steel rebar.

5. Pour 2,000 psi concrete.

6. Saw cut or hand form control joints at 12 feet centers and traverse contraction joints at 20 centers (approximately 2 inches deep).

Figure 7-27. Concrete Ford.

of a concrete, slightly dish-shaped slab across the watercourse, and a discharge apron or energy dissipator on the downstream side to prevent scour during high flows. The structure should be designed to pass both sediment and debris during high flows. Improperly installed concrete fords can be plagued by scour around their edges, leaving the ford elevated and impassable.

A improperly constructed ford crossing is vulnerable to erosion. High traffic levels and/or high water flows can cause erosion of both natural and artificial streambed materials. On small, poorly incised, ephemeral or intermittent streams a ford may be needed if there is insufficient channel depth to install a culvert. In fact, a rock lined rolling dip with a rock apron face (sometimes called a "sill") is generally desirable to permanent culverts on these swales and small watercourses. Fords have the advantage, over culverted fills, of never plugging.

Fords on small streams are generally rock armored to prevent erosion of the road surface and fill during periods of runoff. The fill face on the downstream side of the fill can either be protected with rock armor, by a vertical concrete sill with an energy dissipation apron or fitted with a large overside drain (berm drain) to prevent erosion. The key is to design the broad ford with the proper stream crossing cross sectional area to accommodate the 50 year storm. This includes the proper width and length of armor across the fill face. Unimproved fords, which consist of a stream channel that has been filled with a substantial quantity of soil and left unprotected by armor or surfacing is a hazard to water quality and should not be constructed.

Rolling Dip Construction

Rolling dips (Figure 7-28) are simply breaks in the grade of a road. They are sloped either into the ditch or to the outside of the road edge to drain and disperse road surface runoff. Rolling dips are installed in the road bed as needed to drain the road surface and prevent rilling and surface erosion, and are most frequently used on outsloped roads. As a road becomes steeper, rolling dips should be made deeper and placed at a steeper angle to adequately capture and divert road runoff.

It is easier to properly locate and construct rolling dips when they are designed into the original road plan. However, they may also be installed on existing roads to improve surface drainage where they can be built in about one hour, or less, using a medium size bulldozer (D-7 size). Unsurfaced roads are more easily reconstructed with rolling dips, but rocked road surfaces can also be reconfigured.

The estimated locations and length of road which must be excavated to construct a rolling dip are included in the road log for each road segment and for each site. Excavation for a rolling dip typically begins 30 to 80 feet up-road from where the axis of the dip is planned. Material is progressively excavated from the road bed, slightly steepening the grade, until the axis is reached. This is the deepest part of the excavation, with the overall depth being determined by the slope of the road. The steeper the road, the longer the excavation and the deeper the dip will have to be in order to reverse grade. See Table 18

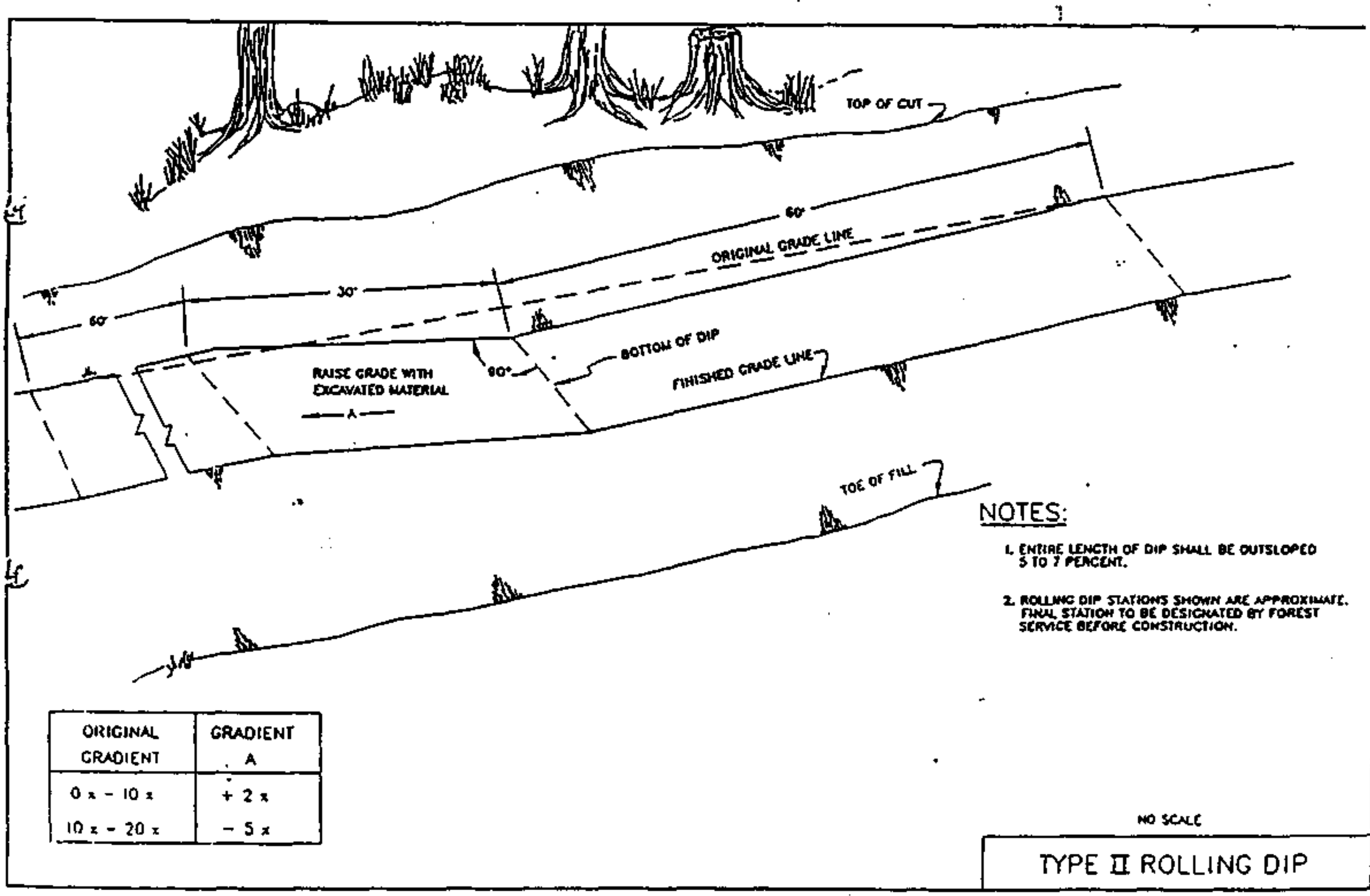


Figure 7-28. Rolling Dip.

and Chapter 4 in the "Handbook for Forest and Ranch Roads", (June 1994) for dimensions and numerous examples of rolling dips.

In order to safely and effectively direct runoff to the side of the road, the axis of a rolling dip should be slightly angled to the road alignment. On the down-road side of the rolling dip axis, the road bed slope should actually rise slightly to ensure that runoff cannot continue down the road surface. This is called a "grade change." The rise in grade is carried for about 10 to 20 feet before the road surface begins to fall again at its original slope. This transition from axis bottom, through rising grade, to original falling grade is achieved in a road-distance of 15 to 30 feet. Unlike a waterbar, the reverse grade portion of a rolling dip is not usually composed of fill, unless the fill materials can be thoroughly compacted. It is best if the entire drainage structure is excavated into original ground.

Rolling dips require very little maintenance if they are constructed properly and at an adequate spacing. They should not collect enough runoff to develop significant erosion. The length and depth of the rolling dip should be adequate to divert road runoff but not so great as to interrupt or endanger traffic at normal speeds. Care should be taken to ensure that grader operators do not fill the depressions with soil or cut deeply into the lower part of the rising section, thereby eliminating the change-in-grade.

Critical Rolling Dip Construction

Stream crossings with a high diversion potential (DP) occur wherever the road climbs through the crossing and one approach slopes away from the stream crossing. If the culvert plugs on a crossing with a high DP, backed up flood waters will be diverted down the road alignment. If the crossing has no DP, backed up flood waters will flow onto the road surface, over the fill and back into the natural channel. The fill may be washed-out, but streamflow is not diverted out of the channel and onto adjacent, unprotected roads and slopes.

These high DP crossings should be corrected by constructing a broad rolling dip over or immediately down-road from the fill. New stream crossings should be constructed to prevent stream diversion of flood overflow if the culvert were to become plugged. This can be done by designing the road to "dip" into and out of the stream at the crossing site (a dipped crossing), or by installing a broad rolling dip on the down-road side of the crossing, so that flood overflow will be directed back into the natural stream channel.

This latter structure is called a "critical dip." If the culvert plugs, the critical dip will capture the overflow and the stream will then flow over the road bench and back into the channel, not down the adjacent road bed. This treatment effectively prevents stream diversions from occurring at culverted stream crossings when a culvert inlet becomes plugged. To an equipment operator, constructing a critical dips is done exactly the same way as a rolling dip, however each dip serves a different function along the road. Stream crossings on all newly built or reconstructed roads should not be constructed in a manner that gives any opportunity for future stream diversion. In the pilot project, a number of high DP stream crossings will be protected by the construction of a critical rolling dip.

Berm Removal

Berms along the outside edge of the road, constructed by years of road surface grading, have been created along the majority of road segments in the Navarro River watershed. Erosion, and maintenance requirements, are high in many of these road sections. Berms along the outside edge of the road do not allow road runoff to leave the road. Instead, runoff is concentrated down the road for long road lengths resulting in landowners spending large sums of money to rock and protect the road surface from rills and gullies. This approach generally is treating a symptom of the problem, with the real problem being the presence of the berm.

Many landowners have attempted to breach the berm at some interval, but this is not often very effective for long periods because of several reasons. Most road surfaces vary from flat to insloped for much of their length, with only short outsloped segments. Most road runoff has limited opportunities to physically even get to the berm to be discharged off the road. If the location of breaches in the berm are not carefully located, then the effectiveness of any berm breaches is severely compromised. Many breaches in the berm are not severe or of an appropriate length to prevent minor deposition of sediment eroded from the road surface to clog or block the berm breach. Secondly, even rocked road surfaces rut as a result of winter use, particularly when vehicles travel along the same line on the road. The ruts capture road runoff and prevent flow from getting to berm breaches.

It is often argued berms are advantageous since they serve as ready stock-piles of material to fill potholes and ruts in the road. This may be true, however we would propose that the water quality consequences of maintaining berms along roads, as well as the long-term costs to landowners to continually grade and/or rock their roads, may far out-way the advantage of having pothole spoil materials close at hand. Instead, we propose stockpiling future road maintenance materials at suitable locations along the road where they can be easily retrieved and carried by the grader to where they are needed. The benefits of rapidly shedding rainfall and runoff from the road prism, through the removal of most berms, can result in significant environmental and financial returns to landowners.

As a part of efforts to improve road surface drainage and reduce maintenance requirements and costs, local removal of the outside berm has been prescribed. Spoil material can be reworked onto the road surface (if the road is not rocked), it can be hauled off to a stable storage site, or it can be sidecast (as long as there is no chance it could erode and enter a stream channel). In these sections, the road surface can be locally reshaped and resurfaced (where needed) to improve road surface drainage and reduce erosion rates. This could entail outsloping and/or the construction of rolling dips (as prescribed in the road log) to frequently drain the road surface and prevent water from concentrating and flowing down the road bed.

Sidecast Excavation

Sidecast materials which were pushed onto steep slopes during road construction or during subsequent maintenance activities can become unstable and deliver sediment to nearby stream channels. Where this is the case, we have prescribed sidecast excavation. This treatment removes unstable or potentially unstable fill and earth material from the outer edge of a road or landing. Excavated material can be pushed to a local storage area or it can be hauled to a stable spoil disposal site where it will not erode and deliver sediment to a stream. The fill is then shaped to assure dispersed runoff.

The up-road and down-road boundaries of a sidecast excavation site are marked by flagging identifying the beginning and end of each treatment area. These flags are labeled "START" and "END" and are referenced to station numbers both on the flagging and on the road log. Generally, the finished grade at the outslope location should be a free draining, concave-up surface. This ensures that bulk of unstable fill material will be removed from the outside of the road bench.

Stream Crossing Excavations

Road/Stream Crossing Excavations (RX) involve the removal and disposal of road (crossing) fill, culverts, and organic debris from a stream channel, and shaping the completed excavation (sideslopes) to blend with the surrounding land. In most cases, the finished product will closely mimic the original (pre-road construction) stream channel and side bank configuration.

Important information and general descriptions for each RX treatment has been included in the Road Log. Information includes some or all of the following for each stream crossing site: total estimated volume expected to be excavated; final channel bottom width (measured at one-foot above the deepest point at the center of the channel) to be constructed; completed channel grade to be constructed; approximate side bank steepness (measured perpendicular to channel center-line) to be constructed; excavation width at the road surface (usually at the point of maximum depth - normally at the outboard edge of road); and other conditions unique to each site.

Along the RX centerline, the upper and lower limits of channel excavation are defined by the location of "TOP" and "BOTTOM" stakes or flags in the field, respectively (see Figure 7-29). The completed channel grade connects the TOP and BOTTOM stakes at a specified grade(s). This grade may be a straight line (a single grade specified) connecting these two points, or may be a concave line (range of grades specified).

If no grade has been specified in the Road Log, a straight line or slightly concave-up profile shall be constructed. Unless otherwise specified, all excavated stream channels shall have side slopes no greater than 50% and channel bottom widths no less than 5 feet.

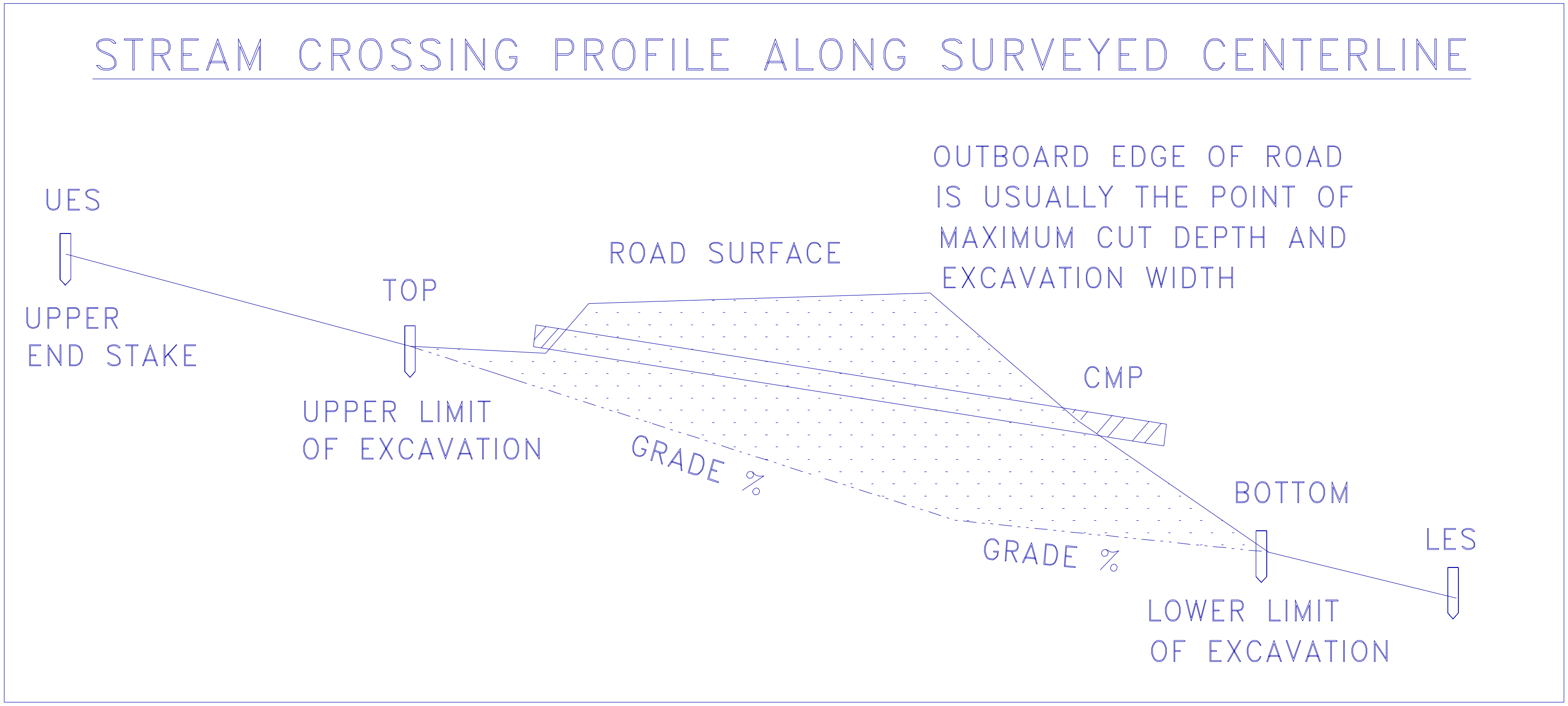


Figure 7-29. Stream Crossing Profile Along Surveyed Centerline.

For most stream crossing excavation sites, two points are marked by flagging in the field. These are the "top left edge of cut (LEC)", and "top right edge of cut (REC). These points, along with the specified channel width and side bank steepness, determine the overall cross-sectional shape of the excavation. The cross-sectional shape and channel grade at each particular location may, however, vary through the entire length of the excavation (i.e., from TOP to BOTTOM).

In all cases, RX treatments have been designed with TENTATIVE grades which provide the basis for the volumes to be excavated during these treatments.

By monitoring the RX excavations as they progress, the contractor can adjust the excavation's grade and alignment to preserve the latent boundary conditions which may include: original channel armor (small organics and rock in the original channel bed); bedrock outcrops; stumps; or, other naturally introduced large organics. These boundary conditions exist naturally in a stream channel or its valley and prior to road building, acted as natural control for the channel forming processes.

In the event streams are flowing at the time of excavation, the contractor shall minimize sedimentation to those streams. Temporary diversions around the limits of the excavation or sediment retention barriers (silt fencing, straw bales or other barriers) necessary to complete this work shall be the contractor's responsibility. However, any such temporary structures which are installed, including any sediment which is trapped, shall be removed by the contractor prior to signing the excavation as being completed.

All berms, tracks, and other surface irregularities (on the side banks) of excavated stream crossings shall be smoothed to encourage free draining (not concentrated) surface flow.

Any stumps in the growth position encountered during excavation shall be left in place. No stumps or live trees greater than one-foot in diameter shall be undercut (root ball exposed) during excavation.

<u>Storage Area and Fillsite Treatment</u>

The road logs and treatment maps designate storage areas for spoil materials. The finished fillsite should be shaped conformably into the existing cutbanks and fill should only be placed in designated locations. Unless otherwise specified, the steepness of any finished fillsite should not exceed 3:1 (30%). All berms, tracks, and other surface irregularities should be smoothed and finished fillsites should not trap or pond surface water. Free draining surface flow should be in the same direction as that of the adjacent lands.

<u>Straw Mulching, Seeding and Planting</u>

Straw from bales should be spread evenly over a predesignated areas (see road treatment logs) at an application rate of 6,000 lbs/acre. At this application rate, the ground surface will be visible in no more than 5% of the mulched area.

a) Straw should be spread evenly at the designated rate and within the designated bare and/or disturbed areas.

b) Baling wire should be removed from the site and disposed of properly.

c) Straw should be as free as possible from exotic seeds. Hay should not be used.

d) Mulching should be the last task performed on the work area, following any heavy equipment operations, seeding and fertilizer application.

Equipment, Material and Personnel Requirements

Heavy equipment needs: The following pieces of heavy equipment constitute the most efficient and cost-effective combination for erosion prevention work on the four pilot treatment areas in the Navarro River basin.

a) hydraulic excavator, track driven, minimum 25-35 foot surface reach, 1.5 - 2.5 cubic yard bucket, maximum 12-13 foot outside track width,

b) track driven dozer; high track D-6, D-7, or equivalent, late model, preferable power angle/tilt U-blade with 6-way motion and hydraulic ripping attachment,

c) backhoe, wheeled with extendible boom.

d) dump truck(s), 10 yd^3, with locking rear differential.

Material needs: A wide variety of material will be utilized in the conduct of this project. Materials and supplies needed may include:

a) Eighty pound bales of straw for mulching,

b) Annual grass seed (native species preferable),

c) If desired, 16-20-0 dry, homogenized, pelletized fertilizer,

d) Flat bed 1 ton (or greater) long bed 4x4 truck or pickup to transport straw, laborers, culverts and other materials

e) Commercial belly grinders to spread seed and fertilizer

f) Brush cutting tools and equipment

g) Shovels and other hand tools for erosion control work

h) Vibratory hand compactor

i) Planting materials and tools for revegetation work

j) Culverts and related hardware

k) Miscellaneous tools, equipment and supplies needed to provide final layout of equipment prescriptions and to conduct project supervision (flagging, spray paint, measuring tapes, film (for documentation), Mylar film and other drafting supplies, water bottles, packs, safety and emergency first aid supplies, etc.)

Personnel needs: Personnel are needed to operate the heavy equipment, perform the hand labor erosion control work and to coordinate and supervise both the heavy equipment and labor activities. Basic personnel needs for the conduct of this project are as follows:

a) *Excavator and dozer operators*, preferably experienced in similar erosion control projects involving sidecast removal and proper stream crossing culvert installation along narrow, mountainous roads,

b) *Backhoe and dump truck operators* experienced with culvert installation and maintenance, and able to work on steep, narrow mountainous roads,

c) *Laborers* (1 per excavator/tractor pair) to set chokers, transport and spread straw, spread seed and fertilizer, punch straw, perform manual excavations and clean-up, and install culverts, downspouts and trash-racks,

d) *Project coordinator/supervisor* to train field personnel and equipment operators in appropriate "erosion-proofing" techniques, lay out and coordinate specific heavy equipment and labor intensive tasks at each work site; arrange for material ordering and logistics (seed, fertilizer, mulch, heavy equipment, etc.); monitor, track and supervise project and work progress; and prepare final report.

8.1 INTRODUCTION

Implementation of the Navarro Watershed Restoration Plan will require involvement of the whole Anderson Valley Community. It is therefore essential that Anderson Valley residents have a clear understanding of the findings and recommendations contained in the Plan. An informed Anderson Valley populace, conversant in watershed concepts and issues, will be effective in organizing creative, workable solutions to the problems facing the Navarro's fishery and water quality. This section describes several existing and planned means that may be used to inform Anderson Valley residents of the Plan's results, and for involving residents in implementation of the Plan.

8.2 DEMONSTRATION PROJECTS

The Plan includes designs for several demonstration projects (see Section 7.0). Most of the sites for these projects are in areas easily accessible to the public. The landowners involved in the demonstration projects have agreed to allow interested members of the public on their property to observe the results of the projects.

These demonstration projects, if implemented, will serve as study sites for those interested in performing restoration work. Site plans and before and after photographs will be available at the project's document repository (see Section 8.4). The demonstration project sites may be visited by individuals, elementary and high school classes, and participants in restoration workshops.

8.3 ANDERSON VALLEY UNIFIED SCHOOL DISTRICT

The Anderson Valley Unified School District (AVUSD) is host to the Watershed Project. The Project seeks to include in the elementary, middle, and high school curricula watershed concepts, a greater understanding of the ecology of the Navarro Watershed, and skills for building the community and improving the environment. The Watershed Project is co-sponsored by the AVUSD, Americorps, the California Conservation Corps, the Fish and Wildlife Foundation, the Annenburg Foundation, the North Coast Rural Challenge Network, and private donors.

The Watershed Project has a program coordinator who works with interested teachers to include watershed concepts and activities in their lesson plans, and who works directly with students on classroom and outdoor lessons. Lessons stress the interconnectivity of watershed elements, the effects of changes in the landscape on salmon and steelhead, and the natural history of Anderson Valley. The Project has developed a nature trail and outdoor classroom at Anderson Valley Elementary School that is used for classes and field activities. Several classes have become involved in gathering and analyzing field data, including rainfall, stream turbidity, and stream flow. The last two of these were part of the volunteer monitoring effort coordinated by the Mendocino County Water Agency. One class is hatching, raising, and releasing steelhead.

In the 1997-98 school year, the Watershed Project expanded to include a stream restoration class at the High School, taught jointly by a local stream restoration expert and the owner of a local native plant nursery. The aim of the class is to teach high school students stream restoration concepts and techniques, and to involve them in restoration projects. The class also involves the creation of a native plant nursery at the High School. Students gather and propagate native plants for use in restoration projects. The goal of the class is to train local youth for careers in stream restoration work. A more immediate goal is to develop a summer employment program for involved youth.

The Watershed Project is expected to play a major role in the implementation of the Plan by giving Anderson Valley's young people a greater understanding of the Watershed, as well as skills for restoring and protecting the Watershed.

8.4 ANDERSON VALLEY LENDING LIBRARY

The Anderson Valley Lending Library, located at the Boonville Fairgrounds, has agreed to be the repository for Plan documents. This will include the Plan and its appendices, air photos, maps, supporting documents gathered by the project's consultants, management team, and Advisory Group, and other related materials donated by involved parties. The Library has agreed to dedicate a shelf to these documents.

In order to publicize the availability of materials at the Library, the project coordinator will prepare and distribute a press release and public service announcement to local media.

8.5 WORKSHOPS

The survey conducted as a requirement of the 205(J) grant included questions regarding respondent's interest in attending workshops on restoration issues and techniques. Response was generally positive. Workshops may be used to teach and demonstrate a variety of restoration techniques. Workshops should include both lecture/discussion, site visits, and hands-on practice.

While no party has emerged as a definite sponsor of workshops, several have expressed interest. These include University of California Cooperative Extension, the RCD/NRCS, the California State Coastal Conservancy, and the AVLT. Possible topics for workshops include the following:

Upslope Erosion Control
- Hillslope vineyards and orchards
- Building sites
- Gully control and remediation
- Grazing
- Timber harvest

Roads
- Road building and maintenance techniques for heavy equipment operators

- Road assessment, planning techniques for landowners, other interested parties

Riparian Corridor Protection and Restoration
- Revegetation
- Exclusionary fencing

Bioengineering Techniques for Stream Bank Stabilization

In-Stream Channel Habitat Restoration
- Fish passage structures
- Pool structures

Water Conservation Practices
- Agricultural
- Commercial
- Residential

Workshops will preferably be held during the winter rainy season, and may be from 1/2 to 3 days long, depending on the topic and the target audience.

In addition to these hands-on workshops, the AVLT has for several years sponsored an occasional evening workshop series. These workshops feature guest speakers who are experts on a variety of conservation topics. The AVLT expects to continue this series, focusing both on broad conservation topics and on topics closely related to the Plan. Workshops are free and open to the public.

8.6 PLAN DISTRIBUTION

The Plan itself is expected to be instrumental in providing information on watershed restoration issues, methods, and priorities to Anderson Valley residents. The Plan should be distributed as broadly as possible. To accomplish this, the availability of the final Plan will be publicized once it is available. Publicity will include the following:

- Distribution of copies of the plan to agencies involved in providing technical assistance on land management to local landowners;

- Press release to all local newspapers announcing results of planning process, availability of plan;

- Public service announcement to local radio stations announcing availability of plan;

- Article summarizing plan results and order form in AVLT's newsletter (distributed to all watershed landowners);

- Flyer announcing availability of the Plan posted in local shops and public places, and distributed to local realtors;

- Mailer announcing plan availability to entire project mailing list (approximately 200 names).

8.7 GEOGRAPHIC INFORMATION SYSTEM FOR COMMUNITY PLANNING

A Geographic Information System (GIS) should be created to facilitate community-based watershed planning, monitoring, and education. A GIS database could be created to compile data gathered in the course of preparing this Plan, as well as all currently available physical and biological data on the watershed. Interested members of the community could be trained to analyze and apply the data. The GIS would be capable of producing sophisticated maps that facilitate understanding of watershed conditions, processes, and changes. The intent of the GIS would be to provide the community with a powerful, flexible tool with which to continue to monitor the Watershed and respond to changing conditions within it.

9.1 INTRODUCTION

Section 5.0 sets forth priorities for restoration of water quality and the salmonid fishery in the Navarro watershed focusing on implementation of the Plan to address these priorities and achieve the goals and objectives set out in Section 2.0. This implementation plan includes an overall strategy for implementation; describes the roles of private organizations and governmental agencies in implementation; reviews available funding sources; and summarizes permit requirements.

Sections 3.0 and 4.0 indicate that the problems affecting the Navarro's water quality and the salmonid fishery are cumulative and widespread. Stream sedimentation, high summer water temperatures, and lack of pool habitat exist in all of the Navarro's major subbasins. In order to restore the Navarro, it will be necessary for a large number of landowners, representing the majority of the land area in the Watershed, to work individually and with their neighbors to decrease erosion, protect and enhance riparian areas and stream habitat, and to reduce water consumption. Because of the scale and breadth of actions required, restoration is likely to take the form of a set of actions, large and small, coordinated and individual, that together will move the Navarro River and its watershed toward greater stability, productivity, and diversity.

9.2 STRATEGIES FOR PLAN IMPLEMENTATION

9.2.1 IMPLEMENTATION OF RECOMMENDED LAND MANAGEMENT PRACTICES (RLMP'S)

The RLMP's contained in Section 6.0 are intended for use primarily by individual landowners interested in reducing the impact of past and present land use practices on fish habitat and water quality (though some RLMP's, such as road treatments and water conservation, are well-suited to coordinated efforts). Adoption of the RLMP's by landowners in the Watershed is an essential component of Plan implementation. From the outset, this Plan was envisioned as a voluntary effort by interested landowners to make improvements on their own properties and in their own land management practices to improve fish habitat and water quality. The RLMP's provide a comprehensive set of recommendations for landowners engaged in any of the major land uses in the watershed.

Effective implementation of the Plan is dependent on widespread adoption of the RLMP's. It is therefore imperative that individual landowners take responsibility for obtaining, reviewing, where necessary modifying, and adopting the RLMP's that pertain to their circumstances. It is furthermore imperative that watershed groups, other non-governmental organizations, and government agencies focus attention on the RLMP's and facilitate their adoption.

9.2.2 RESTORATION OF PRIORITY BASINS AND TRIBUTARIES

Section 5.0 identifies those subbasins that are considered key to recovery of coho salmon and steelhead trout, and describes the types of treatments that will be necessary in these subbasins to conserve and restore salmonid habitat. Within the high priority basins restoration should have a broad, basin-wide focus, and should begin with the most cost-effective methods to address the major limiting factors identified in the subbasin. In most of the high-priority basins, the following restoration treatments will be necessary, to varying degrees:

a) Reduction of sediment from upslope sources, especially roads and gullies.

b) Revegetation, exotic species removal, and/or exclusionary fencing in disturbed and degraded riparian areas.

c) Stabilization of streambanks, preferably using bioengineering methods that also enhance stream habitat.

d) Placement of fish habitat structures in streams that lack pools and cover.

e) Establishment of conservation easements or other protections to ensure the long-term viability of the restoration effort.

Because this plan features only demonstration project restoration designs, restoration of the priority subbasins will require more detailed assessments and project design before proceeding with implementation. The assessments should identify the most important and cost-effective means of overcoming the major factors limiting the fishery and impinging on water quality in the subbasin.

Few of the priority subbasins are owned by a single land owner. Therefore, restoration of most of these subbasins will require coordination and cooperation among landowners, and, where desired, with government agencies and private organizations.

9.2.3 RESTORATION OF MAJOR TRIBUTARY STREAMS

An important strategy for decreasing stream temperatures and stream sedimentation, and therefore for improving water quality, is for riparian landowners to cooperate in the restoration of whole reaches or lengths of degraded streams. Restoration will involve reduction of sediment input to stream channels from stream banks and near-stream sources; revegetation of riparian areas; protection of riparian areas from grazing and browsing pressure while they are recovering; and reduction or cooperative scheduling of summer diversions. Addressing major sources of upslope sediment delivery to streams is also important to ensure the success of this strategy. This strategy will be necessary for the long-term restoration of the major tributary streams, especially Rancheria Creek, Anderson Creek, and Indian Creek. It may also be employed on reaches or whole lengths of degraded smaller tributary streams that exhibit high summer water temperatures and that carry excessive sediment loads.

Except where a single landowner owns an entire stream or stream reach, this strategy will require cooperation among owners. Landowners may choose to structure formal or informal agreements for sharing project costs and responsibilities, or may choose to work with interested government or non-government organizations. Landowners involved in this type of restoration project may find it useful to form a watershed coordinating group. Coordination between individual landowners increases the likelihood that grant funding and technical assistance from resource agencies will be obtained.

9.3 ROLE OF WATERSHED COORDINATING GROUPS

The Navarro Watershed Restoration Plan's Community Advisory Group was formed to oversee preparation of the Plan. With the completion of this task, the AG's work will conclude. The existence of one or more new watershed coordinating groups will be important in restoring the Navarro River watershed.

The AG itself has discussed expansion of its role beyond oversight of the Project. Possible functions of an expanded community advisory group, identified by the AG, are facilitating technology transfer and communication; building trust between elements of the community; developing and recognizing local authority over land and resource management; and developing a mechanism for regulatory input. Other possible roles of a broad-based group might include acting in an advisory capacity for the development of TMDLs and ESA listings, and oversight and coordination of Plan implementation.

New watershed groups with more limited foci may also be formed to coordinate efforts of individual landowners with common restoration interests. For example, owners within a particular subbasin who are interested in restoring the subbasin may form a group in order to pool resources, to request assistance and funds from government agencies, and to share information. Other groups may represent the interests of landowners who are engaged in particular land uses or who are concerned about particular issues, such as forest practices or water use. These groups may be on-going or may dissolve after the implementation of a particular project.

Two groups other than the Plan's Advisory Group that may be expected to be involved in Plan implementation are already in existence. One of these groups, Friends of the Navarro, pre-dates the plan. Friends of the Navarro advocates for enforcement of existing environmental regulations that are meant to protect the River and its watershed, and for the establishment of new regulations. The group promotes stream monitoring, and many members actively participate in volunteer monitoring. Membership is open to any interested party.

The Navarro Watershed Landowners Group is open to all landowners engaged in agriculture in the Navarro Watershed. The purpose of this group, which was formed late in 1997, is to assist its members in complying with the TMDL process, ESA listings, and any other regulatory actions affecting members' land management practices, and to coordinate voluntary efforts to benefit water quality and fisheries resources. The group intends to build on the findings and recommendations of the Plan, and to coordinate its members' implementation of aspects of the Plan. The Group's meetings are open to the public.

9.4 INVOLVEMENT OF NON-GOVERNMENTAL GROUPS IN PLAN IMPLEMENTATION

Several non-governmental organizations are expected to be involved in Plan implementation. The anticipated role of some of the organizations is described below.

ANDERSON VALLEY LAND TRUST (AVLT)

The AVLT, one of the sponsors of this project, expects to be involved in implementation of the Plan through exercise of its main missions: public education and establishment of conservation easements. The AVLT publishes a quarterly newsletter that is distributed to all watershed landowners, and which covers current topics related to conservation and restoration. In addition, the AVLT sponsors an occasional workshop series that features guest speakers on a variety of current conservation topics.

The AVLT works with interested landowners to establish conservation easements. Conservation easements are permanent, deeded land use restrictions for public benefit conservation purposes (see full description in Section 6.0). Conservation easements can be used by interested landowners to ensure permanent protection of fish habitat, water quality, and stream flow. Conservation easements can bring substantial income tax, property, and estate planning tax benefits to landowners, compensating them for their voluntarily-imposed land use restrictions. There is limited funding that may be available from a variety of sources such as the USFS/CDF-administered Forest Legacy Program for owners of forestland, including oak woodlands, to cover project costs (inventories, forest management plan, other easement design costs) related to donation of conservation easements to protect forest values and water quality (Table 9-1).

ANDERSON VALLEY WINEGROWERS ASSOCIATION (AVWA)

The winegrowing community may assist in the restoration of the Navarro watershed through the institution of practices that reduce the impact of their farming activities on streams. These practices are constantly being improved and disseminated among winegrowers through various technical publications, professional societies, and public associations. The AVWA itself serves as a forum for dissemination and discussion of new and improved farming methods.

Winegrowers may improve stream habitat by improving water conservation through diversion of winter run-off (rather than pumping ground or surface water in the summer); using drip or underground irrigation instead of overhead sprinklers; growing and maintaining early dormancy cover crops; selection of rootstock that is drought tolerant

Table 9-1. Funding Sources.

Agency	Program	Description	Eligibility	Recipient's Cost Share	Contact
Funding Sources for Watershed-Wide or Subbasin-Wide Restoration Projects					
Americorps/California Conservation Corps	Americorps Watershed Stewards Project	In-stream assessment, near-stream assessment, and restoration of fish habitat	Private landowners	None required, but cash or in-kind contribution preferred	Michelle Rose (707) 725-8601 or Gary Flosi (707) 725-1912
California Department of Fish and Game	Fishery Restoration Grant Program	Watershed evaluation, assessment, and planning, project maintenance and monitoring, watershed organization support and assistance, technical training and education projects, cooperative fish rearing	Government agencies, non-profit organizations, educational institutions, private individuals and contractors	None required, but preferred	Gary Flosi (707) 725-1912
California Department of Fish and Game, Wildlife Conservation Board	Riparian Habitat Conservation Program	Funds major projects that conserve, protect, enhance, or restore significant riparian habitat	Nonprofit organizations, federal, state, and local government agencies, including special districts	25%	Scott Clemons (916) 445-1072
California State Coastal Conservancy	Coastal Watershed Restoration Program	Funds may be available to pay some or all of the cost of high-priority restoration projects, as well as demonstration projects.	Local government agencies, non-profit organizations, and individuals	Preferred	Julia McIver (510) 286-4166
USEPA/SWRCB	319(h) Clean Water Grants	Non-point source implementation program for water quality improvement	Non-profit organizations, government agencies, educational institutions	40% non-federal (cash or in-kind)	Ken Harris (916) 657-0876

Table 9-1. Funding Sources (continued).

Agency	Program	Description	Eligibility	Recipient's Cost Share	Contact
Funding Sources for Individual Landowners and Site-Specific Projects					
California Department of Fish and Game	Fishery Restoration Grant Program	In-stream habitat restoration, watershed and riparian habitat restoration	Government agencies, non-profit organizations, educational institutions, private individuals and contractors	None required, but preferred	Gary Flosi (707) 725-1912
California Department of Fish and Game	Fish-related Incentives for Sustainable Habitat – Timber Tax Credit Program	Provides tax credits to private landowners for projects benefiting salmon and steelhead, including road stabilization, riparian and in-stream habitat improvement, and improvements to irrigation systems	Private landowners, both corporate and individual	None	Mark Zuspan (707) 839-3378
California Department of Forestry and Fire Protection	California Forest Improvement Program (CFIP)	Forestry, watershed, and riparian protection and enhancement through reforestation, site preparation, erosion control, revegetation, and fish and wildlife habitat improvements	Private landowners with stewardship plans on holdings of 20-5,000 acres	25%	Tess Smith (707) 964-5674
California State Coastal Conservancy	Coastal Watershed Restoration Program	Funds may be available to pay some or all of the cost of high-priority restoration projects, as well as demonstration projects.	Local government agencies, non-profit organizations, and individuals	Preferred	Julia McIver (510) 286-4166
Mendocino County Resource Conservation District	Landowner Assistance Program	Assists landowners in design and implementation of site-specific projects, including erosion control, streambank stabilization, and fish and wildlife restoration	Private landowners		Tom Schott (707) 468-9223

Table 9-1. Funding Sources (concluded).

Agency	Program	Description	Eligibility	Recipient's Cost Share	Contact
Funding Sources for Individual Landowners and Site-Specific Projects (continued)					
Mendocino County Fish and Game Commission	Fish and Wildlife Grants	Grants of up to $5,000 for projects for the conservation of fish and wildlife in Mendocino County.	Individuals and groups within Mendocino County	Cash or in-kind contributions receive preference	Craig Belle (707) 882-2150
Natural Resources Conservation Service	Environmental Quality Incentive Program (EQIP)	Provides technical, financial, and educational assistance for agricultural and timber producers to address significant natural resource needs and objectives, including erosion control, stream habitat protection and enhancement	Agricultural producers	25%	Tom Schott (707) 468-9223
USFS/CDF California Forest Stewardship Coordinating Council	Forest Legacy Program	Program seeks to identify and protect environmentally important forestland threatened by present or future conversion to non-forest uses. Program accepts donated conservation easements and pays project costs for conservation easements.	Owners of working forest lands, including oak woodlands	25%	Jim Geiger (916) 653-8286 or 1-800-738-TREE

and suited to the growing site; and decreasing water use through using new instrument technologies to measure the water needs of the vines.

SALMON TROLLERS MARKETING ASSOCIATION

The Salmon Trollers Marketing Association has been a participant in the preparation of the Navarro Watershed Restoration Plan. The Association may become involved in restoration activities including monitoring of stream conditions and fish population and distribution; and through design and implementation of site-specific restoration projects. The Association conducts assessments of fish population and distribution using spawner surveys and outmigrant trapping, either independently or in cooperation with the Department of Fish and Game.

OTHER ORGANIZATIONS

Several other groups that have participated in drafting this Plan may be involved in its implementation. These include the Anderson Valley Grange, the Cattlemen's Association, the Mendocino County Farm Bureau, and the Mendocino County Woolgrowers. These groups are made up primarily of landowners engaged in agricultural enterprises. The groups may be involved in Plan implementation through information gathering and dissemination to their members; sponsorship of workshops; and through representation on future watershed coordinating groups.

9.5 INVOLVEMENT OF GOVERNMENT AGENCIES IN PLAN IMPLEMENTATION

Several government agencies may be directly or indirectly involved in implementation of the Plan. These include the following:

MENDOCINO COUNTY WATER AGENCY

The Mendocino County Water Agency (MCWA) plans to continue monitoring of stream conditions, including temperature, turbidity, changes in stream bed elevation, and flow, in order to continue to develop more detailed baseline data and to measure changes in stream conditions over time. The MCWA will continue to collect data using its own staff, and to coordinate volunteer monitoring efforts. If there is community interest in doing so, the MCWA may also apply for a Section 319(h) water quality improvement grant (administered by the SWRCB).

CALIFORNIA STATE COASTAL CONSERVANCY

The California State Coastal Conservancy (CSCC) expects to fund and oversee implementation of high-priority restoration projects identified in the Plan. The focus of CSCC efforts will be on restoration of fish habitat through cooperative projects with interested landowners.

CALIFORNIA DEPARTMENT OF FISH AND GAME

California Department of Fish and Game (CDFG) is expected to continue to support efforts to restore the Navarro's salmon and steelhead fishery. CDFG may assist in Plan implementation in four ways: CDFG staff direct Americorps/CCC crews who conduct stream habitat typing, as well as in-stream and riparian restoration. CDFG conducts these efforts on private landholdings. CDFG prefers to work on large landholdings, or where there is the ability to organize contiguous smaller land owners. It is anticipated that this program will execute much of the in-stream habitat restoration work recommended in the Plan, including development of pools, increasing cover elements, and implementing streambank stability projects. CDFG's Wildlife Conservation Board may be a source of funding through the Riparian Habitat Conservation Program. This program is particularly geared to large riparian restoration and protection projects. CDFG's Fishery Restoration Grants program funds private and public projects directed at salmon and steelhead recovery, including in-stream, riparian, and up-slope projects, as well as watershed planning efforts and education. CDFG district biologists also perform studies on fish populations, distribution, and habitat conditions.

NORTH COAST REGIONAL WATER QUALITY CONTROL BOARD (NCRWQCB)

The NCRWQCB is expected to build on the results of this Plan for implementation of Total Maximum Daily Load (TMDL) limits for sediment and temperature in the Navarro (see introduction to Section 6.0). The NCRWQCB is expected to work with landowners or landowner groups to set numerical objectives and performance standards. The NCRWQCB may also perform or coordinate stream monitoring to measure progress toward achievement of TMDLs.

STATE WATER RESOURCES CONTROL BOARD (SWRCB)

The SWRCB administers federal EPA clean water grant funds, included the 205(j) grant that partially funded this project. The SWRCB also administers 319(h) grants, which are given for implementation of water quality improvement plans. The SWRCB is also the government agency that controls allocation of surface water resources. This plan includes recommendations for water conservation practices, but does not carry the authority of government regulation. Because of the increasing demand for scarce water resources in the Navarro Watershed, the SWRCB is expected to play an increasingly active role in regulating surface water diversions.

MENDOCINO COUNTY RESOURCE CONSERVATION DISTRICT/U.S.D.A NATURAL RESOURCES CONSERVATION SERVICE (RCD/NRCS)

The RCD/NRCS works with interested landowners and groups to help improve land management practices, conserve natural resources, and restore degraded habitat. The RCD/NRCS is particularly interested in restoring Mendocino County's salmonid fisheries. The RCD/NRCS is expected to be heavily involved in restoration activities, by assisting interested landowners and organizations in voluntary efforts to protect land and water resources and productivity. The RCD/NRCS administers several cost share programs to assist landowners with preparing and implementing resource conservation plans for their properties, and may also serve as the recipient and administrator for restoration grants from other agencies. The District also sometimes sponsors private contractor's proposals for funding from government agencies.

NATIONAL MARINE FISHERIES SERVICE (NMFS)

As implementing agency for salmon and steelhead Endangered Species Act listings, NMFS has broad oversight authority for regulating land use to protect these species and ensure their recovery. While NMFS is not expected to be actively involved in implementing this Plan, those who are involved in its implementation will need to refer to NMFS for guidance and approval of their actions.

CALIFORNIA DEPARTMENT OF TRANSPORTATION (CALTRANS)

CalTrans is responsible for upkeep and maintenance of state highways, including routes 128 and 253, which pass through the Navarro Watershed. CalTrans is expected to become involved in implementation by surveying roads to identify erosion problems associated with road drainage, and to identify barriers to fish migration associated with culverts. CalTrans will then prioritize these problems, and develop and implement appropriate treatments to mitigate them. CalTrans may seek the assistance of the NCRWQCB, CDFG, RCD/NRCS, watershed groups, and individual landowners in their assessment and prioritization of road-related fishery and water quality problems.

UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION (UCCE)

UCCE is expected to be involved in Plan implementation through dissemination of information on land management practices, and through organization of grassroots efforts to manage resources collectively. Among its other activities, UCCE has recently co-sponsored a series of short courses on water quality planning for ranchers. The other sponsors of the course are the Mendocino Farm Bureau and the Natural Resources Conservation Service. This course grew out of a provision in the California Rangeland Water Quality Management Plan, which was adopted by the State Water Resources Control Board in July, 1995, for a voluntary and cooperative approach to complying with the requirements of the Clean Water Act and Coastal Zone Management Act. The course provides tools for landowners to comply with the Total Maximum Daily Load standards for protection of water quality in impaired water bodies (see introduction to Section 6.0). Participants develop maps of their ranches, complete a water quality assessment of their ranch, develop a draft plan, develop a monitoring program for their ranch, and complete a Letter of Intent. They learn about grazing effects on water quality, how to identify water quality problems and how to fix them as they develop a plan for their ranch.

9.6 FUNDING SOURCES

Several sources may be available for funding restoration projects. Table 9-1 lists likely sources of funds. The table is divided into programs that fund large-scale, watershed-wide or subbasin-wide projects, and those that fund efforts of individual landowners or small groups of landowners. Many of the programs listed below were previously mentioned in relation to the agencies and groups expected to be involved in Plan implementation. Similarly, it is most likely that funds for implementation will come from a number of public and private sources to support a variety of restoration and conservation programs.

9.7 PERMITS FOR PLAN IMPLEMENTATION

Depending on their nature, individual restoration projects may require one or more permits from regulatory authorities. Permits from local, state, and federal agencies are described in section 2 of Section 6.0. Table 9-2 indicates which permits may be required for implementation of the range of restoration projects recommended in the Plan. Project scale and location are important in determining whether a permit is required. Anyone planning a restoration project should consult with the agencies indicated in the table to determine if a permit is required.

9.8 MONITORING

Monitoring is essential to provide a basis for evaluation of restoration activities undertaken to implement the Plan. Implementation of the Plan should include monitoring of both water quality and the fishery.

WATER QUALITY

Water Quality monitoring will be continued by the Mendocino County Water Agency. Additional monitoring may be performed by the North Coast Regional Water Quality Control Board, and by private individuals and groups. Successful restoration of the Navarro will result in lower summer stream temperatures, less sediment carried by the River and its tributaries, and higher, more consistent summer flows. Water quality monitoring will include:

- Continued monitoring of winter and summer stream turbidity and electrical conductivity, as indicators of sediment load;
- Future evaluation of stream widths using air photos, and cross sections using field surveys, to determine changes in bed form and infer changes in sediment load;
- Continued monitoring of summer stream temperatures using continuous recording devices;
- Continued monitoring of summer flows in major tributaries.

Table 9-2. Permits Possibly Required for Restoration Projects.

	County			State		Federal		Notes
Type of Restoration Project	**Coastal Develop-ment Permit***	**Floodplain Develop-ment Permit**	**Grading Permit**	**CDFG Sect. 1603 Agree-ment**	**Environ-mental Quality Act (CEQA)**	**NMFS Incidental Take Permit****	**Army Corps of Engineers Sect. 404**	
Upslope								
Road-related erosion control			X	X		X		Grading permit only required for major road work; other permits only if involves stream crossing
Non-road related erosion control				X		X		Permits only required if involves in-stream or near-stream work
Riparian								
Exclusionary fencing	X							
Revegetation								
Invasive Species Removal	X			X				Requires 1603 permit only if within stream channel
In-Stream								
Streambank Stabilization	X	X	X	X	X	X	X	Permit requirements depend on scale and location of project
Habitat structures	X	X	X	X	X	X	X	Permit requirements depend on scale and location of project
Fish passage structures	X	X	X	X	X	X	X	Permit requirements depend on scale and location of project

*Coastal Development Permit only required within the Coastal Zone.
**Incidental Take Permit only required in habitat occupied by threatened or endangered species.

FISHERY

The ultimate mark of successful implementation of the Plan will be a return of healthy and abundant steelhead and coho salmon runs in the Navarro. California Department of Fish and Game regularly monitors summer juvenile presence/absence, and occasionally surveys juvenile or adult populations. There is sufficient information on the current state of the fishery from studies performed by CDFG, National Marine Fisheries Service, and this project to set a general baseline against which future changes may be measured. Monitoring of changes in the fishery should be built into individual restoration projects, such as restoration of a particular stream reach or subbasin, and should also be conducted periodically on a watershed-wide basis. We anticipate that CDFG and NMFS, along with private parties, will perform monitoring of the fishery.

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APPENDIX A

SEDIMENT PRODUCTION AND CHANNEL CONDITIONS IN THE NAVARRO RIVER WATERSHED

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A.0
SEDIMENT PRODUCTION AND CHANNEL CONDITIONS IN THE NAVARRO RIVER WATERSHED

A.1 INTRODUCTION

This order-of-magnitude sediment budget was prepared to quantify and determine the distribution of significant sources of sediment production to stream channels in the 315 mi^2 Navarro River watershed. The sediment budget was developed from field reconnaissance and measurements made during the spring and summer of 1996. Office analysis involved detailed aerial photographic interpretation and review of scientific literature to identify sediment production rates from watersheds that are similar to the Navarro watershed. The results of the sediment budget provide a context for prioritizing erosion control measures, and in conjunction with other studies to characterize fish habitat and channel conditions, provide a context for identification of appropriate watershed restoration efforts. The primary goal of the watershed restoration planning is to restore and enhance the Navarro's anadromous fishery and to improve water quality.

Until recently, the preparation of most sediment budgets required a long-term monitoring effort with extensive field inventory, sampling, and data analysis. The goal of the traditional sediment budget was to describe and quantify geomorphic processes, as well as rates of sediment production, transport, and storage. In the Navarro River watershed we used the new "rapid" approach to the preparation of a sediment budget, as described by Reid and Dunne (1996). The rapid sediment budget, as the name implies, is carried out over a short time frame, utilizing available information, and may include only a small amount of fieldwork.

Rapid sediment budget analyses consists of four primary components: (1) preliminary field reconnaissance to identify the geomorphic processes that deliver sediment to stream channels, (2) estimation of sediment production rates for each of the significant geomorphic processes identified, (3) quantification of stored sediment in channels and (4) an estimation of the transport capacity of the fluvial system. Geomorphic processes and rates of sediment production are observed or measured in the field at representative sampling areas. The sediment production rates are used to guide development of the sediment budget and the selection of published rates for purposes of comparison, or to be utilized in analytical models. Information on rates and processes are extrapolated to the larger watershed area based upon a regional analysis that stratifies the basin into areas of similar characteristics with respect to geology, vegetation and land-use patterns that influence rates of sediment production.

For the Navarro sediment budget, a preliminary field reconnaissance was conducted during the spring of 1996, with additional field work and sampling carried out during the summer of 1996. A sediment routing diagram was prepared to describe the mechanisms by which sediment moves from hillslopes, valleys, and streambanks into stream channels.

We observed that erosional processes and rates of erosion vary dramatically across different geological terranes (Figure A-1).

In coherent and semi-coherent Coastal Belt (Figure A-2), road-related erosion, debris slides, debris flows, stream-side landsliding and deep-seated landsliding are the dominant sediment production mechanisms. In the Melange terrane (Figure A-3), gullying on hillsides, bank erosion, and stream-side landsliding are the dominant sediment producers. Along the alluvial flats, bank erosion is the dominant process. On the routing diagrams, sediment storage elements are depicted as large rectangles, while erosional and transport processes are shown as rounded-rectangles. The lines between boxes show the processes and pathways by which sediments move from one storage element to another, until they ultimately reach the streambed. These sediment production mechanisms are described in detail in Section 2, *Non-Road Related Sources of Sediment Production,* of this report.

Road related erosion was recognized as a dominant sediment producer in the coherent and semi-coherent Coastal Belt terranes, but not in the melange or on the alluvial flats. This is partly due to the much higher densities of roads in the forested Coastal Belt. Road-related sediment production mechanisms can be treated by watershed restoration efforts, and are therefore a primary focus of our attention. Road-related erosion has been the topic of numerous scientific research efforts (Reid and Dunne 1984, McCashion and Rice 1983, Best *et al.* 1995, LaHusen 1984, Reid *et al.* 1981, Reid 1981) because of the many ways in which roads alter natural geomorphic processes (Figure A-4). Two analytical models characterizing road-related sediment production patterns in the Navarro watershed are discussed in section 3 of this report.

Section 4, *Channel Studies*, describes sediment and non-sediment related impacts to salmonid habitat and discusses the disposition of sediments that are delivered to stream channels. In Section 4.1, *Channel Sediment Routing,* how sediment input to the channels is accommodated is characterized. In Section 4.2, *Bedload Yield*, we estimate the bedload transport capacity of the mainstem Navarro River near the mouth. Section 4.3, *Channel Sediment Storage,* describes the volume, distribution, and recent historical patterns of sediments stored in the channel of the major tributaries and mainstem Navarro River. We also discuss recent historical changes in channel width. Section 4.4, *Channel Conditions*, discusses channel morphology, pool and bank forming factors, and changes in channel width.

Sediment production rates presented in this report are estimated average annual rates pertaining to the combined effects of present-day land-use (1980's and 1990's) and physical attributes of the basin. Based upon observations made during field assessments for this study, present-day rates of sediment production (1980's-1990's) are considerably lower than recent historical rates (i.e., the 1950's-1970's). Considering that much of the excess sediment production to channels during the 1950's through 1970's, appears to have been transferred through the Navarro River basin (see Section 4), and because

Figure A-1. Erosional Terrain Units.

Figure A-2. Sediment Routing Flow Chart for Coherent Coastal Belt.

Figure A-3. Sediment Routing Flow Chart for Melange.

Figure A-4. Road-related Sediment Production Flow Chart.

restoration priorities need to address what is happening today and expected into the future, an accounting of present-day rates and processes is considered much more relevant than recent historical conditions.

With the exception of roads and bank erosion processes, most substantial sediment production sources to channels in the Navarro River basin are delivered episodically during large storms. Therefore when interpreting average annual sediment production rates, it is important to remember that inter-annual variation in sediment production rates is extreme; particularly when comparing wet and dry years.

This Technical Appendix describes the purpose, methods, and data used to quantify sediment production and to characterize channel conditions. The results of each study are also provided. A discussion of the results and their implications for restoration planning have been separately provided under Chapter 3, *Sediment Production and Channel Conditions.*

A.2 NON-ROAD-RELATED SOURCES OF SEDIMENT PRODUCTION

A.2.1 INTRODUCTION

Although erosion can occur on hillslopes by a variety of processes, only a few processes actually deliver sediment to channels. Those processes are referred to as sediment production. In the Navarro River basin, substantial sources of non-road-related sediment production to channels can be grouped into four major categories:

1. gullies occurring on grass-covered hillslopes underlain by melange and Coastal Belt bedrock geology units (grassland gullies);

2. bank erosion and shallow landslides (originating in hillslope swales, which include debris flows and debris slides) to smaller first- and second-order stream channels;

3. stream-side sources (which include various shallow landslide and bank erosion processes) adjacent to large streams; and

4. rapid, deep-seated, rotational and/or translational landslides (for example, the Floodgate landslide).

We performed field reconnaissance and measurement surveys, interpreted sequential aerial photographs, and reviewed published data regarding measured sediment production rates for similar basins, in order to estimate rates of sediment production from grassland gullies, stream-side sources (shallow landsliding and bank erosion on larger streams), bank erosion (small streams), shallow landslides occurring in hillslope swales, and deep-seated landslides in the Navarro River basin. Distribution and rates, by major sediment production category, vary in relation to geology, vegetation, topography, and land-use activities. We further stratified sediment production rates based upon stream-order[1] because sediment production processes and rates differ somewhat between headwaters (low-order) and high-order trunk streams.

A.2.2 Summary

Estimated contributions from non-road-related sediment production sources are presented in Table A-1 for various sub-basin types defined by a combination of geology and vegetation cover. The sediment budget illustrates that non-road-related sediment production rates are lowest in forested Coastal Belt terrain, followed by grass-covered Coastal Belt. Sediment production rates are considerably higher in the Valley Fill unit, and still higher in the Melange unit. Conversely, road-related sediment production rates (presented in Section 3) are highest in an absolute and proportional sense in the forested Coastal Belt terrain, and much lower in the grass-covered portions of the watershed. This result points to the utility and potential benefits of comprehensive road erosion control and prevention programs in forested sub-basins.

We performed separate and independent analyses of road- and non-road-related sediment production. In our analysis of non-road-related sediment production, we did not attempt to quantify the proportional influences of various land-use activities (e.g., logging, grazing, agriculture) on overall sediment production rates. Based upon field observations, historical descriptions of the Navarro watershed, and review of other sediment budget studies, we conclude however, that land-use activities have undoubtedly increased the incidence of stream-side sediment production, shallow landsliding in hillslope swales, grassland gullying, and deep-seated landsliding in the basin. For example, intensive, clear-cut logging and road building occurring in the 1940's through 1960's, is associated with a dramatic increase in the frequency of shallow stream-side landslides in the basin. Slow healing of these landslide scars, and recurrent activity is a somewhat persistent legacy of the historical era.

The combination of shallow landsliding within first- and second-order basins, and stream-side erosion processes occurring in higher order streams comprises about 78 percent of all (non-road related) sediment production in forested sub-basins within the Coastal Belt geology (see Table A-1). Given the widespread occurrence of these features; their direct proximity to stream channels; and their common association with very steep inner gorge slopes, undertaking stream-side restoration treatments may not be economically or technically feasible. Perhaps the best way to reduce land-use related

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[1] Stream-order is a hierarchical classification based upon converging branches of a stream system. For example, a headwater channel, is called a first-order stream. At the confluence of two or more first-order streams, a second-order stream begins. At the convergence of two or more second order streams, a third-order stream begins, and so on. We defined stream-order based upon mapping of topographic crenulations apparent on 1:24,000 scale topographic maps. Crenulation mapping was performed accordingly to U.S. Forest Service methods.

Table A-1. Sediment Production by Geology-Vegetation Units (sources other than roads).

Geology-Vegetation (General Locations)	Drainage Area (mi^2)	Stream Order	Source	Sediment Production[2] (tons/yr)	(tons/mi^2/yr)	% of Total
Melange-Grassland	37.5	1 and 2	Bank Erosion	5,482	146	3.7%
		1 and 2	Shallow Slides	10,091	269	6.9%
(Anderson Ck basin,		3 thru 6	Stream-Side	79,090	2,111	53.2%
upper Rancheria Ck)		na	Gullies	54,032	1,442	36.3%
			subtotal	**148,700**	**4,000**	**100.%**
Coastal-Belt, forested	211.5	1 and 2	Bank Erosion	9,362	44	7.4%
		1 and 2	Shallow Slides	31,835	150	25.1%
(North Fk. Navarro,		3 thru 8	Stream-Side	58,016	274	45.7%
lower Rancheria Ck, Mainstem Navarro)			Deep-seated Landslides	27,642	131	21.8%
			subtotal	**126,900**	**600**	**100.%**
Coastal-Belt, grass/scrub	53.6	1 and 2	Bank Erosion	3,763	70	6.4%
		1 and 2	Shallow Slides	14,000	261	23.9%
(North Fk. Navarro,		3 thru 6	Stream-Side	17,052	318	29.1%
Rancheria Ck, Indian Ck, Mainstem Navarro		na	Gullies	23,723	443	40.5%
			subtotal	**58,500**	**1,100**	**100.%**
Valley Fill	13.2	1 thru 4	Stream-Side	15,500	1,200	53.3%
(Anderson Valley, Navarro River		5 thru 7	Stream-Side	14,571	1,116	46.7%
			subtotal	**30,100**	**2,300**	**100.%**
NAVARRO RIVER WATERSHED				**365,500**	**1,200**	**100%**

na = not applicable. Gullies are not considered stream channels and therefore stream order does not apply.

[2] Sediment production subtotals are rounded to the nearest one-hundred tons in all tables.

increases in stream-side sediment production or shallow landslides would be to reduce logging within sensitive riparian corridors and hillslope features.

Historical failures of deep-seated landslides, although infrequent spatially and temporally in the Navarro River watershed, result in substantial point sources of sediment production to channels when they do occur. Based upon numerous interviews, review of published landslide mapping, field reconnaissance, and interpretation of time sequential aerial photographs of the basin, we identified five large, deep-seated landslides which failed within the period of photographic record (1952 to 1992). All of the deep-seated landslides that we identified occur in deeply incised inner gorge features where forested slopes are underlain by Coastal Belt bedrock. Each of the features that we found, except for the Floodgate landslide, occur on the mainstem of lower Rancheria Creek or on two of its tributaries (Bear Trap Creek and Ham Canyon). Estimated average annual sediment production from the deep-seated landslides represents about 22 percent of the sediment budget (non-road related sources) in forested Coastal Belt basins. In a few cases, major haul roads on some deep-seated slides may have contributed to failure of the slides. Where major haul roads have contributed to failure of deep-seated landslides, it would be prudent to recommend that the existing haul roads be relocated.

In grass-covered slopes underlain by Coastal Belt bedrock, hillslope gullies comprise about 36 percent of sediment production (see Table A-1). Although gullies can naturally develop in Coastal Belt terrane, the magnitude and extent of their sediment contribution can be greatly accelerated due to land-uses such as ranching, vineyards, orchards, and road development. Considering their quantitative importance in both the Coastal Belt and melange terrane units and given that many are accessible by roads, remedial treatment of gullies should be given a high priority.

The Anderson Valley comprises about 90 percent of the total area of valley fills in the Navarro River basin. The results of stream-side sediment production surveys and aerial photo interpretations indicate that unit sediment production from bank erosion in valley fills is extremely high, about 3,000 tons per square mile per year or about four times greater than total unit sediment production from forested sub-basins in the Navarro River basin. An estimated 50 percent of total valley fill bank erosion occurs on major trunk streams located in the Anderson Valley (Anderson Creek, Robinson Creek, and unconfined reaches of the Navarro River within the Anderson Valley). The remainder occurs along the banks of lower-order tributaries and gullies in the valley fills.

Anderson Creek in the Anderson Valley appears to be actively aggrading with coarse sediments and widening (see Section 4.2 *Channel Storage Analysis*). Due to the active aggradation and widening, stream bank stabilization and in-channel treatments to restore fish habitat conditions would generally prove to be ineffective at this time and are not recommended. Rather, upland erosion control treatments should be considered a priority to reduce sediment delivery, and thereby minimize the resulting aggradation and channel widening which is occurring. For other channels we observed in the valley fills, substantial channel aggradation or incision is not apparent. Streambank stabilization treatments in these channels would have a greater likelihood of success than in Anderson Creek in the Anderson Valley.

Estimated contributions from each sediment production source (other than roads) are presented for the five major Navarro River drainage basins in Tables A-2 through A-6. Table A-7 summarizes sediment production for the five basins. The Anderson Creek drainage has the highest sediment production rate (2,000 tons/mi^2/yr), primarily due to streamside erosion (in higher order channels) and gullies in the melange terrane (see Table A-2 and Table A-7).

The lowest sediment production rate, 500 tons/mi^2/yr is found in the North Fork Navarro River basin (see Table A-3 and Table A-7). Most sediment production within the North Fork Navarro, approximately 78%, is derived from stream-side erosion processes and shallow landslides in the forested Coastal Belt terrane.

Sediment production rates in the Rancheria Creek (1,500 tons/mi^2/yr Table A-7), Mainstem Navarro River (1,000 tons/mi^2/yr Table A-7), and Indian Creek basins (900/tons/mi^2/yr, Table A-7), are intermediate between the Anderson Creek and North Fork Navarro basins. Over half (approximately 58%) of sediment production in the Indian Creek drainage is due to erosion in the grass/scrub Coastal Belt terrane (see Table A-4). In the Rancheria Creek basin most sediment production, over 50%, is due to streamside and gully erosion in the melange terrane. The Rancheria Creek basin is responsible for 37% of all non-road related sediment production in the watershed. In the mainstem Navarro River drainage most sediment production, about 45%, is due to deep-seated landslides and streamside sources in the forested Coastal Belt. Average annual non road-related sediment production over the Navarro watershed is 365,500 tons/yr, or 1,200 tons/mi^2/yr (Table A-7).

The remainder of Section 2 presents our analysis of each major non road-related sediment source.

A.2.3 Sediment Production From Grassland Gullies

A.2.3.1 Overview

In the Navarro River watershed, gullies on grass-covered slopes are a substantial source of sediment production. Based on review of geologic data and field observations, we determined that gullies on grass-covered slopes are underlain by two bedrock geology units of the Franciscan Assemblage: 1) a semi-coherent Coastal Belt unit that is rich in mudstones and/or tectonically controlled (e.g., has a high intensity of faulting in sandstone rich blocks) (O'Laughlin, personal communication); and 2) a melange unit which constitutes a deeply ground-up equivalent of the Coastal Belt rocks, in combination with lesser amounts of other rock types.

Table A-2. Sediment Production in the Anderson Creek Basin (sources other than road).

Geology-Vegetation (General Locations)	Drainage Area (mi^2)	Stream Order	Source	Sediment Production (tons/yr)	(tons/mi^2/yr)	% of Total
Melange-Grassland	16.5	1 and 2	bank erosion	2,408	146	2.6
		1 and 2	shallow slides	4,433	269	4.8
		3 thru 6	streamside	34,743	2,111	37.9
		na	gullies	23,736	1,442	25.9
			subtotal	**65,300**	**4,000**	**71**
Coastal-Belt, forested	20.7	1 and 2	bank erosion	917	44	1.0
		1 and 2	shallow slides	3,117	150	3.4
		3 thru 8	stream-side	5,680	274	6.2
			subtotal	**9,700**	**500**	**11**
Coastal-Belt, grass/scrub	3.5	1 and 2	bank erosion	246	70	0.3
			shallow slides	914	261	1.0
		3 thru 6	streamside	1,113	318	1.2
		na	gullies	1,549	443	1.7
			subtotal	**3,800**	**1,100**	**4**
Valley Fill	5.4	1 thru 4	streamside	6,819	1,272	7.4
		5 thru 7	streamside	5,980	1,116	6.5
			subtotal	**12,800**	**2,400**	**14**
ANDERSON CREEK	**46.0**			**91,600**	**2,000**	**100%**

[a]All subtotals are rounded to the nearest one-hundred tons.

Table A-3. Sediment Production in the North Fork Navarro Basin (sources other than road).

Geology-Vegetation (General Locations)	Drainage Area (mi^2)	Stream Order	Source	Sediment Production[a] (tons/yr)	(tons/mi^2/yr)	% of Total
Coastal-Belt, forested	69.7	1 and 2	bank erosion	3,083	44	8.2
		1 and 2	shallow slides	10,482	150	28.0
		3 thru 8	stream-side	19,103	274	50.9
			subtotal	**32,700**	**500**	87
Coastal-Belt, grass/scrub	4.2	1 and 2	bank erosion	295	70	0.8
		1 and 2	shallow slides	1,097	261	2.9
		3 thru 6	streamside	1,336	318	3.6
		na	gullies	1,859	443	5.0
			subtotal	**4,600**	**1,100**	**12**
Valley Fill	0.1	1 thru 4	streamside	127	1,272	0.3
		5 thru 7	streamside	112	1,116	0.3
			subtotal	**200**	**2,400**	**1**
NORTH FORK NAVARRO 74.0				**37,500**	**500**	**100%**

[a]All subtotals are rounded to the nearest one-hundred tons.

Table A-4. Sediment Production in the Indian Creek Basin (sources other than road).

Geology-Vegetation (General Locations)	Drainage Area (mi^2)	Stream Order	Source	Sediment Production[a] (tons/yr)	Sediment Production[a] (tons/mi^2/yr)	% of Total
Melange-Grassland	1.4	1 and 2	bank erosion	208	146	0.6
		1 and 2	shallow slides	382	269	1.0
		3 thru 6	streamside	2,997	2,111	8.1
		na	gullies	2,048	1,442	5.5
			subtotal	**5,600**	**4,000**	**15**
Coastal-Belt, forested	17.5	1 and 2	bank erosion	775	44	2.1
		1 and 2	shallow slides	2,637	150	7.1
		3 thru 8	stream-side	4,805	274	13.0
			subtotal	**8,200**	**500**	**22**
Coastal-Belt, grass/scrub	19.6	1 and 2	bank erosion	1,376	70	3.7
	6	1 and 2	shallow slides	5,119	261	13.9
		3 thru 6	streamside	6,236	318	16.9
		na	gullies	8,675	443	23.5
			subtotal	**21,400**	**1,100**	**58**
Valley Fill	0.7	1 thru 4	streamside	891	1,272	2.4
		5 thru 7	streamside	781	1,116	2.1
			subtotal	**1,700**	**2,400**	**5**
INDIAN CREEK	**39.2**			**36,900**	**900**	**100%**

[a]All subtotals are rounded to the nearest one-hundred tons

Table A-5. Sediment Production in the Rancheria Creek Basin (sources other than road).

Geology-Vegetation (General Locations)	Drainage Area (mi^2)	Stream Order	Source	Sediment Production[a] (tons/yr)	(tons/mi^2/yr)	% of Total
Melange-Grassland	19.6	1 and 2	bank erosion	2,866	146	2.2
		1 and 2	shallow slides	5,276	269	4.0
		3 thru 6	streamside	41,350	2,111	31.6
		na	gullies	28,249	1,442	21.6
			subtotal	**77,700**	**4,000**	**57**
Coastal-Belt, forested	56.5	1 and 2	bank erosion	2,500	44	1.9
		1 and 2	shallow slides	8,502	150	6.5
		3 thru 8	stream-side	15,493	274	11.8
			deep 1s	11,907	211	9.1
			subtotal	**38,400**	**700**	**28**
Coastal-Belt, grass/scrub	17.4	1 and 2	bank erosion	1,222	70	0.9
		1 and 2	shallow slides	4,545	261	3.5
		3 thru 6	streamside	5,536	318	4.2
		na	gullies	7,701	443	5.9
			subtotal	**19,000**	**1,100**	**14**
Valley Fill	0.1	1 thru 4	streamside	178	1,272	0.1
		5 thru 7	streamside	156	1,116	0.1
			subtotal	**300**	**2,400**	**.002**
RANCHERIA CREEK	**93.6**			**135,400**	**1,400**	**100**

[a]All subtotals are rounded to the nearest one-hundred tons

Table A-6. Sediment Production in the Mainstem Navarro Basin (sources other than road).

Geology-Vegetation (General Locations)	Drainage Area (mi^2)	Stream Order	Source	Sediment Production[a] (tons/yr)	(tons/mi^2/yr)	% of Total
Coastal-Belt, forested	47.2	1 and 2	bank erosion	2,087	44	3.9
		1 and 2	shallow slides	7,097	150	11.1
		3 thru 8	stream-side	12,934	274	20.2
			deep 1s	15,736	334	24.6
			subtotal	**37,900**	**800**	**59**
Coastal-Belt, grass/scrub	8.9	1 and 2	bank erosion	625	70	1.0
		1 and 2	shallow slides	2,325	261	3.6
		3 thru 6	streamside	2,831	318	4.4
		na	gullies	3,939	443	6.2
			subtotal	**9,000**	**1,100**	**15**
Valley Fill	6.9	1 thru 4	streamside	8,714	1,272	13.6
		5 thru 7	streamside	7,642	1,116	12.0
			subtotal	**16,400**	**2,400**	**26**
MAINSTEM NAVARRO	**62.9**			**63,900**	**1,000**	**100%**

[a]All subtotals are rounded to the nearest one-hundred tons

Table A-7. Sediment Production by Basin (sources other than roads).

	Drainage Area (mi^2)	**Sediment Production** (tons/yr)	(tons/mi^2/yr)	% of Total Production in Navarro Watershed
Anderson Creek	46	91,700	2,000	25%
Indian Creek	39	36,900	900	10%
Mainstem Navarro	63	63,900	1,000	17%
North Fork Navarro	74	37,500	500	10%
Rancheria Creek	94	135,500	1,500	37%
Navarro Watershed	**315**	**365,500**	**1,200**	**100%**

Gullies are responsible for approximately 17% of all non-road related sediment production within the watershed. Within the melange-grassland terrane, gullies account for 36% of sediment production (55,000 tons/yr.) and within the Coastal-Belt grass-scrub terrane, gullies account for 40% (24,000 tons/yr.) of sediment production.

A.2.3.2 Methods and Results

We reviewed physical data describing factors known to influence sediment production rates due to gullying in the Navarro River watershed including: a) bedrock geology and uplift rate; b) soil attributes, associated vegetation, and hillslope gradients; c) average annual precipitation and timing and recurrence intervals[3] of large historical floods; d) land-use history; and e) association of grassland gullies with roads, livestock grazing, and agriculture. Physical data for Navarro River watershed grass-covered slopes underlain by semi-coherent Coastal Belt are listed in Table A-8; data for slopes underlain by melange are listed in Table A-9. We then reviewed reports which describe sediment production rates for gullies on grass-covered slopes underlain by Franciscan melange (Kelsey 1980; Trihey & Associates, 1996) and/or incoherent sandstones and mudstones of the Franciscan Assemblage (Walter 1985; Best *et al.* 1995) in watersheds which have physical attributes that are similar to the Navarro. Basin attributes and measured rates of gullying at those sites are listed in Tables A-10 through A-13.

A.2.3.2.1 Gullying Rates in the Coastal Belt

Based upon a review of this literature, site conditions at Lone Tree Creek (see Table A-10) (Lehre 1982) and Redwood Creek prairies (see Table A-11) (Walter 1985) are most similar to conditions in the semi-coherent Coastal Belt in the Navarro River basin. Rates of sediment production for gullies at Lone Tree Creek is 460 tons/mi^2/yr (160 metric tons per km^2 per year) and Redwood Creek prairies[4] is 430 tons/mi^2/yr (150 metric tons per km^2 per year). Therefore, we estimate that long-term sediment production rate from grassland gullies on slopes underlain by the semi-coherent Coastal Belt (in the Navarro River basin) is about 440 tons/mi^2/yr (155 metric tons per km^2 per year).

A.2.3.2.2 Gullying Rates in the Melange

Other studies provide measured rates that are useful for estimation of sediment production from gullies on grass-covered slopes (in the Navarro River watershed) that are underlain by the melange. Best *et al.* (1995) estimate that total hillslope fluvial sediment production (rilling plus gullying and sheet erosion) in oak woodland and grasslands in Lacks Creek, a tributary of the Redwood Creek watershed, is about 1,450 tons/mi^2/yr (510 metric tons per km^2 per year) using erosion plot data measured in grass and oak

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[3] amount of time on average between flood events of comparable magnitude. For example, there is a 1-in-10 chance that a 10 year recurrence interval flood will occur in any given year.

[4] rectified to remove the influence of gullying caused by logging roads and highways that cross the Redwood Creek prairies

Table A-8. Attributes of Grass-Covered Slopes Underlain by Coastal Belt Geology: Navarro River Watershed.

Physical Attribute:	Description:
Drainage Area (mi^2)	54
Drainage Density (mi/mi^2)	12
Topography	Steep, Narrow, V-Shaped Canyons, Narrow to Gently Rounded Ridgetops, Hillslope Hollows Smooth-to-Rolling or hummocky; rapid, shallow "soil-mantle creep" erosion is common
Vegetation	Grassland, oak-woodland, savanna, and scrub
Precipitation/Storm History	49 inches mean annual precipitation 10 to 25 - year recurrence interval for storms in 1955, 1964, 1974, 1986, 1995
Soils	Shallow Loam (15") on soft sandstone/mudstone, bedrock. Shallow to Moderate depth loam (15-30") to gravelly clay loam over coherent and incoherent sandstones/mudstones
Geology	Semi-coherent coastal belt: mudstone rich and/or sandstone rich but intensively faulted. Uplift rate = 0.3 mm/yr
Land-Use History	Sheep-Cattle grazing since 1870's Ranch roads, some logging roads, and more recently residential roads Douglas fir Logging: Late 1930's thru early 1950's (peak)
Road/Gully Association	Road density is typically low; road-related gullying addressed in road sediment production study

Table A-9. Attributes of Grass-Covered Slopes Underlain by Melange Geology: Navarro River Watershed.

Physical Attribute:	**Description:**
Drainage Area (mi^2)	37
Drainage Density (mi/mi^2)	15 - (grass-covered slopes)
Topography	Smooth-to-Rolling or hummocky; rapid, shallow "soil-mantle creep" erosion is common
Vegetation	Grass and Oak-Woodland
Precipitation/Storm History	49 in. mean annual precipitation 10 to 25 - year Recurrence Interval Storms in 1955, 1964, 1974, 1986, 1995
Soils	Deep clay loam, or gravel clay loam (50-60") Severe hillslope fluvial erosion hazard under bare ground Earthflow landsliding and slumping are common
Geology	Franciscan melange with blocks of greywacke, chert, amphibolite, blue shcist, etc. Uplift rate = 0.3 mm/yr
Land-Use History	Sheep-Cattle grazing since 1870's Ranch roads, some logging roads, and some residential roads Douglas Fir Logging: Late 1930's thru early 1950's
Road/Gully Association	Road density is typically low; road-related gullying addressed in road sediment production study

Table A-10. Lone Tree Creek: Attributes of Grass-Covered Slopes Underlain by Geology Similar to Coastal Belt Terrain in Navarro Watershed.

Physical Attribute:	Description:
Drainage Area (mi^2)	.7
Drainage Density (mi/mi^2)	11.5
Topography	Gentle, rounded upland ridgecrests (5-30%), Narrow Steep Canyons (35-85%), Hillslope Hollows 35 to 50 m apart Smooth-to-rolling or hummocky terrain; rapid, shallow "soil-mantle creep" is common
Vegetation	Grassland - 50%, Shrub - 30%, Mixed hardwood forest - 20%
Precipitation/Storm History	34 inches mean annual precipitation 15 to 20 year recurrence interval storms in 1973
Soils	Thin soils outside swales (0.8m ≥ depth), Swale soils are 1.5 to 5 m deep. Texture; stony to very stony loams Bulk density of colluvial soil = 1.15-1.5 g/cm^3, Weathered bedrock = 1.45-1.9 g/cm^3, Unweathered bedrock = 2.65 g/cm^3
Geology	Intensively sheared greywacke (similar to semi-coherent Coastal Belt) Uplift rate = 0.3 mm/yr
Land-Use History	Grazing since 1850's Highway 1 crosses basin on ridge divide Parkland since 1950's
Road Gully Association	Nearly all gullies emanate from swales, as do debris slides and flows Landslides fail at colluvial bedrock contract or above at a denser clay-rich layer in the colluvium
Gully Sediment Production Rate	460 $tons/mi^2/yr$ (160 metric $tons/km^2/yr$)

Table based on data from Lehre (1982)

Table A-11. Redwood Creek Prairies: Attributes of Grass-Covered Slopes Underlain by Geology Similar to Coastal Belt Terrain in the Navarro Watershed.

Physical Attribute:	Description:
Drainage Area (mi^2)	19.7
Drainage Density (mi/mi^2)	no data
Topography	Lacks Creek Unit: sharp ridge crests, narrow v-shaped canyons Coyote Creek Unit: subdued rolling terrain, earthflows
Vegetation	Prairie grassland
Precipitation/Storm History	63 to 98 inches mean annual precipitation 10 to 25.- year recurrence interval storms in 1955, 1964, 1972, and 1975
Soils	Coyote Creek Unit (Xeralf soils): hummocky-to-smooth earthflow terrain; poorly drained Lacks Creek Unit (non-Xeralf soils): loamy, well-drained soils, stable slopes, well developed swales and channels with occasional gullies
Geology	Mostly sandstones and mudstones of incoherent Coyote Creek unit Small amount of the study area is underlain by coherent Lacks Creek unit
Land-Use History	Grazing since 1850's
Road Density /Gully Association	Very strong association between gullies logging roads and highway roads (48.7-62.8% of all gully erosion) Ranch roads = 9.4% gully erosion / "natural" = 37.2% gully erosion
Gully Sediment Production Rate[5]	430 tons/mi^2/yr (150 metric tons/km^2/yr)

Table based on data from Walter (1985)

[5] only includes proportion of gullying not related to roads - 37.2% of total.

Table A-12. Lacks Creek: Attributes of Grass-Covered Slopes Underlain by Geology Similar to Franciscan Melange.

Physical Attribute:	Description:
Drainage Area (mi^2)	0.1
Drainage Density (mi/mi^2)	no data
Topography	Hummocky-to-smooth earthflow terrain Lacks Creek Unit: sharp ridge crests, narrow v-shaped canyons Coyote Creek: subdues rolling terrain, earthflows
Vegetation	Grassland and oak woodland
Precipitation/Storm History	98 inches mean annual precipitation
Soils	no description
Geology	Incoherent sandstones and mudstones of Coyote Creek unit
Land-Use History	Grazing since 1850's Small ranch road near divide
Road/Gully Association	Not associated with roads
Gully Sediment Production Rate	total hillslope fluvial erosion (rilling, gullying, channel enlargement) 1,450 tons/mi^2/yr (510 metric tons/km^2/yr)

Table based on data from Best *et al.* (1996)

Table A-13. Willow Creek: Attributes of Grass-Covered Slopes Underlain by Franciscan Melange.

Physical Attribute:	Description:
Drainage Area (mi^2)	2.3
Drainage Density (mi/mi^2)	15
Topography	Smooth textured rolling terrain with good drainage, and rolling, smooth-to-hummocky terrain, moderate to poor drainage Widespread slow mantle creep and localized slumps
Vegetation	Grassland prairie
Precipitation/Storm History	49 inches mean annual precipitation Large storms 1955, 1964, 1982, 1986, 1995
Soils	Mostly thick loam or clay loam Shallower soils on Great Valley sequence bedrock
Geology	Franciscan melange (67%) Great Valley Sequence conglomerate (33%) Uplift rate = 0.3 mm/yr
Land-Use History	Sheep-cattle grazing since 1860's Ranch Roads
Road Density /Gully Association	Low road density/ranch roads and a short segment of "rocked" county road in grasslands Most grassland gullies are not associated with roads Most gullying during large storms in 1982, 1986, and 1995
Gully Sediment Production Rate	1,400 tons/mi^2/yr (490 tons/km^2/yr)

Table based on data from Trihey & Associates, Inc. (1996)

woodland slopes (see Table A-12). The bedrock unit which underlies Lacks Creek is the incoherent sandstone and mudstone unit of Coyote Creek. On the Coyote Creek unit, topography is gentle with rolling-to-hummocky slopes and poorly incised drainages. Typical erosional processes in this terrain are earthflows, gullies, and debris slides along streamside inner gorges. These topographic attributes and sediment production processes closely resemble those found in the Franciscan melange in the Navarro River watershed. Therefore, the fluvial erosion from the Lacks Creek plot in Redwood Creek basin is representative of that which occurs in the melange terrane of the Navarro watershed.

Trihey & Associates (1996) estimated average annual sediment production from gullies on grass-covered slopes in Willow Creek (see Table A-13), a small basin in the Russian River Watershed of western Sonoma County. Willow Creek is underlain primarily by Franciscan melange where sediment production rates due to gullying were found to be approximately 1,400 tons/mi^2/yr (490 metric tons per km^2 per year). This value is nearly identical to the estimate for Lacks Creek.

Sediment production rates for grassland gullies in Willow Creek and Lacks Creek, however, are quite a bit lower than estimated rates of sediment production for grass-covered melange slopes in the Van Duzen River basin (Kelsey 1980). Kelsey describes variation in topography on melange slopes to define five physiographic slope types which correspond to variable rates of hillslope fluvial sediment production. Slope types Ia - “smooth-textured rolling terrain with good drainage”, and Ib - “rolling, smooth-to-hummocky terrain, moderate to poor drainage, widespread slow mantle creep, (and) localized slumps” are common within the Navarro River basin melange. Kelsey (1980) estimated that hillslope fluvial sediment production for slope type Ia and Ib is about 4,000 tons/mi^2/yr and 14,000 tons/mi^2/yr (1400 and 4900 metric tons per km^2 per year) or about three-to-ten times higher than values estimated for Willow and Lacks creek.

Given the proximity of the Van Duzen River to the Mendocino Triple Junction, uplift rates are quite a bit higher than in the Navarro River basin (Merrits and Vincent 1987). Other factors such as grazing intensity, and recurrence interval and timing of recent large storms[6] may explain the higher gully sediment production rates in the Van Duzen River basin. Kelsey notes (pers. comm.), that the frequency of gullies and earthflows are in fact much higher in the Van Duzen River basin than in melange terrain in the Navarro River basin. Therefore measured rates from the Willow Creek and Lacks Creek basins provide the best estimate of gullying rates, approximately 1,400 tons/mi^2/yr, for grassland melange slopes in the Navarro River watershed.

[6] Kelsey, 1980, estimates that the recurrence interval of the 1964 flood in the upper Van Duzen River is 20-to-100 years

A.2.4 DEEP-SEATED LANDSLIDES

A.2.4.1 Overview

In this analysis, we estimated sediment production from "active, rapid", deep-seated landslides (hence referred to as deep-seated landslides), such as the Floodgate Landslide which failed in March of 1995. That landslide complex consists of a deep-seated rotational-translational landslide, and a very large debris flow. The distinction between deep-seated (≥ 10 feet) and shallow landslides (typically less than 5 feet) is somewhat artificial because, in reality, there is a natural continuum of landslide depths. The distinction is made however, because frequency of deep and shallow landslides, their average volumes, and sediment grain-size distributions are typically quite different. Sediment production from "active" earthflows, another type of deep-seated landslide, which occur in the melange and Coastal Belt units, is accounted for in the grassland gully and stream-side sediment production categories, since these are the actual mechanisms by which earthflow sediment is usually delivered to channels.

A.2.4.2 Methods and Results

Based upon field reconnaissance, review of landslide mapping which provides partial coverage for the Navarro River basin, and review of time-sequential aerial photographs, we formed the initial opinion that deep-seated landslides are relatively rare within the Navarro River Basin. Overall, deep-seated landslides are probably not major contributors to the sediment budget. To best determine their frequency, we performed a census to identify how common deep-seated landslides actually are within the various geologic terranes of the Navarro watershed. This census involved: a) review of published landslide mapping (Manson 1984-a,b,c,d); b) contacting individuals who are knowledgeable about recent and historical failures of deep-seated landslides; and c) review of aerial videos and photography over the Navarro River watershed taken during September of 1996 and February of 1997. Based upon review of these data, we constructed a list of known locations of recent and historical deep-seated landslide failures. We then reviewed time-sequential aerial photographs (1952, 1965, 1981, 1992) in those locations to evaluate first appearance of the landslide features, and whether or not failures have been recurrent within the photo period. Review of sequential aerial photographs led to discovery of two additional deep-seated landslides which appear to have failed during the December 1964-January 1965 storms.

All identified deep-seated failures occur in forested Coastal Belt terrain on steep inner gorge slopes. Interviews with CDMG geologists (J. Bawcom, T. Spittler, personal communication) provided data describing surface area and in a few cases depths of some recent deep-seated landslide failures. These data, in addition to published data for the Floodgate landslide (Bawcom 1996), and soil survey data for western Mendocino County (NRCS, in-press) were used to estimate volumetric contributions from each known deep-seated landslide. Using a bulk density of 1.6 metric tons per cubic meter for landslide debris, the estimated rate of sediment contributed from deep-seated landslides is approximately 130 tons/mi^2/yr (45.5 metric tons/km^2/yr) for the Navarro watershed.

Table A-14 identifies the location, type, estimated dimensions (length, width, and depth), estimated sediment delivery ratio and approximate volume of sediment production for each landslide. Although deep-seated landslides comprise only about 7.5 percent of non-road related sediment production watershed-wide, they represent about 25 percent of all non-road related sediment production in the forested Coastal Belt terrain.

A.2.5 Stream-Side Sediment Production

In this analysis, we estimated present-day rates of stream-side sediment production for a suite of erosion terrane units defined by combinations of geology, vegetation, and stream-order. Stream-side sediment production processes are organized and discussed based on stream size and the principal erosion mechanisms that deliver sediment to channels. We have divided streams into two sizes: small streams (first and second-order channels) and large streams (third and higher-order channels).

In the Navarro watershed, for both small and large streams, sediment production is due to bank erosion and shallow landsliding processes. By our definition, streamside sediment production includes sediment input to channels from bank erosion and shallow landsliding at the toes of hillslopes, and bank erosion along streamside terraces. Bank erosion processes including spalling, slumping, and dry ravel. Shallow landsliding processes include debris flows, debris slides, and rock-falls. For this investigation, we grouped together each of these discrete erosion process, to provide a composite quantitative estimate of total stream-side sediment production.

A.2.5.1 First- and Second-Order Streams: Estimates of Sediment Production

Based on field observations, we identified the following sources of sediment production from hillslopes to first- and second-order stream channels:

a) bank erosion processes; and

b) shallow landslides - debris slides and debris flows - originating in hillslope swales and/or the inner gorge.

We estimated rates of sediment production to low-order streams based upon review of published literature regarding streamside sediment production rates, and limited field reconnaissance.

A.2.5.1.1 Bank Erosion

Measuring sediment production from bank erosion along small streams (first- and second-order) is often quite difficult and time consuming. This is because small streams are often difficult to access, and factors influencing bank erosion rates along small streams - channel form and flow regime - are often quite variable within and between stream-reach and sub-basin types. Therefore, we did not measure bank erosion rates in

Table A-14. Sediment Production Estimates From Deep-seated Landslides in the Navarro River Watershed (1952-1997).

Slide Name	Type (s)	First Appearance	- - - Best Estimate - - - Length (ft)	Depth (ft)	Width (ft)	Sediment Delivery Ratio	Sediment Production Volume (yd^3)	Comments	Recurrent Activity
Lower Rancheria	debris flow	1997	700	4	315	0.85	28,000	coalescing ds below road? first appeared in 1965	1965-1997
Big Canyon-Township Gulch	debris flow plus translational/ rotational	1965				0.6	400,000	similar in size to Floodgate	
Ham Canyon	translational/ rotational	1997				0.5	28,000	equal or larger in size than Lower Rancheria	no evidence
Bear Trap	translational/ rotational	1965	500	30	250	0.5	70,000		1995?
Floodgate	1. debris flow					0.9	175,000		
	2. translational/ rotational		1,000	40	300	0.5	225,000		
						Total Volume (yd^3)	**922,000**		
						Total Mass (tons)	**1,240,000**	(1,125,000 metric tons)	
						Long Term Rate ($t/mi^2/yr$)	**130**	(45.5 metric tons/km^2/yr)	

small streams. Instead, we estimated bank erosion rates in small streams by a surrogate means which involved:

a) estimating the rate at which soil creep transports sediment down-slope to stream banks; and

b) assuming that the soil creep rate is equal to bank erosion rate over the long-term.

Similar to the approach of Deitrich and Dunne (1978) this analysis is based upon the assumption that, in small streams average channel width over the long-term, is principally controlled by climatic, and geologic (bedrock geology and structure) features, so that, substantial net widening or narrowing does not occur. Therefore, by estimating long-term rates of soil creep, we can approximate the long-term average rates of bank erosion.

Soil creep includes both biogenic and physical processes. Physical soil creep processes such as soil expansion and contraction (by wetting and drying), and plastic deformation under gravitational stress are often important in clay-rich soils. Biogenic processes, such as, treethrow in forests and animal burrowing in grasslands, may be the dominant creep mechanisms in soils that do not have a high clay content. Biogenic processes move pockets of soil down-slope as opposed to physical soil creep which moves the entire soil column to a given depth.

We reviewed published data regarding rates of soil creep and biogenic processes together with attributes of the basins where measurements were made, in order to estimate rates of soil creep and biogenic processes in the Navarro River basin. Rates of soil creep and biogenic processes measured in basins which have similar hydrologic, vegetation, and physical attributes to those found in the Navarro River basin are listed in Table A-15.

When comparing biogenic and physical soil creep rates, it is useful to express rates in terms of an equivalent down slope transfer rate (over the entire soil column to a defined depth). Because animal burrowing only occurs over a fraction of the total soil area, the down slope transfer rate listed in Table A-15 is as follows:

soil transfer downslope from animal burrowing

=

the downslope transfer rate in the burrows x their proportional occurrence.

In grassland soils that do not have a high clay content, burrowing by mammals (primarily voles and gophers) may be the dominant mechanism by which soil creep occurs (Lehre 1987). The importance of animal burrowing is probably much lower, however, in forest soils because large tree roots are extensive, and these represent major impediments to digging. In forest soils, treethrow is an important agent for downslope transfer of soil (see Table A-14). Typical rates of treethrow are ≤ 0.08 in/yr or about 1.22 $in^3/in/yr$ (assuming a depth of movement of 3.3 ft).

Table A-15. Soil Creep and Biogenic Sediment Production Rates in Basins Similar to the Navarro Watershed.

	Location	Data Source	Annual Precipitation (in)	Hillslope Gradient (ft/ft)	Total Depth of Movement (ft)	Average Rate (in/yr)	Comments
Soil Creep	Lone Tree Creek Marin County, CA	Lehre (1987)	34	0.35 - 0.85	1.3	0.3	best analog for Coastal Belt w/ grassland cover
	Knowles Creek, Oregon Coast Range	Benda and Dunne (1987)	63	0.60 - 1.00	1.6	0.7	best analog for Coastal Belt w/forest cover
	Redwood Creek Humboldt County, CA	Swanston et. al. (1996)	80	mean = 0.26	13.0	0.39 - 0.10	West-side sloped underlain by Schist
Burrowing	Lone Tree Creek Marin County, CA	Lehre (1987)	34	0.35 - 0.85	0.50	0.52[a]	
Tree Throw	Olympic Mountains Coastal Washington,	Reid (1981)			≥depth of rock	0.7	period = approx. 1900-1980?
	Central Appalachian Mountains[b]	Denny and Goodlett (1956)			≥depth of rock	0.6	
	Tatra Mountains, Poland[5]	Kotarba (1970)			≥depth of rock	< 0.08	period= approx. 1835-1970?

(a) Burrowing is estimated to occur over about 10% of the surface area of the slopes; therefore, burrowing rate is expressed in terms of an equivalent average soil creep rate (in/yr) over the entire area.
(b) Although in very different physiographic regions than the Navarro Watershed, the Central Appalachia Mountains and Tara Mountains are included here to demonstrate that rates of sediment production are very similar to that found in the Olympic Mountains, Washington.

In basins that do not have clay-rich soils, actual downslope transfer of sediment by physical soil creep is probably small in comparison to biogenic processes. Therefore, considering that typical rates of treethrow and animal burrowing are about 3 in3/in/yr; (see Table A-15), it is estimated that for Coastal Belt geology in the Navarro River basin, the average rate of soil creep plus biogenic processes is about 3 in3/in/yr. In melange grasslands, a large proportion of the soils have a high percentage of clay (i.e., Yorkville soils), are often deep (4.3 ft), the bedrock is pervasively sheared, and "active" earthflows are much more common than in the Coastal Belt geology. Therefore we estimate that physical soil creep rates are likely to be higher in melange grasslands, perhaps two times, or about 6 in3/in/yr. This estimate assumes a high rate of soil creep, 0.1 in/yr, and an average soil depth of 4.3 feet near stream channels in the melange. Because soils developed on the melange often have a high clay content, animal burrowing is not expected to be widespread and hence, is probably negligible in comparison to soil creep in melange grasslands.

Sediment production due to soil creep was calculated based on the three steps and associated formulas in Table A-16. Estimated rates of soil creep to first- and second-order streams are listed by geology-vegetation unit in Table A-17. Based on this evaluation of soil creep processes, we estimate that sediment production due to bank erosion in first and second order channels in forested Coastal-Belt terrane is 34 and 11 tons/mi/yr., respectively. In Coastal-Belt grasslands, bank erosion is responsible for 53 tons/mi/yr., to first order channels and 17 tons/mi/yr., in second-order channels. In the melange terrane, the sediment production rate in first-order channels is 104 tons/mi/yr., and in second-order channels is 42 tons/mi/yr., from bank erosion.

A.2.5.1.2 Shallow Landslides Generated in Topographic Hollows

Several previous studies have documented the importance of shallow landsliding in topographic hollows (Dietrich and Dunne 1978; Lehre 1982; Benda and Dunne 1987). We reviewed these studies including hydrologic and physical attributes of the basins where the research was conducted in order to estimate rates of shallow landsliding from hollows in the Navarro River watershed (Table A-18). Note that roads are not a substantial contributor to the landsliding rate in any of these study areas. Grazing probably increases landsliding rate for Lone Tree Creek (Lehre 1982). Landsliding rates for Knowles Creek and Rock Creek pertain to undisturbed old-growth forests. Rates of shallow landsliding from hollows in younger forest and/or repeatedly logged forests in the Navarro River basin (exclusive of road causes) are most likely higher. Although there is considerable variability in land-use history, geology, and precipitation between the sites listed in Table A-18, landsliding rates are fairly similar. Note that landsliding rates for Rock Creek, and the 1952-1973 rate for Lone Tree Creek, are probably higher than the long-term average rates at these sites, because large storm events were common during the measurement periods. Landsliding rate for Knowles Creek basin probably provides a reasonable approximation of the long-term shallow landsliding rate at that site.

Table A-16. Calculation of Soil Creep Rate.

Step	Description	Formula
1	Soil creep volume per unit length of channel ($cm^3/cm/yr$)	(soil creep rate, mm/yr) x (0.1 mm/cm) x (soil thickness, cm) x (unit length of channel, cm)
2	Watershed-wide volumetric rate of soil creep	(volume per unit length of channel, $cm^3/cm/yr$) x (drainage density, km/km^2) x (1 m^3/1,000,000 cm^3) x (1000,000 cm/km) x (proportional stream length) x (drainage area, km^2) x (2 streambanks)
3	Watershed-wide soil creep rate in terms of mass per year	(watershed-wide volumetric rate of soil creep, m^3/yr) x (hillslope soil bulk density, metric tons/m^3).

Table A-17. Sediment Production to Small Streams from Soil Creep Processes.

Soil Creep Rate (in/yr)	Soil Thickness (in)	Drainage Density[a] (mi/mi^2)	Stream Order[b]	Proportion of total stream length in specified stream-order	Drainage Area[c] (mi^2)	Best Estimate Rate (t/mi/yr)	Total Input (tons per year)
Geology-Vegetation Unit: Coastal Belt-Forested[d]							
0.7	32	8.0	1	0.63	211.5	**34**	**7,200**
			2	0.20		**11**	**2,300**
Geology-Vegetation Unit: Coastal Belt-Grassland/Scrub[e]							
0.52	6.0	9.3	1	0.63	53.6	**53**	**2,840**
			2	0.20		**17**	**910**
Geology-Vegetation Unit: Melange-Grassland and/or Scrub[f]							
0.12	51.0	10.9	1	0.49	37.5	**104**	**3,900**
			2	0.20		**42**	**1,575**

(a) average length of channels of all stream-orders per unit watershed area

(b) for example, at the head of a channel, a first-order stream begins; at the confluence of 2 or more first-orders channels, a second-order channel is formed, and so on.

(c) total area extent of geology-vegetation unit within the Navarro River basin

(d) Best estimate calculated: assuming total creep rate = treethrow rate measured in Olympic Peninsula = 1.9 mm/yr (Reid 1981; using average soil depth = 80 cm (NRCS, in-press, Wosika 1981); and bulk density = 1.3 metric tons per m^3 (Wosika 1981)

(e) Best estimate calculated: assuming soil creep rate - burrowing rate at Lone Tree Creek = 20 cm^3/cm/yr = (rate, 13/3 mm/yr) x (average depth, 15 cm) (Lehre 1987).

(f) Best estimate calculated: assuming total soil creep rate = physical soil creep rate (3 mm/yr); using average soil depth = 130 cm and bulk density = 1.4 metric tons/m^3/ (NRCS, in-press).

Table A-18. Rates of Sediment Production from Shallow Landsliding in Basins Similar to the Navarro Watershed.

Site	Geology	Vegetation Cover	Stream Order	Basin-Wide Density Topographic Hollows (mi/mi^2)	Annual Precipitation (in)	Shallow Landsliding Rate (tons/mi/yr)	Period	Comments
Lone Tree Creek Marin County, CA (Lehre 1982)	incoherent unit of the Franciscan Assemblage	grassland or hardwood forest	1 thru 3	209	34	34 94	1870's-1970's 1952-1973	provides approximation of long-term rate includes many large storms, therefore, higher rate than long-term average
Knowles Creek Oregon Coast Range (Benda and Dunne 1987)	Tyee and Flournoy Formations (rhythmically bedded sandstones-mudstones)	Old-growth Douglas Fir Forest	1 2	161	63	12 23	Holocene	average rate through Holocene
Rock Creek Oregon Coast Range (Dietrich and Dunne 1978)	Basaltic Vocanics	Old-growth Douglas Fir Forest	4	35	118	32	1961-1973	period includes 1964 storm (likely higher than long-term rate)

From the sites listed in Table A-18, geology, topography, and vegetation cover at Lone Tree Creek are most similar to attributes of grass and scrub-covered slopes in the Navarro River basin that are underlain by Coastal Belt rocks (coherent and semi-coherent units). Annual precipitation in the Navarro River watershed is somewhat higher, however, than at Lone Tree Creek (e.g. 39-to-59 inches vs. 34 inches). Therefore, the Lone Tree Creek rate, 34 tons/mi/yr., is used as our best estimate of shallow landsliding rate from hollows in grass and scrub covered Coastal Belt slopes in the Navarro River watershed. Based upon field observations and review of aerial photographs, the shallow landsliding rate from hollows in grass-covered melange is similar to the rate for Coastal Belt grasslands.
For forested slopes in the Navarro River watershed, all geology types, the rate of shallow landsliding from hollows should be somewhat lower than for grass or scrub covered slopes because tree roots provide considerable shear strength to the soil. It is our opinion that the shallow landsliding rate from hollows on forested slopes in the Navarro River watershed should be about 2/3 of the measured rate for Lone Tree Creek. Based upon rates presented in Table A-18, it appears that long-term rates for shallow landsliding only vary over a narrow range, 12-to-34 tons/mi^2/yr, even though there is much variation in physical attributes, vegetation, and precipitation between the sites. Using the shallow landsliding rates from Lone Tree Creek, calculations of shallow landsliding to first- and second-order streams in the Navarro River watershed are presented in Table A-19.

A.2.5.2 Stream-side Sediment Production: Third- to Eighth-Order Streams

Estimated rates of stream-side sediment production in third- to eighth-order streams in the Navarro River watershed are derived primarily from measurement surveys on third-to-fifth-order streams (Table A-20). Previously collected streamside sediment production data for North Fork Caspar Creek (Napolitano unpublished) in third- and fourth-order reaches and Willow Creek (Trihey & Associates 1996), a tributary to the Russian River in Sonoma County in fourth- and fifth-order reaches were also used to define a range of rates. Qualitative data regarding active erosion and stream-bank conditions, collected as part of the channel condition and sediment storage studies, were also reviewed to qualitatively assess the basin-wide applicability of measured rates in higher order streams. Based on our field observations and channel conditions studies in Coastal Belt sites, shallow debris slides typically dominate sediment production and bank erosion processes deliver much less sediment per unit length.

Field sampling approach and protocols for streamside sediment production were developed based upon field trial and refinement. Stream reaches that were sampled varied from about one-quarter to sixth-tenth of a mile in length.

Walking along the stream channel, crew members identified sediment production sources at spatially discrete sites. Each site was then assigned an erosion feature number, and classified based upon erosion process type(s) (e.g. shallow debris slide, slump, ravel, bank spalling, etc.), and channel setting (straight reach, outside bend, inside bend, debris jam, etc.). Based upon interpretation of vegetation patterns and erosion scar morphology, we further classified features as either active (0-to-10 years old) or historical (> 10 years

Table A-19. Rates of Shallow Landsliding From Hollows to First & Second-Order Streams Coastal Belt Franciscan Assemblage.

Drainage Area (mi^2)	Drainage Density (mi/mi^2)	Stream Order	Proportion of total stream length in specified stream order	Minimum Rate (t/mi/yr)	Maximum Rate (t/mi/yr)	Best Estimate Rate (t/mi/yr)	Total Input (tons)	Comments
Coastal-Belt Forested								
211.5	8.0	1 and 2	0.83	11	34	22	31,800	Best Estimate = (2/3) x long-term rate for Lone Tree Creek
Coastal-Belt Grassland and/or Scrub								
53	9.3	1 and 2	0.83	22	67	34	14,000	Best Estimate = long-term rate for Lone Tree Creek
Melange-Grassland								
37.5	11.0	1 and 2	0.73	22	67	34	10,100	Best Estimate = long-term rate for Lone Tree Creek

Table A-20. Sites Where Stream-Side Sediment Production Was Measured.

Site	Reach Length (mi)	Geology-Vegetation	Stream-Order	Source
South Branch North Fork Navarro River	0.5	coherent Coastal Belt-conifer forest	5	this study
Jimmy Creek	0.5	coherent Coastal Belt-mixed forest	4	this study
Buckskin Creek (tributary of Jimmy Creek)	0.5	coherent Coastal Belt-mixed forest	4	this study
North Fork Indian Creek	0.5	semi-coherent Coastal Belt-mixed forest	5	this study
Adams Creek (tributary of upper Rancheria Creek)	0.3	valley fill-mixed forest	3-4	this study
East Fork Shearing Creek		Melange-grassland	3	this study
North Fork Caspar Creek, near Fort Bragg, CA	1.5	coherent Coastal Belt-conifer forest	3-4	(Napolitano, unpublished data)
Willow Creek, in western Sonoma County, CA	1.0	valley fill-mixed forest	5	(Trihey & Associates 1996)

old). Typically active features were estimated to be <1-to-5 years old and historical features were estimated to be 20-to-40 years old. In many cases, active erosion features occurred along the margins or within sub-areas of much larger historical erosion features.

In order to estimate the volume of sediment delivered to the channel at each site, we first estimated erosion scar dimensions (average depth, width, and height). For large landslides occurring on inner gorge slopes, scar height was estimated by range finder, visually, or by climbing the slope and using a tape to measure slope distance. For smaller landslides and bank erosion features, scar heights were estimated visually or using a 25 foot surveyor's rod. Scar depth(s) were either visually estimated or measured with a surveying rod. Average scar width was estimated by pace, visually, or by measurement with a surveyor's rod. Because some sediment eroded on hillslopes or channel banks is redeposited before reaching the channel, sediment delivery ratio (SDR), or percentage of erosion that actually reaches the channel, was also estimated. SDR was estimated based upon recognition of changes in topography and sediment character (layering, sorting, texture, color) along the slope. At each site, erosion volume multiplied by SDR equals sediment production to stream channels. We converted volumetric sediment production rates (volume per unit time) into units of mass (weight) per unit time using previously collected soil texture and particle size, or soil bulk density data (mass per unit volume) (Wosika 1981; NRCS, in-press).

Volumes of sediment production per unit time were further subdivided into two sediment grain-size categories: coarse (gravel or larger grains, $D_i \geq 2$ mm) and fine (sand or smaller grains, $D_i < 2$ mm). Percentage of coarse and fine sediment input from an erosion site was visually estimated over the unvegetated portions of the scar.

A.2.5.3 Results of Sediment Production to Large Streams

We used the average rate for those sites (200 tons per mile of stream length) as our best estimate of actual average rate for third- through eighth-order streams in the Navarro River basin which are underlain by the coherent or semi-coherent Coastal Belt geology. Minimum and maximum measured rates at Coastal Belt sites were 74 and 375 tons per mile of stream length, respectively. At Coastal Belt sites, shallow debris slides typically dominate sediment production.

Actual rates of streamside sediment production may be somewhat higher in sixth-to-eighth-order streams confined within an inner gorge (for example, segments of lower Rancheria Creek, North Fork Navarro and mainstem Navarro) because inner gorge slope length probably increases with stream-order and consequently typical landslide volume would increase. This effect may be counter-balanced, however, by the more frequent occurrence of streamside terraces and wide valleys in the higher-order streams. Where these geomorphic features occur, erosion from shallow landslides may be stored on terraces or within the valley flats, without actual sediment delivery to channels. Considering the range of measured rates of streamside sediment production, we are confident that the best estimate for the Coastal Belt is within an order of magnitude of actual average rate of streamside sediment production.

One stream survey was conducted in the melange terrane: in the east fork of Shearing Creek, a third-order stream (see Table A-20). Rates measured in Shearing Creek were approximately 700 tons per mile of stream length, or about four times the average rate in the Coastal Belt. This rate was used as our best estimate of average stream-side sediment production in the melange.

Calculations of streamside sediment production for third-order to eighth-order streams in the Navarro River watershed are presented in Table A-21.

A.2.5.4 Valley Fill Sediment Production

Erosion of channel and flood plain deposits is not considered to be sediment production because these sources are derived from other present-day sediment production processes and delivery to the channel (already accounted for when it entered the channel). Unlike flood plains, valley fill terraces are “ancient” or “inactive” river deposits, where sediment is no longer accumulating because they are not overtopped by the river under present-day conditions even during extreme floods. Therefore, where valley fill banks are being actively eroded along a stream, sediment production occurs because the river is taking sediment out of an “inactive” deposit with little or no present-day replenishment. For this reason valley fill bank erosion comprises a unique sediment production source.

Within the Navarro River basin, valley fill deposits cover approximately 13 square miles or about 4 percent of the watershed. The Anderson Valley accounts for nearly all of this area. Other valley fills in the watershed include: the Yorkville Valley (only a small portion of which occurs within the eastern margin of the watershed); and much smaller valleys located adjacent to several small streams.

Along the small streams, valley-fill banks are often steep, poorly consolidated, and sparsely covered by shrubs or very young trees suggesting that present-day bank erosion rates are quite high in these locals. Bank erosion rates also appear to be quite high in reaches of Anderson Creek in the Anderson Valley where the channel is wide and braided, as evidenced by the lack of mature stream-side vegetation and large increases in channel width that are discernible on time-sequential air photographs. Along other parts of Anderson Creek, the channel is quite narrow, deeply incised, and stream margin trees are quite old suggesting that bank erosion rates are much lower in these reaches.

A.2.5.5 Methods and Results: First- Through Fourth-Order Streams

To estimate sediment production from bank erosion along small (first- through fourth-order) streams incised into valley fills, we: a) performed field surveys on third- and fourth-order reaches of Adams Creek; b) reviewed previously collected valley fill sediment production estimates (Trihey & Associates 1996) made on Willow Creek, a small tributary to the Russian River in Sonoma County; and c) we reviewed qualitative

Table A-21. Rates of Sediment Production from Shallow Landsliding and Bank Erosion to Third Through Eighth-Order Streams.

Drainage Area (mi^2)	Drainage Density (mi^2/mi)	Stream Order	Proportion of total stream length in specified stream order	Best Estimate Rate (t/mi/yr)	Total Input (tons/yr)
Coastal Belt Forested					
211.5	8.0	3 thru 8	0.17	**200**	**58,000**
Coastal Belt-Grassland and/or Scrub[a]					
53	9.3	3 thru 8	0.17	**200**	**17,100**
Melange-Grassland and/or Scrub[b]					
37.5	10.9	3 thru 5	0.24	**700**	**62,900**
		6	0.03	**700**	**7,900**

(a) Best estimate = mean rate of 4 streams surveyed in Coastal Belt
(b) Best estimate = rate measured in East Fork Shearing Creek

descriptions of bank conditions[7] that we collected to describe channel conditions on two small streams incised through valley fills: upper John Smith Creek and Beasley Creek.

Field surveys to estimate sediment production from valley fill bank erosion on Adams Creek (and similarly on Willow Creek) involved:

a) notation of the pattern of bank erosion;

b) at each bank erosion site, measurement of bank erosion dimensions (height, length along the channel, and depth of erosion);

c) estimation of age categories for bank erosion features (where vegetation was present and bank erosion had caused root exposure) by notation of vegetation type and/or trunk diameter for tree species, and occasionally by coring trees and counting tree rings to calibrate age class estimations based upon tree diameter; and

d) visual estimation of percentage coarse (gravel or larger grains) and fine sediment in exposed banks.

Typically, sediment delivery ratio from valley fill bank erosion was 100 percent; but occasionally the sediment delivery ratio was less. Volumetric sediment production rates (volume per unit length per year) were calculated for present-day (0- to 10 years ago) and historical periods (depending upon vegetation ages and/or other historical data). Equation 1.0 illustrates how volumetric erosion rates were calculated:

<u>(equation 1.0)</u>

$$\Sigma\,(Va + Vb + \ldots + Vn) \div \text{period of erosion} \div \text{stream reach length} = \text{bank erosion rate},$$

where:

$\Sigma\,(Va + Vb + \ldots + Vn)$ refers to the sum of the individual volumes for each bank erosion feature identified in the reach surveyed.

On the two small streams surveyed, rates of bank erosion varied between 55 tons per mile per year (Willow Creek) to 210 tons per mile per year (Adams Creek). We used 125 tons per mile per year as our best estimate of typical bank erosion rate based upon comparison of Adams and Willow Creek measurement sites to other small streams incised through valley fills where we collected qualitative data describing bank conditions (upper John Smith Creek and Beasley Creek). Calculations for sediment production rates from Valley Fill deposits along small streams is shown in Table A-22.

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[7] bank heights, pattern and frequency of "active" bank erosion, diagnosis of causes for bank erosion (recent high flows, channel aggradation-widening, channel obstruction, etc.), stream margin vegetation (type and age class), bank sedimentology.

A.2.5.6 Fifth-Order and Larger Streams

To define volumetric bank erosion rates for large streams incised through valley fills, we used data collected along Anderson Creek in the Anderson Valley. This included bank heights measured in the field along Anderson Creek together with back-wearing rates estimated on time sequential air photos (1981 and 1992) at several locations within several defined stream reach types,[8] including reach types with similar conditions to those observed along the mainstem Navarro River in the Anderson Valley. We performed field surveys to measure typical valley fill bank heights, describe bank conditions (see footnote[4]), channel pattern, and width-to-depth ratio over several miles of Anderson Creek and mainstem of the Navarro River. Based upon field observations and air photo interpretations, reach types were also defined along the Navarro River within the Anderson Valley and volumetric erosion rates estimated along reach types in Anderson Creek were applied to mainstem Navarro River. Table A-23 summarizes bank erosion measurements by reach type along Anderson Creek. Sediment production estimates for stream reaches along Anderson Creek and mainstem Navarro River in Anderson Valley are presented in Table A-24. Rates estimated for reaches along the Navarro River are based upon qualitative comparison to reach types along Anderson Creek where bank erosion rates were calculated.

The estimated average rate of sediment production from valley-fill bank erosion in large streams (5th order thru 7th order) is 970 t/mi/yr (Table A-25) The range of rates for large streams, estimated for various stream reach types, appears to vary considerably as a function of channel morphology and stream-side vegetation community. The estimated total average annual sediment production from valley fill bank erosion for small and large streams combined is about 2,400 tons/mi^2/year (840 metric tons per km^2 per year).

A.2.6 Implications for Restoration

The origin, distribution, and relative magnitude of sediment sources discussed above provide a context for identifying and prioritizing restoration treatments on a watershed and subbasin scale. Although there is some variability between subbasins, gullying and stream-side erosion processes (shallow landslides and bank erosion) associated with the larger stream channels (stream order 3 and higher) are typically the largest sediment sources in the Navarro watershed (see Tables A-2 to A-6). The technical feasibility and associated costs for treating these, and other sediment sources, are very much dependent upon site-specific conditions. Access to restoration sites, local topography, and proximity to sensitive landscape features (riparian vegetation, stream channels, and steep inner-gorge slopes), are some of the factors which will influence the technical and

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[8] stratified based upon channel width and incision, streamside vegetation type, channel sinuosity and pattern (meandering, straight, braided)

Table A-22. Estimate of Average Sediment Production Rate for Valley Fill Deposits in Small Streams.

Valley Fill Drainage Area (mi^2)	Drainage Density (mi/mi^2)	Stream Order	Fractional Stream Length	Best Estimates (t/mi/yr)[a]	Total Input (tons)
13.1	10.5	1 thru 4	0.90	**125**	**15,455**

(a) average of rates measured on Adams Creek (tributary to upper Rancheria Creek) and Willow Creek (tributary to Russian River).

Table A-23. Valley Fill Bank Erosion: Field Survey Data for Anderson Creek.

Table A-24. Estimates of Sediment Production Along Anderson Creek and the Navarro River by Reach Type.

Table A-25. Estimate of Average Sediment Production Rate for Valley Fill Deposits in Large Streams.

Drainage Area (mi^2)	Drainage Density (mi/mi^2)	Stream Order	Fractional Stream Length	Best Estimates (t/mi/yr)[(a)]	Total Input (tons)
13.1	10.5	5 thru 7	0.10	**970**	**14,600**

(a) rate for large (fifth- to seventh-order) streams derived from stratification of reach types and measurements on Anderson Creek and qualitative estimation of relative rates for similar reach types of mainstem Navarro River in Anderson Valley.

economic effectiveness of specific restoration treatments. Regardless of how feasible or cost-effective a given restoration treatment might be at one location, it would be inappropriate to conclude that the performance of that restoration treatment would be the same at a different location. For this reason it is recommended that any restoration treatments contemplated for the Navarro watershed be preceded by a site-specific evaluation of its technical feasibility and associated costs for the particular setting.

Accelerated sediment production in the Navarro watershed is manifest as chronic fine sediment deposition on the streambed, which has been observed in all of the major sub-basins and across a wide range of stream reach types. Actions to reduce sediment delivery to stream channels, and to thereby improve fish habitat will need to address the widespread nature of the fine sediment problem. Although treating any of the sediment production sources in the watershed, regardless of the terrane type or erosion processes, will contribute toward minimizing fine sediment deposition and improving fish habitat, the largest sediment production processes, gullying and stream-side erosion, must be addressed throughout the watershed in order to achieve a sufficient reduction in sediment production to be meaningful for recovery/restoration of coho and steelhead habitat.

As a result of the sediment budget investigation, we conclude that a relatively small percentage of the landscape within 315 mi2 watershed area is directly responsible for generating most of the sediment delivered to channels (perhaps only a few percent of the drainage area of the basin). These areas are hillslope hollows, the inner gorge (both are sites of initiation for gullies and shallow landslides), and the stream-side corridor (bank erosion). Over a long-term planning horizon, protection and management of the hillslope hollows, inner gorge, and stream-side corridors, will represent a more significant and cost-effective step towards reducing sediment production than will direct treatment of the sediment production sources.

The significant findings from our assessment of non-road-related sediment production and the implications of these findings for restoration planning are summarized below by basin.

A.2.6.1 Anderson Creek Basin

- Sediment production rates are highest, about 4,000 tons/mi^2/yr, in the melange-grassland terrane. Gullies and streamside sediment production (bank erosion and shallow landsliding) along third to sixth-order streams are the principal sources of all production in the melange terrane (see Table A-1), about 36% and 53% respectively. Most of the melange terrane is found in the Anderson Creek (16.5 mi^2) and the mid-to-upper Rancheria Creek (19.6 mi^2) basins (see Figure A-1). In the Anderson Creek drainage, 71% of the sediment production is due to erosion from 36% of the basin drainage area, that is, the portion of the basin which is underlain by melange geology. Restoration efforts in the Anderson Creek and mid-to-upper Rancheria Creek basins should focus on developing restoration treatments and land management programs to reduce sediment production from streamside sources (bank erosion and shallow landsliding), and gullying.

- It is commonly acknowledged that sediment production due to gullying can be accelerated by land-uses such as grazing and road development. Restoration programs such as exclusion fencing, head-cut stabilization, revegetation, and de-watering should be considered to minimize acceleration of sediment production in all basins where gullying is considered a significant component of the sediment budget.

- Anderson Creek is actively aggrading with coarse sediments, and as a result, is eroding its streambanks (see discussion of Valley Fill terrane unit in section 4). Streambank stabilization or in-channel treatments to improve fish habitat would likely be ineffective in this stream system, and thus are not recommended. The most effective means to restore channel stability in Anderson Creek is to reduce upland sources of sediment production (see restoration implications above).

A.2.6.2 Indian Creek Basin

- Gullies are the largest source of sediment production in the Coastal-Belt grass/scrub terrane. Most of the Coastal-Belt grass/scrub terrane (19.6 mi^2) is located in the Indian Creek basin (see Table A-4). Restoration treatments to control gully erosion in the Indian Creek basin should be given a high priority, because gullies are responsible for approximately 24% of total sediment production.

- Stream-side erosion in the larger channels and shallow slides to smaller channels (Coastal-Belt grass/scrub terrane) are responsible for about 17% and 14% of sediment production in the basin. Therefore, restoration treatments to stabilize and revegetate streambanks should be a part of any restoration plan for the Indian Creek basin.

A.2.6.3 Mainstem Navarro Basin

- Most sediment production in the basin, approximately 24%, is due to deep-seated landslides in the forested Coastal-Belt terrane. In order to reduce the potential of major haul roads from causing (or contributing to) the failure of new deep-seated landslides, restoration planning should include funding to assist landowners with road relocation, road-closure, improved road-side drainage, or other road-related sediment reduction measures.

- Also in the forested Coastal-Belt terrane, approximately 20% of total sediment production is due to stream-side erosion processes. Therefore, streambank stabilization treatments should be in any restoration plans for the mainstem Navarro basin.

- Unlike Anderson Creek, other channels in Valley Fills, such as the mainstem Navarro River (see Figure A-1), do not appear to be out of balance with coarse sediment production. Therefore, streambank stabilization treatments on the mainstem Navarro are likely to have a much greater likelihood of success than in Anderson Creek.

A.2.6.4 North Fork Navarro Basin

- Shallow landslides in first and second-order sub-basins, and stream-side erosion processes in higher order streams account for approximately 71% of sediment production in the forested Coastal-Belt geology (see Table A-1). Most of the North Fork Navarro basin is within the forested Coastal-Belt terrane (69.7 mi^2). Shallow landslides to low-order channels and stream-side erosion processes in larger streams account for about 79% of total sediment production in the basin. These erosion features are widespread and commonly associated with steep inner gorge slopes. Near-term, active restoration treatments may be technically difficult to implement and are likely to be costly, depending upon site-specific conditions. Over the long-term, restoration planning should consider programs to protect sensitive riparian corridors and hillslope features to reduce the initiation of shallow slides and bank erosion. Such programs might include establishing riparian buffer strips to maintain streambank stability, and careful control of road development within the inner gorge.

- It is estimated that road-related erosion is responsible for over 50% of the total sediment production in the North Fork Navarro basin (see section 3). A comprehensive road remediation program should be considered an important component for reducing sediment production in the basin.

A.2.6.5 Rancheria Creek Basin

- Deep-seated landslides occur infrequently in the Navarro watershed, and are usually associated with the deeply incised inner gorge features where forested slopes are underlain by Coastal-Belt bedrock. Except for the Floodgate landslide, recently active slides are located on the mainstem of lower Rancheria Creek and its tributaries. Deep-seated landslides account for approximately 9% of sediment production in the Rancheria Creek basin (see Table A-5). Similar to the mainstem Navarro basin, in order to reduce the potential for major haul roads from causing or contributing to the failure of new deep-seated landslides, restoration planning should include funding to assist landowners with road relocation, road-closure, improved road-side drainage, or other road-related sediment reduction measures.

- In the Rancheria Creek basin, 53% of sediment production is due to stream-side erosion processes along the larger channels, and gullies in the melange geology (located in the mid-to-upper portion of the basin, see Figure A-1). Restoration efforts should focus on developing programs to reduce sediment production from streamside sources (bank erosion and shallow landsliding), and gullying.

A.3 ROAD-RELATED SEDIMENT PRODUCTION

Road related sediment production can be divided into two general types: chronic and discrete. Chronic processes include surface, cutbank (backcut) and inboard ditch erosion. In steep terrain, cutbanks may never stabilize. These chronic processes deliver fine sediment to watercourses via stream crossings and cross-road drains (ditch relief culverts). The volume of chronic sediment production is largely a function of the level of use and maintenance along the roadway.

Discrete processes include the initiation of landslides above or below the road, gullying and debris flows, failed stream crossings or fill slope failures in sensitive areas. Discrete failures commonly result from diverted watercourses flowing into areas that are not capable of carrying the excess water. The landslides and gullies typical of catastrophic failures introduce both coarse and fine sediment to stream channels, and often become chronic sources of fine sediment until vegetation establishes on freshly eroded surfaces. The effects of sediment production from some catastrophic failures can persist for many years.

The mechanisms that accelerate road-related sediment production are numerous. The relative magnitude of each mechanism depends on site specific characteristics, and on standards of road design and construction. The scope of this project did not include a detailed review of site conditions, or design and construction standards. Instead, we have identified, at the watershed level, the nature, the magnitude and geographic distribution of changes in rates of sediment production that result from road construction in the Navarro River watershed.

Two analytical models were developed with the goals of (1) describing the geographical distribution and magnitude of accelerated sediment production due to roads, and (2) characterizing the mean annual sediment production in the basins of the Navarro River watershed. The models provide an order-of-magnitude estimate of sediment production rates for each of the five major basins, as well as for the entire Navarro River watershed.

A.3.1 METHODS

Parameters used to quantify sediment production rates for the analytical models were derived from field observations, aerial photographic interpretation, and technical literature. Development of the analytical models for road-related sediment production is described in greater detail below.

A.3.1.1 Field Observations

Preliminary field reconnaissance during the spring of 1996 resulted in a sediment routing flowchart which identified the significant geologic settings and geomorphic processes contributing sediments to stream channels (see Figures A-2, A-3, A-4). During the summer of 1996 we conducted field sampling and inventory of near channel and road-related sediment production in the South Branch of the North Fork Navarro River, Yale Creek, Adams Creek, Shearing Creek, the North Fork of Indian Creek, and along the mainstem of Rancheria Creek. Field surveys were performed to assess the overall condition of roads including Bridge Creek Road, Peachland Road, Masonite Road, Nash-Mill Road, and un-named roads to Helen Libeu and Connie Best properties.

The field sampling was useful for developing a sense of the various sediment production mechanisms operating in different parts of the watershed, as well as approximate production rates in different parts of the basin. The impressions gained from these field observations provide the basis for validating the overall reliability of our analytic models. It was observed during the field studies that, roads constructed in the melange terrane and on the alluvial flats are fundamentally different from those in the Coastal Belt terranes. Due to the inherently unstable and dynamic nature of the melange terrane, most roads are constructed along the more stable ridges and are generally smaller in overall dimension.

A.3.1.2 Regional Road Density Analysis

Following the field surveys, we began an intensive regional analysis of the Navarro River basin, utilizing USGS orthophotoquads (flown in 1976; scale = 1:24,000) and sequential aerial photographs (1952, 1965, 1981; scale = 1:20,000 and 1992, scale = 1:31,680) to stratify the watershed into five different road density classes. Road density was selected as a primary criterion for stratification because the important influence road construction has on accelerating sediment production. Road density is also a parameter that can be measured or estimated from aerial photographs with a relatively high degree of certainty.

The analysis required delineation of areas with similar road densities using the 1976 orthophotos, thus dividing the basin into numerous "polygons" representing the various road density classes. The 1976 photos provided a good representation of basin conditions during, or shortly following, a period of intensive logging and road construction. In order to provide a more current assessment of basin conditions, each polygon was checked and revised based on the 1992 aerial photos.

The area of each polygon was determined with a digitizing tablet and the Geographic Information System (GIS) computer program Arc/Info. This technique allowed for accurate determination of polygon areas, and the GIS program provided the additional capability of assigning certain attributes to each of the polygons in order to estimate sediment production. The use of Arc/Info also allowed for the presentation of the results of the analysis in map form.

A.3.1.3 Assigning Sediment Production Attributes to the Road Density Polygons (Ternary Code)

In order to estimate and apply sediment production rates in the analytical models, it was necessary to know more than just the density of roads delineated by each polygon. It is also important to know the following attributes of roads: (1) the type and use patterns of the road systems, (2) the variable rates of sediment production associated with different geologic terranes and the likelihood of sediment delivery from a road system to stream channels, and (3) the present-day landscape condition, i.e., the extent of new disturbance, or the degree of recovery from prior disturbances. Each of these three factors, forthwith described as the "ternary code", were characterized and assigned to each polygon. The three factors are defined as the road type/density factor (RDF), the sediment delivery potential (SDP), and the condition change factor (CCF). The ternary codes represent particular values used in the analytical model which determine specific sediment production rates for each of the polygon areas.

A.3.1.3.1 Road Type/Density Factor (RDF)

The first and most important number of the ternary code is the road type and road density factor (RDF). The significance of this parameter is supported by numerous studies and observations which recognize road construction as the land-use activity most directly linked to accelerated erosion in the Pacific Northwest (Reid 1981; McCashion and Rice 1983; Reid and Dunne 1984; Best *et al.* 1995). The RDF code serves as an ordinal ranking of road density, and as a categorical descriptor of the dominant use pattern of the road system, i.e., whether the road is an industrial timber road, a residential access road, or a ranch road. Road use types and densities were characterized into the following classes:

Road Type	**Road Density**	**Ternary Code**
ranch, jeep trails only	very few or no roads	0
ranch roads, residential spur roads, some primary road systems	low density	1
multiple use roads: timber, residential, ranch	moderate road density	2
industrial timber-roads, but with fewer roads and skid trails, primarily utilizing cable yarder (i.e. skyline) methods	high road density	3
industrial timber roads, utilizing tractor yarding methods	very high road density	4

It was also necessary to determine the average road density (linear miles of road per square mile) for each of the delineated classes. This was accomplished by selecting representative samples from each road density class, and mapping the representative road systems onto mylar overlays. Road densities were estimated using the line intersection method described by Mark (1974) on the mylar overlays. The following average road densities for each of the five road density classes were estimated:

	Road Density Class	**Average Road Density**	**Average Skid Trail & Secondary Road Density**
RD 0	Very Low or Unroaded	2.5 mi/mi^2	5 mi/mi^2
RD 1	Low Road Density	4.7 mi/mi^2	7 mi/mi^2
RD 2	Moderate Road Density	5.2 mi/mi^2	9 mi/mi^2
RD 3	High Road Density	6.6 mi/mi^2	17 mi/mi^2
RD 4	Very High Road Density	8.6 mi/mi^2	22 mi/mi^2

The results of the road density analysis within the Navarro watershed is shown in Figure A-5. Roaded areas designated as very high density are located in the North Fork Navarro Basin and lower Rancheria Creek. Very low density roaded areas are found in the Anderson Creek and mid-to-upper Rancheria Creek basins. The Indian Creek and mainstem Navarro have a wide range of road density classes distributed over their basins.

Each of the Road Type/Density codes above were assigned a specific numerical value that reflects the degree to which sediment production rates as a result of the different road densities and types. The values were derived from a review of the technical literature that compares sediment production rates in disturbed and undisturbed conditions. Estimates of increases in sediment production attributable to roads in watersheds similar to the Navarro, as reviewed in the technical literature, typically range between 2 and 7 times the undisturbed or baseline condition (Reid 1981; McCashion and Rice 1983; Brown and Krygier 1971). The higher rates of road-related sediment production were associated with watersheds that have steeper topography and a greater amount of precipitation (such as Redwood Creek and Grouse Creek in north Coastal California) than the Navarro watershed.

Much higher rates of accelerated erosion, between 30 and 300 times undisturbed conditions, have been estimated for roads in other types of geologic terrane. For example, in the Idaho Batholith, Megahan and Kidd (1972) found that logging roads accelerated sediment production from decomposed granite by a factor of 300 times. Many of the studies reviewed in the published literature were associated with unstable areas, or a period of time immediately following road construction, or particularly abusive yarding techniques. Some studies provided values for total erosion only, and did not consider actual sediment delivery to stream channels. The values used in our analysis to correspond with each of the road density classes are discussed in Section 3.1.4, *Construction of Analytical Models*.

A.3.1.3.2 <u>Sediment Delivery Potential (SDP)</u>

The likelihood of road related erosion reaching a stream channel typically depends on the proximity and linkage between the road and watercourse. The sediment delivery

Figure A-5. Road Density Classes in the Navarro Watershed.

potential (SDP) is also used here to describe the geologic setting of the polygon. Rates of sediment production can vary by as much as a factor of 5x across the geologic terranes found in the Navarro River basin. The sediment delivery potential, as used to distinguish between different geologic settings, were assigned SDP codes as follows:

SDP Code		Geology		Vegetation/Land-Use
1,2, or 3	=	Coastal Belt terranes	-	mostly forested, with some grasslands
4	=	Alluvial fill deposits	-	mostly agricultural lands
5	=	Melange terrane	-	grasslands on active earthflows

SDP codes of 1, 2, or 3 refer specifically to the potential sediment delivery derived from roads constructed in the Coastal Belt Terranes. The ranking reflects the dominant topographic position of the road systems with respect to watercourses. The ranking is arranged as follows:

SDP Code	Road Position	Sediment Delivery
1	Ridge road systems	Low sediment delivery
2	Midslope roads or climbing roads (riparian to ridge)	Moderate sediment delivery
3	Inner gorge, riparian and lower slope roads	High sediment delivery

The ranking is conservative, in that it assigns the highest sediment production values based on the presence of roads in sensitive locations. For instance if any roads were present in the riparian or lower slope setting, the polygon was assigned a high sediment delivery potential (SDP code of 3). We chose this conservative approach based on the field observations from this and prior studies that roads constructed along stream corridors deliver the largest volumes of sediment to the channel.

Roads with SDP values of 3 are assigned a sediment delivery factor of 0.8, indicating that 80% of the material eroded from the riparian or inner gorge road system is delivered to the stream channel. Roads with SDP values of 1 are assigned a value of 0.2, reflecting a much smaller amount of sediment delivered to streams from these types of roads. Roads that were mid-slope (SDP=2) were assigned an intermediate sediment delivery value of 0.6.

Sediment production from roads in the Melange terrane and Alluvial fill (agricultural lands) are treated as a separate case from the Coastal Belt terrane. The erosion processes acting in these areas are fundamentally different from those acting in the highly roaded areas of the Coastal Belt, and therefore there is no “low”, “moderate” or “high” SDP rankings associated with the topographic position of roads in the Melange terrane or Alluvial Fill deposits as there is with Coastal Belt terrane.

SDP ternary codes of 4 or 5 indicate that the polygon falls in the Alluvial Fill deposit or Melange terrane respectively. These areas are assigned a sediment delivery factor of 100% because the erosional processes are fundamentally different from those acting in the Coastal Belt terrane. The dominant erosional process in the Alluvial Fill is bank erosion resulting from lateral channel migration. The dominant erosional processes in the Melange terrane are streamside landsliding and grassland gullying. These processes are not significantly altered by road related erosion, and all of the eroded material is generally delivered directly to the stream channel.

A.3.1.3.3 Condition Change Factor (CCF)

Accelerated sediment production from roads generally decay with time elapsed since construction and heavy use, yet can increase with renewed activity. The condition change factor describes the changes in the land-use patterns based on comparison of the 1976 and 1992 air photos. A positive value indicates increased sediment production associated with continued or increased road construction and logging activities in the area, while a negative value indicates a decrease in sediment production corresponding to recovery of vegetation and an apparent decrease in the use level of road systems. Each polygon on the 1976 orthophotoquad was checked on the 1992 WAC aerial photographs, and polygons were re-drawn as necessary to denote the change in land-use over this time period. A total of 55 aerial photos from 1992 were reviewed in this process. CCF values were assigned based on the following criteria:

Condition Change Factor	Description
9*	vegetation recovery, and an apparent road density decrease
0	no apparent change in vegetative cover or road density
1	continued decline in vegetative cover and/or moderate road density increase
2	continued decline in vegetative cover and/or extreme road density increase

* - due to constraints within the Arc/Info program, negative numbers could not be used, so "9" was used in the code instead

Values for the CCF adjustment factors range from 0.8 to 1.4, indicating either a 20% decrease in sediment production with time, or a 40% increase. Decay rates may actually be greater than this, as a result of improved road construction and maintenance practices conducted on residential roads and industrial timber roads

A.3.1.4 Construction of Analytical Models

Two models were developed independently to estimate the road related sediment production for the watershed. To facilitate reference to the two models, they will be referred to as the "basin" approach and the "roads" approach. In general, the "basin" model develops sediment production rates by applying the ternary code to accelerate baseline rates of sediment production from each of the geologic terrane types. The "roads" model does not directly use the type of geologic terrane. Instead, miles of road are identified by their level of use (heavy use, moderate use, low use, or abandoned) and each level of use has an associated sediment production value. Both models utilize the results of the regional road assessment, using the calculated area of the different road density classes to determine the total length of roads in a polygon. The roads model was primarily constructed to provide an additional independent means of estimating the magnitude of road-related sediment production and to cross-check results of the basin model.

A.3.1.4.1 The Basin Approach

The "basin" model approach is based on the premise that human activity accelerates sediment production rates, and that the magnitude of the acceleration depends primarily on the timing, type and spatial distribution of disturbance activities. The sediment production from an individual polygon in the basin model is calculated by the following formula:

$$SP_p = A_p \times SP_g \times RD_i \times SD_i \times CCF_i \quad \text{(Equation 1.0)}$$

where,

A_p = area of polygon (mi^2)

SP_g = unit sediment production rate for a given geologic terrane (Tons/mi^2)

RD_i = adjustment factor for disturbance-related sediment production acceleration (dimensionless)

SD_i = sediment delivery adjustment factor (dimensionless)

CCF_i = condition change adjustment factor (dimensionless)

The "adjustment factors" (ternary code values) in the equation above reflect the magnitude of accelerated erosion resulting from road construction, the decrease in sediment production resulting from partial sediment delivery to streams, and the increase or decrease in sediment production resulting from changes in land-use over time. The sediment production rates associated with a given geologic terrane (Sp_g) were independently derived (see Section 2) and used in the basin model. A brief discussion of these sediment production rates are provided below.

Unit Sediment Production Rates Related to Geologic Setting

For the purposes of this model, the geology of the Navarro River basin has been subdivided into three primary erosion terrane-types: the Coastal Belt terrane, the Melange terrane, and the Quaternary Alluvial deposits (see Figure A-1). With regards to sediment production from roads, we have assumed that the Coherent Coastal Belt terrane and the semi-coherent Coastal Belt terrane respond similarly to disturbances such as road construction and logging. Few technical studies have attempted to assign different rates to the coherent and semi-coherent subdivisions of the Coastal Belt; thus we were limited by the availability of published sediment production rates to distinguish these subterranes. However, there was abundant information available for sediment production rates from the Coastal Belt geology.

The unit sediment production rate (tons/mi^2/yr) used in our analysis for a given geologic terrane is derived from a combination of literature review and field assessment. Rates of sediment production derived from published data are based on numerous previous studies carried out in geologically similar provinces in the Pacific Northwest. We selected from studies that were conducted on lands that consisted of rocks comprised of off-scraped marine deposits of the Franciscan (or Franciscan-equivalent) formation.

Our field reconnaissance studies in the Navarro watershed indicated that sediment production from basins within the Melange terrane is much higher than from basins in the Coastal Belt terrane. Published rates were generally found to be at least an order of magnitude higher in the melange terrane than in the Coastal Belt terrane. Sediment production rates in the Alluvial deposits are less than those in the Melange terrane, but higher than those from the Coastal Belt terrane due to the proximity of most failures in the Alluvial deposits to an active watercourse.

Rates of average annual sediment production for the Coastal Belt, Melange, and Valley fill units, (input to the Basin model), were derived as follows:

1. for the Coastal Belt unit, published estimates of stream sediment yields were reviewed (Rice *et al.* 1979; Nolan and Janda 1979; Kelsey 1980; Madej *et al.* 1986; Napolitano 1996) to develop a best estimate of approximately 700 tons per square mile per year;

2. for the Valley Fill unit, we used stream-side sediment rates measured in valley fills in the Navarro River basin to develop a best estimate of approximately 2400 tons per square mile per year

3. for the Melange unit, we reviewed published stream sediment yields for nearby basins underlain primarily by melange together with sediment production rates estimated for the melange in the Navarro River basin to develop a best estimate of approximately 4,000 tons per square mile per year.

Basin Model: Rates of Sediment Production Without Roads

We first used the basin model to estimate rates of sediment production (expressed in tons/mi^2) assuming there were no roads, landings, or skid trails constructed in the watershed. This is a "minimum" sediment production based on expected erosion rates from each of the geologic terrane types. In this case, RD, SD, and CCF factors are assigned a value of 1 in the model and thus, do not accelerate or decelerate the rates of sediment production. The values assigned to the ternary code adjustment factors for the baseline rates of sediment production are provided in Table A-26. Thus, sediment production rates for the Navarro watershed in the minimum scenario (no roads) are based

Table A-26. Ternary Code and Geologic Terrain Values For Estimated Background Sediment Production Rates Using Basin Model.

Road Density (RD)		Sediment Density (SD)		Condition Change (CCF)	
Name	**Factor**	**Name**	**Factor**	**Name**	**Factor**
RD4	1.00	SD5	100%	CCF2	1.0
RD3	1.00	SD4	100%	CCF1	1.0
RD2	1.00	SD3	100%	CCF0	1.0
RD1	1.00	SD2	100%	CCF9	1.0
RD0	1.00	SD1	100%		

Sediment Production Rates for Different Geologic Terrains ($tons/mi^2/yr$)	
700	Coastal Belt Terranes
4,000	Melange Terrane
2,000	Alluvial Fill Deposits

on values assigned to the different geologic terrane types and their relative distribution in the watershed.

Basin Model: Maximum and Best-Estimate of Sediment Production

The basin model was also used to estimate the maximum and "best-estimates" (i.e., the most likely values intermediate between the minimum and maximum values) of sediment production due to the presence of roads. The ternary code values used in these two scenarios were selected based on the range of values available in the scientific literature. We relied heavily on the study by Reid (1981) in the Clearwater Basin, Washington which has geology that is similar to that found in the Navarro watershed. Based on this study, an acceleration factor of 3.4 was selected for roads classified as RD4 in the best-estimate scenario. We then scaled acceleration factors for the other road types, as well as for sediment delivery and the condition change factor based on our best judgments and field observations of road conditions. The accelerated values used for each road type (RD), sediment delivery (SD), and condition change (CCF) factor are provided in Table A-27 for the maximum scenario and Table A-28 for the best estimate scenario.

In the maximum scenario the acceleration factor used for each road type increased over the best estimate scenario. The RD and SD factors remain the same in both scenarios.

A.3.1.4.2 <u>The Roads Approach</u>

The second method for estimating sediment production from roads is based on identification of road types and the level of road-use. The roads model was developed to provide an independent cross-check on the results of the basin model. All road-related erosion processes (surface erosion, cutbank (backcut) erosion, debris flows and landsliding, gully erosion etc.), are accounted for in this model. Total sediment production per mile of road estimated in other studies (Reid 1981), is applied to the road types and road uses found in the Navarro watershed. While these estimates may be general, they are valuable for describing present-day sediment production rates and patterns associated with different types of roads and levels of use.

A ternary code is used in the roads model to identify the different types of roads and their density. However unlike the basin model, the ternary code is not used in the roads model to adjust sediment production rates, and the type of geologic terrane does not differentially influence sediment production across the three erosion terrane units found in the Navarro watershed. A "use-distribution function" is introduced which allocates the total estimated road miles into different use-level categories. Each use-level category differentially affects sediment production.

For this model, we defined three road types, and four different use classes. The road types are defined in the same manner as for the basin model, and consist of: industrial timber roads, residential roads, and ranch roads. Use classes were organized into (1) high-use, (2) moderate-use, (3) low use, and (4) abandoned. Prior studies have made similar subdivisions of use categories (McCashion and Rice 1983; Reid 1981).

Table A-27. Ternary Code and Geologic Terrain Values for Maximum Sediment Production Estimates Using Basin Model.

Road Density (RD)		Sediment Density (SD)		Condition Change (CCF)	
Name	Factor	Name	Factor	Name	Factor
RD4	4.80	SD5	100%	CCF2	1.4
RD3	3.40	SD4	100%	CCF1	1.2
RD2	2.00	SD3	80%	CCF0	1.0
RD1	1.50	SD2	60%	CCF-1	0.8
RD0	1.25	SD1	20%		
Sediment Production Rates for Different Geologic Terrains (tons/mi²/yr)					
	700	Coastal Belt Terranes			
	4,000	Melange Terrane			
	2,400	Alluvial Fill Deposits			

Table A-28. Ternary Code and Geologic Terrain Values for "Best Estimate" of Sediment Production Rates Using Basin Model.

Road Density (RD)		Sediment Density (SD)		Condition Change (CCF)	
Name	Factor	Name	Factor	Name	Factor
RD4	3.40	SD5	100%	CCF2	1.4
RD3	2.50	SD4	100%	CCF1	1.2
RD2	1.50	SD3	80%	CCF0	1.0
RD1	1.25	SD2	60%	CCF-1	0.8
RD0	1.10	SD1	20%		
Sediment Production Rates for Different Geologic Terrains (tons/mi²/yr)					
	700	Coastal Belt Terranes			
	4,000	Melange Terrane			
	2,400	Alluvial Fill Deposits			

Determination of Road Use Classes and Associated Sediment Production Rates

In order to account for different levels of road use, the total road mileage in a polygon is stratified into four separate use categories. This is accomplished by multiplying the total road mileage (RMp) by four constants of proportionality known as the "use-distribution function." Reid (1981) studied patterns of log-truck usage on industrial timber roads in the Clearwater Basin, and found that, on average, 6% of the road network fell into a "high use" category, 5% fell into a "moderate use" category, 39% of the network was in the low use category, and 50% of the road miles were in an abandoned, or non-use category.

Reid (1981) found that sediment production from roads associated with timber production declines approximately by an order of magnitude with each decrease in level of use. For example, a high-use road is expected to produce roughly 800 tons of sediment per mile of road length per year, while a moderate-use road is expected to produce only 80 tons per mile per year. A low-use road produces 8 tons per mile per year, and an abandoned road produces only 0.8 tons per mile per mile. The use distribution, and associated sediment production for each use as applied to the Navarro watershed is shown in Table A-29.

The use distribution and sediment production associated with timber roads was derived from the work performed by Reid (1981) in the Clearwater Basin, which has a geologic setting that is similar to that found in the Coastal Belt of the Navarro watershed. For residential and ranch roads, the use distribution in the Navarro watershed was developed based on our best judgment and field observations since there were no published studies for ranch and residential roads similar to the timber roads in the Clearwater Basin. There are also no existing published studies for sediment production rates from residential and ranch roads (which are primarily found in the alluvial fill and melange terrane). Therefore we used field observations and a limited amount of sediment production data collected to assess the general condition of several residential and ranch roads in the Navarro watershed. These observations provided some guidance to scale and apportion sediment production rates to each level of use. Our field observations of residential roads included Peachland Road in the Rancheria Creek basin, Nash-Mill Road in the Mill Creek basin, the road to Helen Libeu's property in the Indian Creek basin, and the road to Connie Best's property in the Con Creek basin. For ranch roads we made field observations of the Galbraith and Mailliard properties in the Yale and Adams Creek basins, and on the Mailliard property in the Shearing Creek basin. In addition to these surveys, we made observations of timber road conditions and collected sediment production data for the Masonite Road and for two major haul roads in the Cook Creek basin (South Branch North Fork Navarro).

By multiplying the total road miles in a polygon (RMp) by the use distribution function (UDF), we get four separate road mileages that correspond to the number of miles of road that fall into a high, moderate, low or abandoned state of use.

Table A-29. Use Distribution and Sediment Production Rates used in the Road Model.

Use Distribution Function			
Level of Use	Timber	Residential	Ranch
High	0.06	0.1	0.05
Moderate	0.05	0.3	0.1
Low	0.39	0.3	0.7
Abandoned	0.5	0.3	0.15
Sediment Production Rates (tons/mi)			
Level of Use	Timber	Residential	Ranch
High	885	265	177
Moderate	88.5	26.5	17.7
Low	8.5	2.65	1.77
Abandoned	0.85	0.265	0.177

RMp x UDF = RMh, RMm, RMl, and Rma

where,
RMh = road miles in the high-use category
RMm = road miles in the moderate-use category
RMl = road miles in the low-use category
RMa = road miles in the abandoned category

Once the mileage of road in a given use and road type category was determined, the road length is multiplied by the sediment production rate for that type of road and use classification. By summing all of these values, we estimate the total sediment production associated with roads within that polygon.

For example, if we select an area that has been previously delineated by a polygon in the North Fork Navarro with timber harvest roads having a mean density of 8 mi/mi^2, then it would have a road type/density classification of RD4 (see Table A-29). The total miles of roads in the polygon is calculated by multiplying the average road density of that polygon by the area of the polygon. This can be expressed by the equation:

RMp = RDp x Ap
where,
RMp = total road miles in a polygon
RDp = average road density in the polygon
Ap = area of the polygon

For example, assume that the total area of the polygon in our example is 10 mi2. Then the total road miles is 10 mi2 x 8 mi/mi2 = 80 miles of timber harvest road. The 80 miles of timber harvest roads are then multiplied by the use distribution function to estimate the number of road miles in the high, moderate, low, and abandoned use categories. Using Table A-29, the distribution of road use is as follows: 50% abandoned, 39% low use, 5% moderate use, and 6% heavy use. These proportions applied to our 80 miles of roads results in: 40 miles abandoned, 31 miles low use, 4 miles moderate use, and 5 miles in heavy use. The sediment production rates applicable to each use-class of road is then multiplied by the road miles in each use class. Using Table A-29, sediment production rates under timber harvest roads that are abandoned is .85 tons/mi, for low-use roads 8.5 tons/mi, for moderate use roads 88.5 tons/mi., and for high use roads 885 tons/mi. The results for that polygon are: 34 tons from abandoned roads, 264 tons from low-use roads, 354 tons for moderate-use roads, and 4,425 tons for heavy-use roads. The total sediment production due to roads in that 10 mi2 area is the sum of the different use classes, 5,077 tons or 507 tons/mi2.

A.3.2 Results

A.3.2.1 Sediment Production Scenarios

Three separate scenarios of the Basin model were run in order to present a range of possible sediment production values based on varying the input parameters. The three scenarios consist of: (1) minimum estimate, (2) intermediate "best-estimate", and (3) maximum estimate. The model results provided in Tables A-30, A-31, and A-32, show sediment yields for each of the five major basins, and for the entire Navarro watershed.

Results of the minimum sediment production scenario, which assumes that there are no roads developed in the basin are shown in Table A-30. For each of the major basins in the watershed, the drainage area is in column 1, the percent of the watershed drainage area is shown in column 2, sediment production is provided in columns 3 and 4, and the proportion of total sediment yield over the Navarro watershed is shown in column 5.

Although we have designated these estimates as "Minimum" because they do not include the influence of roads on sediment production, the results incorporate the effects of land-uses such as grazing, agriculture, and other anthropogenically induced changes on erosion. As described in Section 3.1.4, *Construction of Analytical Models,* the minimum scenario uses the average rates of sediment production for the three erosion terrane units and distributes these rates across the geologic terrane in the watershed. These average rates, derived independently from the Basin Model (see Section 2.2, *Summary*), include the influence of land-uses typically associated with Coastal Belt, melange and valley fill geologic terranes. Hence, the minimum scenario does not characterize sediment production under pristine, "background" conditions where land-uses have not effected the landscape.

Estimating sediment production rates in the minimum scenario is necessary in order to determine the portion of sediment production due to road-related sources. The difference between sediment production in the minimum scenario (sediment production from all sources except roads), and the best-estimate scenario (sediment production from all sources, including roads), is the amount of sediment production due only to roads.

It should be noted that sediment production totals for each basin in Table A-30 are slightly different from those estimates shown in Table A-7. This is because the Basin Model simplifies the geographic distribution of sediment production rates associated with the Coastal Belt terrane. In the Coastal Belt, forested and grass/scrub vegetation communities have different overall rates of sediment production. In forested regions of the Coastal Belt, sediment production is approximately 500 tons/mi^2/yr, and in grass/scrub communities about 1,100 tons/mi^2/yr (see Table A-2). When composited together as a weighted average over the Navarro watershed, sediment production in the Coastal Belt accounts for about 700 tons/mi^2/yr. The Basin Model does not differentiate between forested and grass/scrub sediment production rates in the Coastal Belt, since this would have greatly increased the complexity and effort required to develop the model. Rather, we have used the weighted average, 700 tons/mi^2/yr, as the sediment production

Table A-30. Basin Model: Minimum Sediment Production Estimates (no roads).

	Drainage Area (mi^2)	Percent of Drainage Area	Sediment Production (tons)	Sediment Production ($tons/mi^2$)	Proportion of Sediment Production
Anderson Creek	46	15%	95,600	2,100	26%
Indian Creek	39	12%	33,400	900	9%
Main Stem Navarro	63	20%	55,700	900	15%
North Fork Navarro	74	23%	51,800	700	14%
Rancheria Creek	94	30%	130,400	1,400	36%
Navarro Watershed	315	100%	366,900	1,200	100%

Table A-31. Basin Model: Best-Estimate Sediment Production (includes road-related sources).

	Drainage Area (mi^2)	Percent of Drainage Area	Sediment Production (tons)	Sediment Production ($tons/mi^2$)	Proportion of Sediment Production
Anderson Creek	46	15%	113,700	2,500	23%
Indian Creek	39	12%	38,100	1,000	8%
Main Stem Navarro	63	20%	85,900	1,400	17%
North Fork Navarro	74	23%	105,000	1,400	21%
Rancheria Creek	94	30%	151,100	1,600	31%
Navarro Watershed	315	100%	493,900	1,600	100%

Table A-32. Basin Model: Maximum Estimate Sediment Production.

	Drainage Area (mi^2)	Percent of Drainage Area	Sediment Production (tons)	Sediment Production ($tons/mi^2$)	Proportion of Sediment Production
Anderson Creek	46	15%	136,000	2,900	22%
Indian Creek	39	12%	49,000	1,200	8%
Main Stem Navarro	63	20%	114,500	1,800	18%
North Fork Navarro	74	23%	146,300	2,000	23%
Rancheria Creek	94	30%	185,000	2,000	29%
Navarro Watershed	315	100%	630,500	2,000	100%

rate for Coastal Belt terrane in the Basin Model (Tables A-26, A-27, and A-28). Using the weighted average provides slightly different sediment production results for each basin that that shown in Table A-2, but over the whole Navarro watershed, total sediment production is almost identical between the Basin Model and the independently derived estimates. The most accurate estimate of non-road related sediment production for each basin is that discussed in Section 2, and reported in Table A-7.

On a per square mile basis, the greatest total sediment yield is found in the Anderson Creek drainage, approximately 2,500 tons/mi^2 based on the best-estimates of the basin model (see Table A-31). Much of the Anderson Creek basin has a very low road density (see Figure A-5), however, the high sediment production rates are due primarily to erosion processes associated with Melange terrane. In terms of total sediment yield, the Rancheria Creek basin and the Anderson Creek basin have the highest sediment production values in the watershed, approximately 151,000 and 114,000 tons respectively (see Table A-31), each representing 31% and 23% respectively, of all sediment production in the Navarro watershed. Similar to the Anderson Creek drainage, high yields in the Rancheria Creek basin are probably due, in part, to the Melange terrane units in the mid-to-upper half of the basin. In addition, the lower half of the Rancheria Creek drainage has undergone considerable road development, likely accelerating natural sediment production.

In the basin model, "best-estimate scenario", sediment production for the Navarro watershed is approximately 494,000 tons and in the minimum scenario, the sediment production is 367,000 tons. The difference, 127,000 tons, represents a 34% increase due to the acceleration of sediment production from roads.

Sediment production based on the "maximum" scenario is 630,500 tons, or a 72% increase from sediment production rates without roads. Figure A-6, shows the per square mile total sediment production rates (road and non-road related erosion) across the Navarro watershed based on the best-estimate model results. The proportion of sediment production attributable to each basin differs very little between the best-estimate and maximum scenarios (see Tables A-31 and A-32).

Comparing the basin model minimum (no roads) scenario with the best-estimate scenario (Table A-33), the greatest increase in sediment production due to roads is 51% (720 tons/mi^2) in the North Fork Navarro and 35% (480 tons/mi^2) on the Mainstem Navarro (see Table A-33, last column). The increase in sediment production in the North Fork Navarro basin is due to an extensive road network in forest lands under industrial timber management. While the absolute value of total sediment yield from the North Fork Navarro (105,000 tons) is lower than total sediment yield in some other parts of the watershed, it is important to recognize that the proportional increase in sediment production due to roads is the highest. The smallest increases in total sediment production due to road-related erosion occurs in the much less densely roaded areas of Indian Creek (12% increase), Anderson Creek (16%), and Rancheria Creek (14%) drainage basins.

Figure A-6. Map of Sediment Production Rates.

Table A-33. Road-Related Sediment Production: Basin Model.

	Sediment Production[a] No Roads (tons)	Sediment Production[a] ("Best Estimate") With Roads (tons)	Road-Related Sediment Production (tons)	Road-Related Sediment Production tons/mi^2	Proportion[b] due to Roads	% Increase Due to Roads
Anderson Creek	95,600	113,700	18,100	390	16%	14%
Indian Creek	33,400	38,100	4,700	120	12%	4%
Mainstem Navarro	55,700	85,900	30,200	480	35%	24%
North Fork Navarro	51,800	105,100	53,300	720	51%	42%
Rancheria Creek	130,400	151,100	20,700	220	14%	16%
Navarro Watershed	366,900	493,900	127,000	400	26%	100%

(a) Sediment production values rounded to nearest one-hundred tons.
(b) Proportion of all road-related sediment production in Navarro watershed.

A.3.2.2 Results of Roads Model

One "best-estimate" scenario from the Roads model was prepared, and is shown for each major sub-basin in the Navarro watershed in Table A-34. Unlike the basin model, the roads model provides the sediment yield attributable only to roads.

The calculated sediment production due to roads compares reasonably well with results obtained from the basin model. In the roads model, road-related sediment production for the Navarro watershed is approximately 56,200 tons and in the basin model is approximately 127,000 tons (see Table A-33). This is a 2.3x difference, well within an order-of-magnitude (10x). For each basin, all road-related sediment production values also compare within an order-of-magnitude. The Anderson Creek drainage has the largest difference between the two models, about six times greater in the Basin Model (18,100 tons/yr) compared with the roads model (2,800 tons/yr). From Table A-34, the North Fork Navarro basin similar to the Basin Model, has the largest road-related sediment production per square mile, approximately 340 tons/mi^2.

A.3.2.3 Road-Related Erosion: Implications for Restoration

- Roads are responsible for approximately 26% of the sediment production delivered to stream channels over the Navarro watershed.

- The results of the road-related sediment production models indicate that there has been a relatively small increase in sediment production due to the development of roads, compared with sediment production from other erosion processes, in the Anderson Creek, Indian Creek, and portions of the Rancheria Creek basins.

- Actions taken to reduce erosion from roads in the Anderson Creek, Indian Creek, and upper Rancheria Creek basins, although they may be valuable locally, cannot be expected to substantially reduce total sediment delivery to stream channels on a basin-wide scale.

- Because relatively few roads currently exist in the Anderson, Indian, and upper Rancheria Creek basins, actions should be considered to limit or ensure well-designed new road developments associated with housing, orchards, vineyards, ranching or other land-uses to prevent accelerated sediment production.

- The lower Rancheria Creek sub-basin should be distinguished from the mid-to-upper basin due to the comparatively high density of industrial timberland road development. Acceleration of sediment production due to roads in this portion of the basin is much greater than in the entire drainage as a whole. Within the high-density roaded areas of the lower basin, it is likely that road improvements would substantially reduce total sediment delivery to stream channels in this sub-basin.

- Roads are responsible for approximately 51% of all sediment production in the North Fork Navarro basin, and 35% of all sediment production in the mainstem Navarro

Table A-34. Roads Model: Road-Related Sediment Production.

	Drainage Area (mi^2)	Sediment Production (tons/yr)	(tons/mi^2/yr)	Proportion[a] of Sediment Production
Anderson Creek	46	2,800	60	5%
Indian Creek	39	4,700	120	8%
Main Stem Navarro	63	8,800	140	16%
North Fork Navarro	74	25,200	340	45%
Rancheria Creek	94	14,800	160	26%
Navarro Watershed	315	56,200	180	100%

(a) Proportion of all road-related sediment production in Navarro watershed.

basin. Restoration actions taken to reduce erosion from roads in the North Fork Navarro and Mainstem Navarro basins are likely to substantially reduce sediment delivery to streams.

- Sensitive road locations, such as the inner gorge or riparian roads, tend to deliver a greater portion of road-related erosion to stream channels. Restoration actions related to roads should target these sensitive landscape features.

A.4 CHANNEL STUDIES

Two primary goals for the channel studies were: 1) describe sediment and non-sediment related impacts to salmonid habitat, place these in context with regard to causes, and evaluate prospects for successful restoration treatment; and 2) integrate finding's of the various channel studies, such that, it is possible to describe routing of sediment through channels. Details regarding channel impacts, and channel storage and transport conditions are presented in the channel condition, storage, and bedload sections. Channel sediment routing is presented below.

A.4.1 CHANNEL SEDIMENT ROUTING

A.4.1.1 Introduction

At present, sediment input to channels (sediment production) in the Navarro River basin averages about 1,600 tons per square mile per year (road and non-road related sources). Although the difference cannot be quantified, present-day sediment production is higher than the natural background level. Characterization of sediment production rate alone however, does not inform us about what happens to sediment once it enters the channels. The fate of sediment in a river channel depends both upon characteristics of the sediment, and the capability of the channels to either transport or store that sediment. Characteristics of sediment delivered in to channels which effect its disposition are: a) the total rate at which sediment is delivered to a channel (input rate); b) the size distribution of sediment (which effects the transport rate through the river); and c) the susceptibility of coarse sediment grains to being broken down into finer grains during transport through the channel. Stream reach attributes which effect sediment transport capability include: a) water depth and stream-bed steepness (slope); b) obstructions to flow which may diminish sediment transport ability; and c) the size and frequency of flows that are capable of transporting sediment.

For example, size distribution of sediment input to the channel effects what fraction of sediment is rapidly transported through the river in suspension (suspended load), what fraction is transported at a moderate rate along the river bed (bedload) by frequent high flows, and what fraction is rarely transported during very large floods or not transported at all. Susceptibility of large sediment grain-sizes (gravel and cobble) to physical and/or chemical break down during transport through the channel, may cause substantial change to occur in the relative proportions of suspended-load and bedload in the downstream direction along a river. Changes in stream channel morphology along the river, such as in the steepness of the streambed or the confinement of the channel (ratio of channel width to valley width), also affect sediment transport competence[9] and capacity[10]. Deposition of sediment on flood plains may further complicate the disposition of sediments delivered to stream channels.

Considering the complex nature of sediment transport in channels, it is not possible to make accurate quantitative comparisons between sediment delivery to channels and sediment transport. Instead, it is often possible to qualitatively describe channel reach conditions pertaining to sediment transport, and to use this information together with limited quantitative data to describe what happens to sediment once it enters a channel. Using such an approach, we performed three types of channel studies to compare sediment production and sediment transport:

1. Bedload Yield (Section A.4.2) - to estimate the capacity of channels to transport sediment

2. Channel Sediment Storage (Section A.4.3) - to identify the distribution of large sediment storage features, and to assess historical changes in the amount of sediment stored at these locations (i.e., large-scale sediment deposition causing channel filling and widening);

3. Channel Condition (Section A.4.4) - to describe sediment transport and storage conditions along channels, and the nature and distribution of sediment-related impacts in channels (i.e., fine sediment deposition in pools, channel filling and widening);

A.4.1.2 Approach

Our comparison of sediment production to sediment transport involves four steps:

1. characterization of sediment input by grain-size category (percentage fine, coarse, very coarse sediment) because sediment size influences the rate at which sediment moves through the channel;

2. for coarse sizes (gravel and cobble), estimation of how rapidly these break down into fine sizes, and hence, how fine and coarse sediment load may change in downstream direction;

3. review of qualitative and quantitative channel condition and storage data to assess how stream channels in the basin accommodate fine and coarse sediment loads; and

4. review of bedload yield modeling and qualitative channel data to assess whether coarse (gravel and cobble) sediment input is in balance with the rivers transport capacity.

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[9] largest sediment size that can be moved.
[10] the total rate, in mass per unit time, at which the river can transport sediment.

A.4.1.3 Results

A.4.1.3.1 Sediment Input is Fine, Coarse, and Very Coarse

Based on visual estimated made at field survey sites where streamside or road sediment production was measured, we determined that fine sediment (sand and finer sizes) constitutes at least 70 percent of total sediment input to channels. Typically, we found that road and streamside sediment inputs (for all geology-vegetation unit types), average between 80 and 90 percent fine sediment. We also estimate that sediment production from shallow slides is about 70 percent or more fine sediment, because most soils in hillslope swales in the Navarro River basin contain this percentage or greater fine sediment (NRCS in-press; Wosika 1981). Gullies are another significant sediment production source in the Navarro River watershed. Based on field observations, it is estimated that fine sediment content from gullies is similar to that for streamside, shallow slide, and road sources (70-to-90%). Deep-seated landslides have the potential to deliver large quantities of weathered bedrock to channels which is typically coarse. However, considering that streamside, road, shallow slide, and gully sediment sources represent the majority of sediment input to channels in the Navarro River basin, and that each of these sources is thought to contain between 70 and 90 percent fine sediment, we estimate that about 80 percent of all sediment production to channels is fine sediment - sand or smaller in grain size.

If about 80 percent of sediment input is fine, then about 20 percent of input is coarse (gravel or larger sizes). Most coarse sediment is transported through channels as bedload, at a moderate rate relative to fine sediment which is transported predominately as suspended-load. Some fraction of the coarse sediment load that is input to a particular stream reach may be too large to be transported frequently as bedload. This very coarse sediment resides in the channel for very long periods of time until sufficiently large flows occur or until sediment breaks down into smaller sizes that can be transported during common floods. Based upon our field observations in a wide variety of stream channel types within the Navarro River basin, we estimate that less than 20 percent of coarse sediment input to these channels is very coarse or too large to be frequently transported as bedload. Considering our estimates, that 20 percent of total sediment input is coarse, and about 80 percent of coarse sediment is frequently transported as bedload, we estimate that approximately 16 percent of total sediment production to channels is coarse sediment (mostly gravel in size) that is frequently transported through the channel as bedload (i.e., 80 percent of 20 percent equals 16 percent). Very coarse sediment, too large to be frequently transported as bedload, then comprises about 4 percent of total sediment input to channels; this sediment typically resides in the channel for long periods of time with little transport.

A.4.1.3.2 Coarse Sediment Breaks Down into Fine Sediment During Transport in the River

Much of the coarse (gravel and cobble) sediment input to channels is rapidly broken down into sand and smaller grains during transport along the river because rock types that are common in the Navarro River basin (greywacke sandstone and shale) are often intensively fractured or sheared, and hence, easily broken down into finer sizes during transport. Work by Dietrich and Dunne (1978), Collins and Dunne (1989), and Madej (1995) demonstrate that very large fractions of easily broken rocks, do in fact, break down into suspendible sizes after fairly short distances of transport (< 10 miles) along a stream. Considering that the mainstem channel of the Navarro River (alone) is more than 20 miles long, and that Coastal Belt bedrock in the Navarro River basin is often intensively fractured or sheared, it is our opinion that two-third's or more of all bedload size material (coarse sediment) input to streams in the Navarro River basin is broken down into suspendible sizes by the time that it is transported to the mainstem Navarro River near its mouth. If about two-third's of coarse sediment input to channels is broken down into fine sediment during transport, then only about 5 percent of sediment input to mainstem Navarro River near its mouth is probably gravel or cobble in size (e.g., 1/3 x 16 percent = 5.3 percent), about 91 percent is in the size range that is transported most often as suspended load, and about 4 percent resides in small channels as very coarse sediment storage for long periods of time, undergoing little or no river transport.

A.4.1.3.3 Most Channels in the Navarro River Basin are not Aggrading (Filling with Sediment)

Excessive input of coarse or very coarse sediment can result in channels filling-in with sediment and becoming wide and shallow (channel aggradation). Excess fine sediment input does not usually cause gravel-bed streams (like most streams in the Navarro watershed) to aggrade with sediment for long-periods of time over large areas because fine sediment transport capacity is quite high in gravel-bed streams. We used two approaches to evaluate whether coarse and very coarse sediment input are causing channels to fill-in with sediment: 1) qualitative analysis of channel conditions and changes in sediment storage; and 2) comparison of bedload transport capacity to coarse and very coarse sediment input.

Based on field surveys stratified by stream-reach and sub-basin type, interpretation of channel cross-sections and time-sequential aerial photographs (see channel condition and storage studies for details), we found that most steep (slope[11] > 0.01), confined tributaries (those in narrow valleys) to the Navarro River have a limited ability to store large amounts of sediment in their channels for long periods of time. Although many steep or confined streams filled-in with sediment by 1965, sediment aggradation has not persisted to present-day in those channels.

Exceptions to this general statement (for steep and/or confined tributaries) include: a) North Fork and mainstem Indian Creek (upstream of the North Fork), in which, sediment filling and channel widening still persist today over several miles of channel; and b) North Branch North Fork Navarro River over a mile-long reach between Dutch Henry and Cook Creeks (where we conducted channel condition studies).

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[11] Slope refers to change in elevation of the stream-bed with distance along the channel. For example, if stream-bed slope =0.01, this means that bed elevation changes by 1 foot per 100 foot distance along the channel.

In total about 2.5 of 16 miles of stream channel surveyed for the channel condition study (15 percent) showed moderate-to-strong evidence of aggradation. We believe that other steep and/or confined reaches that were not surveyed are also aggraded, however, based on our analysis it appears that, in general, most steep and/or confined streams have recovered from historical aggradation.

In Indian Creek and North Fork Indian Creek, landsliding was particularly severe during the December 1964-January 1965 storms, and very large quantities of very coarse sediment (cobbles and boulders) were deposited in channels. Substantial amounts of sediment deposition have persisted in North Fork Indian Creek and upper Indian Creek, because neither stream (in the affected reaches) appears to be capable of transporting these very coarse sediment deposits (for details, see description of channel condition in North Fork Indian Creek). Sediment aggradation in North Branch North Fork Navarro River (NBNF) occurs on a much smaller scale (both in terms of distance along the stream and depth of deposits). Sediment aggradation in NBNF also appears to be related to recent sediment input, as evidenced by young alders at the margin of the channel which are dying (alder usually require well aerated roots and channel sedimentation has raised the dry-season water-table above the root zone). We did not conduct field surveys of sediment production to NBNF, and therefore, we cannot offer a site specific opinion as to why recent channel filling has occurred in NBNF between Cook and Dutch Henry Creeks. Based upon sediment production and channel condition surveys in a similar sub-basin and channel reach types (in SBNF), it is our opinion that channel filling on NBNF will be short in duration (i.e., < 10 years).

In large, gentle (slope < 0.01) tributaries which are unconfined, such as portions of Rancheria Creek and on Anderson Creek in Anderson Valley, historical channel filling and widening was much greater than in the steep and confined streams describe above. Although Rancheria Creek (where it flows through a wide valley) appears to be recovering from historical sediment deposition, still contains more sediment today than it did in 1952. Based on interpretation of present-day channel morphology in Anderson Creek in Anderson Valley, channel filling appears to be on-going.

In large streams with gentle slopes which are confined by steep hillslope canyons, such as the mainstem Navarro River and parts of Rancheria Creek, channel filling does not appear to have persisted to present-day.

A.4.1.3.4 Coarse Sediment Load and Transport Capacity Appear to be in Balance

Because we estimated bedload transport capacity at the river mouth (Section A.4.2), it is possible to develop an approximate comparison between bedload transport capacity and the percentage of sediment input to the lower Navarro River as bedload (coarse sediment input). Based upon this comparison, we estimate that bedload supply to the lower reach of the mainstem Navarro River is about 80 tons per square mile per year (e.g., 5% of 1600 tons) or less, as compared to an estimated bedload transport capacity of about 30-to-125 tons per square mile per year (best estimate = 60 tons per square mile per year). Given the approximate nature of the data used to develop this comparison, we conclude that coarse sediment supply appears to be approximately in balance with transport capacity. Conclusions by this approach agree with opinions based on qualitative analysis of channel condition and storage.

A.4.1.3.5 Large Amounts of Fine Sediment are Stored in Pools and Riffles

Based on characterization of sediment input by size class, we estimate that about 90 percent of total input is fine or about 1,450 tons per square mile per year. Because, in most steep streams (slope ≥ 0.01) fine sediment transport rate is primarily a function of the rate of supply, it is difficult to estimate actual fine sediment transport capacity. Therefore, we relied upon qualitative analysis of channel conditions to determine whether channels in the Navarro basin can accommodate present-day loads of fine sediment. We found (see channel condition analysis for details) that although fine sediment transport capacity is quite high in most channel types, the rate at which fine sediment is being input is likely even higher, as evidenced by appreciable quantities of fine sediment deposited in streambeds and pools. It is important to emphasize that present-day rate of fine sediment deposition are not causing substantial increases in channel bed elevation or width. Instead, fine sediment deposition is manifest at a smaller scale, primarily as shallowing of pools (which are partially filled with fine sediment), and as fine sediment filling the interstitial spaces between coarse sediment grains in riffles. In the Navarro watershed, these problems typically increase in magnitude with an increase in channel size or a decrease in stream-bed slope.

A.4.2 BEDLOAD YIELD STUDY

Sediments which are transported in channels near the streambed (usually gravels and cobbles) by either rolling, dragging, skipping, or saltating are commonly referred to as bedload. This is distinguished from suspended sediment load which refers to particles that are small enough to be lifted by the streamflow (usually sand and silts) and moved long distances downstream before settling to the streambed. The bedload, suspended load, and wash load (generally clays carried in suspension by streamflow) constitute the total sediment load. When the sediment supply to a stream channel is greater than its transport capacity, then channel aggradation may occur. Bedload sediments are often that portion of the sediment load which cannot not be mobilized and transported by stream channels. The feasibility of restoring channel and fish habitat conditions that have been altered due to land-use changes and associated increases in sediment production to stream channels depends, in part, on the relative balance of sediment supply and capacity to transport bedload sediments.

We conducted a study to estimate the long-term average bedload transport capacity of the Navarro River near the mouth. The purpose of this study was to provide a means to:

1. estimate the capacity of the Navarro River to transport bedload sediments delivered from tributary streams in the watershed

2. consider the feasibility of performing in-channel restoration treatments on the mainstem Navarro

3. cross-check the results of our independently derived sediment production estimates

A.4.2.1 Summary

We used the Meyer-Peter Müller (1948) and Bagnold (1980) bedload transport formulas to estimate average annual bedload sediment yield for the Navarro River near Navarro (USGS stream gaging site 11468000) during Water Years 1969-1996. We selected this measurement site because: a) it provides an approximate estimate of bedload transport capacity near the mouth of the basin; b) currently there is much interest in restoration of the Navarro River estuary, including how the Floodgate Creek landslide may affect estuary sedimentation; c) the availability of long-term streamflow data at the gage site allow us to define accurately the magnitude and frequency of high flows in the river, and to calculate the amount of shear stress available for bedload transport (force per unit area exerted on the streambed); and d) channel conditions within the study reach are compatible with channel conditions in other streams where the Bagnold and Meyer-Peter Müller formulas have provided reliable estimates of bedload yield. Using the Meyer-Peter Müller formula, we estimate that average annual bedload yield for Water Years 1969-1996 is approximately 63 tons/mi^2/yr (22 metric tons/km^2/year); using the Bagnold formula, the estimate is approximately 17 tons/mi^2/yr (6 metric tons/km^2/year).

The best check to evaluate accuracy of these estimates would be comparison to actual bedload transport rate measurements for the Navarro River. However, no measurements of bedload or suspended load transport rate have been made in the Navarro River (Markham and Boults, USGS Ukiah, CA, personal communication). In the absence of actual bedload transport rate measurements, measured sediment transport rates for nearby streams with similar physical attributes (bedrock geology and uplift rate) and land-use activities, can be used to provide a check on the reasonableness of the calculated bedload yield estimates.

Measured sediment transport rates exist for several watersheds near the Navarro River in which geology and uplift rate are similar. However, present-day and/or historical gravel mining has been substantial in all of these "physically similar" basins, except for the South Fork Eel River near Branscomb. Based on comparison to measured sediment transport rates for South Fork Eel River near Branscomb, it appears that calculated values of bedload yield for the Navarro River near Navarro derived using the Meyer-Peter Müller formula (1948) are reasonable, and probably accurate within about a factor of two times the actual rate.

A.4.2.2 Methods

Estimation of bedload yield using transport formulas involved four sequential steps: 1) selection of a useful site for sediment transport estimation; 2) measurement of channel cross-section and slope, and sediment sampling to quantify the grain size distribution of the streambed surface layer and subsurface deposits; 3) reduction of channel survey and sediment data and review of streamflow and hydraulic geometry data in order to compare the site being modeled to the conditions in channels and flumes where bedload transport formulas have been calibrated; and 4) check for reasonableness of calculated results by comparison to actual sediment measurement data (e.g., data collected at the measurement site or in nearby basins with physically similar attributes and land use activities).

A.4.2.2.1 Selecting a Channel Reach

Because most bedload transport formulas were developed from laboratory flume data, the reach being modeled ideally should have a flume-like channel shape: a fairly straight single-thread channel that is free of obstructions to flow (e.g., little vegetation, woody debris, bedrock or boulders in the channel, and little variation in reach-wide slope or bed elevation in channel cross-section). It should be formed in alluvial (river) deposits because an implicit assumption in all of the bedload transport models is that there is an unlimited supply of sediment (like that in the bed) that is available for transport. Other important considerations in site selection for modeling are: 1) the ability to accurately characterize the magnitude and distribution of the high flows that transport the bedload sediment; and 2) availability of previously collected sediment measurement data and/or ability to easily measure sediment transport through the reach.

We selected an approximately 0.5 mile long reach centered at the Navarro River near Navarro stream gage site, as the reach for bedload transport modeling because 1) it has a long streamflow record (Water Years 1952-1996); 2) the gage is located in a fairly straight, alluvial reach, that has fairly simple and homogeneous channel geometry, and homogeneous sediment sizes in riffles and bars. This reach deviates somewhat from ideal flume-like conditions because young willows and alders are common on the flat tops of many of the low elevation bars which fringe the channel banks, and the bars themselves provide considerable resistance to flow because they cover approximately 50 % of the channel bed area. Channel width-to-depth ratio at bankfull flow is also quite low (W:D approximately 10), and therefore, channel banks probably provide more resistance to flow than is typical in a large stream. A mature redwood forest covers flood plains adjacent to the channel. It appears, therefore, that when the channel floods, vegetation roughness may increase by a substantial amount. These channel attributes probably cause substantial resistance (obstruction) to flow in the channel, when flows are much less or much greater than bankfull discharge. Based on the comparison of actual versus ideal conditions, we believe that there may be a tendency for the formulas to over-predict transport rate because the Navarro River channel is rougher than a flume, and consequently a smaller fraction of its total energy is available for sediment transport.

A large throughput load of sand was observed in the reach, based upon thick sand deposits covering most pools, glides, and runs (this condition deviates from ideal homogeneous distribution of sediment sizes). We believe that time-average sediment grain size distribution of bedload can be accurately approximated, however, by subsurface deposits beneath riffles and bars in the reach (Lisle 1995; Dietrich 1989; Parker and Klingeman 1982), and therefore, it does not appear to be necessary to sample and model the transport of sand throughput material separately.

A.4.2.2.2 Field Data Collection and Review of Streamflow and Hydraulic Data

We surveyed channel cross-section at the USGS cable-way (high flow measurement site) and the longitudinal profile of the stream bed over a reach length approximately equal to 20 times bankfull channel width. At the cross-section, we surveyed topographic breaks associated with bars, thalweg, and banks. We noted active bed width (that portion of the stream bed where clasts appeared to have been moved by high flows in recent years[12] and its position on the transect, channel thalweg, vegetation types, and the intermediate diameters of the largest rocks moved during recent high flows. Positions of habitat/hydraulic units (riffles, pools, bars, glides, runs) were noted on the long profile. Estimated accuracy of surveyed bed and bank elevations is ± 0.1 feet.

We used pebble counts to sample the surface layer of the stream bed, and we used a modified McNeil sampler to obtain bulk samples of subsurface stream bed deposits once the surface layer had been removed at sampling sites. Five pebble counts were performed on riffles and/or bars distributed throughout the surveyed reach to provide data for estimation of critical shear stress for particle entrainment, and to guide sampling intensity for subsurface deposits. We also sampled bulk subsurface sediment deposits to characterize the grain size distribution of the bedload (Dietrich 1989; Parker and Klingeman 1982). We found that there was little variation in surface layer grain sizes of bars and riffles in the measurement reach, and that the surface D90 and D50 (the particle sizes for which 90% and 50% of the sample, by weight, is finer) were quite fine (32mm and 16mm respectively or about 2/3 and 4/3 of an inch). We sampled bulk subsurface sediment deposits in two locations within the active bed width in the vicinity of the USGS discharge measurement cross-section. Each sample was approximately 80 liters in volume. Because the largest single clast in both samples (intermediate diameter 45 mm in sample 1 and 64 mm in sample 2) comprised much less than 1 percent of total sample volume, the combined sample volume is sufficient to reliably characterize D50 of bedload.

Navarro River near Navarro gage provides a continuous record of mean daily flow for water years[13] 1952 to 1996. However, because the stream gage was relocated to its present location in 1969, and because our cross-section and longitudinal profile data were collected at the present gaging station location, we have only calculated bedload yield estimates for the 1969-1996 period. Hydraulic geometry relationships, equations relating stream width, depth, velocity to discharge, varied substantially from the beginning to the end of 1969-1996 period. However, hydraulic geometry was fairly uniform within each of the following periods: water years 1969-1975, 1976-1994, and 1995-1996. Therefore, we defined hydraulic geometry and flow duration curves[14] for each of these periods. Flow duration, hydraulic geometry, channel survey, and sediment data were then used to

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[12] as evidenced by lack of vegetation covering deposits, looseness and imbrication of clasts, and "fresh" appearing surfaces on rocks (e.g., recent tumbling).

[13] water years begin on October 1 and end on September 30 of the named year. For example, water year 1952 began on October 1, 1951 and ended on September 30, 1952.

[14] flow duration curves characterize the percentage of time in the indicated period in which flow of a given magnitude is equaled or exceeded.

construct the bedload yield models used to develop estimates of average annual yield over water years 1969-1975, 1976-1994, and 1995-1996.

A weighted average of these rates is used to estimate long-term average annual bedload yield. Sediment grain size, channel slope, and hydraulic geometry data used to estimated bedload yields are presented in Table A-35.

A.4.2.2.3 <u>Evaluation of Accuracy of Bedload Yield Estimates</u>

Measured sediment transport rates exist for several basins near the Navarro River basin, in which bedrock and surficial geologic units (Coastal Belt and/or melange units of the Franciscan Assemblage, and Quaternary valley fills) and uplift rate (0.3 mm/year) are similar to the Navarro River watershed: Dry Creek near Geyserville, Garcia River near Point Arena, Russian River (near: Ukiah, Cloverdale, Healdsburg), and South Fork Eel River near Branscomb. Logging and ranching are widespread in each of these basins. Present-day and/or historical gravel mining intensity have been substantial in all of the basins listed above, except for the South Fork Eel River near Branscomb. Because gravel mining in the Navarro River basin appears to be at a low to moderate rate relative to natural replenishment, it would be inappropriate to compare the Navarro River to an otherwise similar basin where in-stream gravel mining rate is substantial relative to natural replenishment. We identified only one stream where measured sediment transport rates exist, and where physical attributes and land use activities are similar to the Navarro River basin: South Fork Eel River near Branscomb (Table A-36). Using relationships reported in Reid and Dunne (1995), we reviewed streambed grain sizes, suspended sediment concentration and grain size distributions to estimate bedload yield as a percentage of total sediment yield. Based on those data, we estimate that bedload is

Table A-35. Sediment Grain Size, Channel Slope, and Hydraulic Data for the Navarro River near Navarro bedtbl01.xls.

Table A-36. Comparison Between Physical Attributes and Sediment Transport Rates in the Navarro River and South Fork Eel River Near Branscomb.

Drainage Area (mi^2)	Coastal Belt	Melange	Quaternary Units	Estimated long-term Suspended yield ($tons/mi^2$)	Estimated long-term Bedload Yield ($tons/mi^2$)
SOUTH FORK EEL RIVER NEAR BRANSCOMB					
44	75	20	5	1,480[a]	71-to-145
NAVARRO RIVER NEAR NAVARRO					
303	80	12	8	no data	63

(a) long-term rates extrapolated by Anderson (1979) from time-integrated, suspended sediment measurements over a period of years.

between 5 and 11 percent of total sediment yield in South Fork Eel River near Branscomb. Based on comparison to the South Fork Eel River near Branscomb, it appears that calculated values of long-term bedload yield for the Navarro River near Navarro (derived using the Meyer-Peter Müller bedload transport formulas) are reasonable, and probably accurate within about a factor-of-two (2X) of actual rate (Table A-37). Calculated values of long-term bedload yield for the Navarro River basin derived using the Bagnold (1980) formula appear to be low (see Table A-36), based on the following rationale:

1. In several basins with similar geology and drainage area that are located nearby to the Navarro River basin, bedload yield appears to be between 5 and 11 percent of total sediment yield. Assuming that bedload yield is also between 5 and 11 percent of total yield in the Navarro River near Navarro, then estimated bedload yield of 17 tons/mi^2/yr (using Bagnold formula) would equal an extrapolated total sediment yield of between 160 and 340 ton per square mile per year. This equals only 20 to 60 percent of typical long-term rates.

Long-term total sediment yields (suspended-load plus bedload) has been measured in several basins underlain by the Coastal Belt or other coherent sandstone units of the Franciscan Formation. Total sediment yields are typically between 510 and 860 ton/mi^2/year (Janda 1972, Rice *et al.* 1979; Kelsey 1980, Napolitano 1996).

Total sediment yield from the Navarro River near Navarro is likely somewhat higher than 860 tons/mi^2/year because a substantial fraction of the basin (15 percent) is underlain by Franciscan melange which has a much higher sediment yield per unit area, (typically 5,700 to 8,600 tons per mi^2 per year (Janda 1972; Kelsey 1980).

A.4.2.3 Results/Conclusions

The long-term average bedload yield for the Navarro River watershed, near the mouth, using the Meyer-Peter Muller bedload transport formula is approximately 63 tons/mi2/yr (22 tonnes/km2/yr). Assuming that bedload yield in the Navarro watershed represents between 5 and 11 percent of the total sediment yield (suspended sediment plus bedload sediment), then total sediment yield is estimated to be between 570 and 1,250 ton/mi2/yr (200 and 440 tonnes/km2/yr). We have independently estimated total sediment production in the watershed to be approximately 1,600 tons/mi2/yr (see Chapter 3, Table 3-4). As a cross-check, the results of the bedload yield calculations provide reasonably good agreement with our independent estimates of total sediment production in the watershed.

Conversely, if total sediment production in the watershed is 1,600 tons/mi^2/yr, and bedload represents between 5 and 11 percents of the total yield, then the portion of the total sediment yield which is transported as bedload is between 75 and 165 tons/mi^2/yr. The results of this analysis indicate that the long-term average bedload transport rate is approximately 60 tons/mi^2/yr near the mouth of the Navarro River. This bedload

Table A-37. Estimates of Annual Bedload Yield Using the Bagnold (1980) and Meyer-Peter Muller (1948) Bedload Transport Formula.

Bedload Transport Formula	Average Annual Bedload Yields water years 1969-1975 (tons/mi²/yr)	water years 1976-1994 (tons/mi²/yr)	water years 1995-1996 (tons/mi²/yr)	Long-term Average (1969-1996)	
Meyer-Peter Muller	63	57	105	63	
Bagnold	20	14	34	17	
Bedload Transport Formula	**water year 1992 (tons/mi²/yr)**	**water year 1993 (tons/mi²/yr)**	**Estimated Yields for Recent Years** **water year 1994 (tons/mi²/yr)**	**water year 1995 (tons/mi²/yr)**	**water year 1996 (tons/mi²/yr)**
Meyer-Peter Muller	26	123	9	174	40
Bagnold	9	26	3	51	14
type of runoff year:	below average	wet	dry	very wet	above average

transport rate is within 1.2-to-2.5 times the amount of bedload yield to the mainstem Navarro River.

The difference between the estimated bedload yield and the calculated bedload transport rate is relatively small given the margin-of-error often associated with bedload transport rates determined from formulas. In a study comparing eight sediment transport formulas with measured transport rates in flumes, the computed values ranged from one-half to twice the observed transport rates (Leopold 1994). In addition, our sediment production estimates are accurate to within an order-of-magnitude, and we have made assumptions regarding the proportion of total sediment production that is represented by bedload yield. It is likely that the bedload yield and bedload transport rates are sufficiently close in the Navarro watershed to be considered approximately in-balance. Had the bedload transport capacity been more than an order-of-magnitude smaller than the estimated bedload yield, then we would expect sediment production in the watershed to overwhelm the capacity of the mainstem Navarro to transport those bedload sediments and channel aggradation would be likely to occur.

A.4.3 Channel-Sediment Storage Study

A.4.3.1 Introduction and Summary

The volume, distribution, and grain-sizes of sediment stored in stream channels have direct bearing on fish habitat conditions, channel stability, and sediment yield. In a stream channel at grade, by definition, scour and deposition of sediment are in balance over a period of years, which implies a balance between the transport capacity and sediment load of the stream (Mackin 1948). If over a period of years, however, a stream channel shows a progressive trend toward filling (aggradation) or toward incision (degradation), then the stream is no longer at grade. In such cases, channel-sediment storage changes (i.e., aggradation or degradation) may substantially alter the magnitude and grain-size distribution of sediment yield from a basin. This study focuses on evaluating whether the mainstem Navarro River and its low-gradient, unconfined tributaries aggraded substantially in response to intensive logging and large storm events (1955, 1964, 1974), and if so, whether aggradation has persisted to present-day.

Natural sites for large amounts of channel-sediment storage are highly susceptible to aggradation (Montgomery and Buffington 1993). In most cases, channel aggradation is caused by rapid and/or intensive watershed disturbances which cause sediment input to streams to increase substantially. Channel aggradation may also occur naturally in response to large storm events and natural evolution of hillslope or river features (Helley and LaMarche 1973; Kelsey 1980). Following the December 1964-January 1965 storm, hillslope erosion and channel aggradation in streams throughout northwestern California were pronounced and disproportionate relative to the size of the flood (Waananen *et al.* 1971; Harden et. al. 1978). Intensive road building and recent clear-cutting of forests preceding the December 1964 storm are implicated as likely causes for disproportionate hillslope and channel impacts in Redwood Creek basin (Harden 1996).

In the Navarro River basin, there was a logging boom that began in the late 1930's and continued through the early 1950's (Adams 1971). During that period, large tracts of redwood-dominated forest in the lower basin (downstream of Anderson Valley) were re-entered and cut, and much of the Douglas Fir-dominated forest in the upper basin was cut for the first time (Adams 1971). Tractor yarding, construction of extensive road networks, and the use of streams as skid-trails characterized logging practices in this period. The intensive logging of the late 1930's through early 1950's, coupled with large floods in 1955, 1964, and 1974 (Table A-38) appear to have contributed to substantial aggradation and widening of the Navarro and its tributaries. Long-time residents tell of pools filling with sediment, significant widening of channels, and disappearance of riparian vegetation in the 1950's and early 1960’s (B. Glover, C. Hiatt. personal communications 1996). Interestingly, impacts of the 1974 flood were not commented upon, although it was much larger than the 1964 flood, and almost as large as the 1955 flood. Residents also commented that floods in the late 1950's and early 1960's had significantly greater impacts in terms of channel widening, silt and debris deposition on floodplains, and landsliding than did recent large floods in occurring in 1993 and 1995 that were of similar magnitude (B. Glover, C. Hiatt). Long-time residents indicate that significant fish declines became apparent from the late 1940's on Mill Creek, (B. Glover, personal communication 1996) to the mid-1960's on Anderson Creek (E. Johnson, personal communication 1996). Although residents believe that sediment inputs into creeks have declined since the 1970's, they have not seen fish populations recover (Glover, Hiatt, Johnson, personal communications 1996).

In many streams in northwestern California where channel aggradation and widening were substantial following the 1964 flood, streambed elevations have now degraded to pre-flood levels with little or no narrowing of channel width (Lisle 1982; Nolan *et al.* 1987; Madej 1996). Full narrowing in confined channels to pre-flood widths is typically quite slow because replenishment of sediment is slow and re-establishment of riparian vegetation is difficult given the forces exerted at the base of the hillslopes during high flows (Lisle 1982). In unconfined, alluvial stream reaches, it is more likely that channel narrowing may occur with recovery of pre-flood bed elevation. Time required for narrowing in alluvial reaches is a function of the sequencing of high-flow events, texture of sediment deposited on bars, and height and proximity of deposits in relation to those experiencing frequent scour (Lisle 1981).

Re-establishment of pre-disturbance pool-riffle sequences is another measure of channel recovery. It appears that pool spacing may have recovered in many of the streams in northwestern California that experienced substantial aggradation and widening in 1964 (Lisle 1986), however, pool depths are probably much shallower today in many of the streams (for example, Madej 1996 describes Redwood Creek; Kier Associates 1992, describes the Garcia River). Long-time residents of the Navarro River basin, familiar with mainstem Navarro River (B. Glover) and Anderson Creek (C. Hiatt), report pools as deep as 10-to-12 feet, and 7-to-8 feet in those two streams (personal communications 1996). Pools surveyed during the summer of 1996 in mainstem Navarro River over a

Table A-38. Record of Large Floods Between 1950 and 1995.

two-mile long reach centered at the confluence with North Fork Navarro River were typically less than 4 feet deep.

A.4.3.2 Methods

Our assessment is based on interpretation of: a) changes in channel morphology and width detectable on air photos (1:20,000 to 1:31,680) taken in 1952, 1965, 1981, and 1992; b) channel widths, bar and bank heights, vegetation types and sizes, and median sediment grain-size (D50) in the surface layer of the stream bed[15] that were measured in the summer and fall of 1996; c) repeated surveys through time of channel cross-sections at highway and road bridges (Figures A-7 through A-17); d) historical and recent topographic maps; and e) interview of long-time residents and other individuals who have observed river changes through time.

Changes in the boundaries of the active channel were mapped through time. The active channel was defined as that portion of the channel which appears to have experienced recent hydrologic activity, including scour of vegetation and/or movement of deposited sediments. The active channel therefore includes unvegetated bar areas as well as bars covered with vegetation that appears to be ephemeral and/or recently established. Four vegetation cover types corresponding to the activity level or frequency of scour or deposition of sediment were defined and delineated for channel deposits in the reaches mapped: 1) unvegetated gravel bar; 2) grass-covered deposits; 3) grass dominated with minor coverage by willows and/or shrubs; and 4) riparian woodland (50 % of surface area covered by riparian tree species). Bank heights, active channel width, and vegetation cover types on bars, flood plains and terraces were noted during field reconnaissance of mainstem Navarro River, upper and middle Rancheria Creek, and Anderson Creek in the Anderson Valley (reaches upstream and adjacent to Highway 128). Field observations were evaluated in concert with vegetation cover type and surface relief of deposits detectable on the aerial photographs to delineate active channel boundaries.

Aerial photos of the channels taken in 1952, 1965, 1981 (all at 1:20,000 scale), and 1992 (1:31,680 scale) were enlarged to 1:10,000 scale on a high-resolution Cannon color photocopier. Comparison of features with fixed length or width (such as roads, houses, fence lines, barns, etc.) suggests that scale distortion is insignificant. In some reaches, exact demarcation of active channel boundaries was difficult due to a number of factors. Certain photos appeared washed out making distinction between unvegetated and grass covered features difficult to discern. The 1992 photographs were taken at a smaller scale

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[15] We surveyed Anderson Creek in Anderson Valley; upper and middle reaches of Rancheria Creek; and mainstem Navarro River for 1.0 miles upstream of the North Fork Navarro River confluence. We believe that Navarro River upstream of the North Fork Navarro River, has similar morphology and dimensions as the Mill Creek to Floodgate Creek study reach, and therefore, we used data collected there. In lower Rancheria Creek, vegetation patterns, valley and channel widths, and reach gradient are similar to those in middle Rancheria Creek study reach, and therefore, we used middle Rancheria Creek data to characterize channel boundaries in the lower Rancheria Creek.

Figure A-7. Anderson Creek Cross-section @ Highway 253 - Upstream.

Figure A-8. Anderson Creek Cross-section @ Highway 128 - Upstream.

Figure A-9. Indian Creek Cross-section @ Highway 128 - Upstream.

Figure A-10. Mill Creek Cross-section @ Highway 128 - Upstream.

Figure A-11. Flynn Creek Cross-section @ Highway 128 - Upstream.

Figure A-12. Greenwood Bridge Cross-section @ Navarro River -Upstream.

Figure A-13. Navarro River Cross-section @ Highway 1 Bridge - Upstream.

Figure A-14. Hibbard Road Bridge Cross-section @ Rancheria Creek - Upstream.

Figure A-15. Rancheria Creek Cross-section @ Fish Rock Road - Upstream.

Figure A-16. Maple Creek Cross-section @ Highway 128 - Upstream.

Figure A-17. Ornbaun Creek Cross-section @ Highway 128 - Upstream.

(1:31,680) than 1952, 1965, and 1981 photos (1:20:000). Although this difference was correctable by enlarging all copies of photos to 1:10,000 scale for mapping purposes, sometimes details of 1992 photos were difficult to distinguish. In narrow, confined reaches, riparian canopy sometimes created shadows which partially or totally obscured the channel for a considerable distance. Also, photos taken later in the year would be more likely to show grass-covered bars within the active channel, while photos taken earlier would be more likely to show water covering larger percentage of the active channel. In cases where boundaries between vegetation units were uncertain, dashed rather than solid lines were used. Each channel reach was divided into sub-reaches, with major channel bends/point bars being assigned numbers, and straight reaches given letter designations. The average width of the active channel in each sub-reach was then measured for each photo year using a measuring magnifier, allowing an estimate of active channel width and percentage change over time at each significant bend or straight reach for the periods between the photographs: 1952-1965, 1965-1981, and 1981-1992.

Only a few bridge cross-sections in the Navarro River basin have been repeatedly surveyed, and those within the study reaches are typically very widely spaced. Therefore, in this analysis, we also relied upon channel width increases as an index of channel aggradation. However, as discussed above, subsequent persistence of channel widening does not necessarily indicate a persistence of channel bed aggradation, and therefore, data in addition to channel width changes are usually required in order to discern stream bed degradation.

Based upon inferred sediment storage patterns in the Navarro River basin (described earlier), we selected five study reaches for analysis:

1. Anderson Creek in the Anderson Valley - downstream of the highway 128 bridge to a point downstream of Con Creek;

2. upper Rancheria Creek - upstream of highway 128;

3. middle Rancheria Creek - along highway 128 from Maple Creek to a short distance downstream of Shearing Creek;

4. lower Rancheria Creek - from 1.0 mile upstream of Rawles Canyon to a short distance downstream of Bear Wallow Creek; and

5. mainstem Navarro River -from Mill Creek to Floodgate.

Anderson Creek is developed in a wide valley; Upper Rancheria Creek is unconfined or moderately confined over the study reach. Middle and lower Rancheria Creek and mainstem Navarro River are confined (with few exceptions) throughout the study reaches. Reach-wide average stream-bed slopes are typically gentle in Rancheria and Anderson Creeks (S = 0.004 to 0.009) to very gentle in mainstem Navarro River (S = 0.001).

A.4.3.3 Results

Based upon field observation of a wide range of stream reach types and sub-basin settings (see Section 4.3 Channel Condition Study), it appears that most tributaries of the Navarro River have a limited potential to store large volumes of sediment for long periods of time (e.g., many decades or more) because they are steep ($S \geq 0.01$) and confined within narrow valleys, and large woody debris (LWD) loading is typically very low[16]. We also conclude (in most cases) that in steep tributary streams with narrow valleys, there is little evidence of present-day aggradation or degradation. Therefore, present-day sediment yields in these stream types appear to be similar to the present-day rates of sediment production to the channels (i.e., no net gain or less of sediments in storage).

Conversely, field and air photo observations indicate that a much larger amount of sediment is stored in large low-gradient ($S \geq 0.01$) tributaries of the Navarro River that are developed in wide valleys, than in the steep and confined tributaries described above. This finding is consistent with sediment storage relationships documented in Redwood Creek basin in Humboldt County, California (Pitlick 1996; Madej *et al.* 1996). In both basins, much more sediment is stored in large, low-gradient (gently sloping) streams developed in wider valleys because: a) channel slope decreases abruptly, and hence, sediment transport capacity typically decreases substantially; b) in wide valleys, channels are "free" to meander back and forth, and therefore, deposit alternate bars, each of which may comprise a considerable amount of stored sediment. In general, sediment storage capacity increases with downstream increase in drainage area. Notable examples of large, low-gradient, tributaries developed in wide valleys are the alluvial reaches of Rancheria Creek located discontinuously along and upstream of Highway 128, and most of the length of Anderson Creek within the Anderson Valley. In those stream reaches, very large amounts of sediment are stored in wide, poorly vegetated gravel bars. Lack of vegetation, on bars implies frequent or recent scour and deposition.

Although the mainstem Navarro River is confined within a narrow valley and inner gorge throughout most of its length, large amounts of sediment are also stored in its channel because: a) it is located downstream of nearly all major sediment sources; b) it has a gentle slope throughout its length, and hence, its sediment transport capability is reduced relative to most of its confined tributaries; and c) drainage area and channel width is much larger than in its confined tributaries. As expected, large gravel bars, albeit much narrower than those in alluvial reaches of Rancheria and Anderson Creeks, are found throughout the length of the mainstem of the Navarro River. In most cases, vegetation is restricted to the margins of these bars, and most of the surface areas of the bars are unvegetated. Considering the length of the mainstem of the Navarro River, and the lack

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[16] Based upon field surveys of channel condition, we concluded that evidence of historical loss of LWD is strong across a wide spectrum of stream reach types surveyed. Field observations included: LWD frequency and sizes, pool spacing, percentage of pools formed by LWD, and channel functions provided by LWD.

of vegetation cover, these bars, collectively, appear to represent a significant amount of frequently mobilized sediment.

Assuming that measured increases in channel width are indicative of channel aggradation, we conclude that all of the study reaches aggraded substantially between 1952 and 1965 (Table A-39). Increases in channel width between 1952 and 1965 were greatest in alluvial reaches of Anderson and Rancheria Creeks (about 30 to 50 percent). More confined study reaches of the mainstem Navarro River and Rancheria Creek typically increased, on average, by about 20 percent. Based upon very high width-to-depth ratios and unvegetated mid-channel bars observed on 1952 air photos, it appears that channel aggradation was already in-progress as of 1952 in upper Rancheria and Anderson Creeks. Comparison of 1996 stream-bed elevations to as-built stream-bed elevations (see Figures A-7 and A-8; prepared by Mendocino County Water Agency) also suggests that aggradation was in-progress at those locations as of the times that the bridges were built in 1958 and 1962. Based upon channel morphology observed on 1952 air photos of the mainstem Navarro River, and the middle and lower reaches of Rancheria Creek, it appears that evidence of active channel-aggradation (in 1952) is inconclusive. Bridge cross-section data for the Navarro River at Highway 1 Bridge (see Figure A-13) indicate that some bed aggradation was occurring between the late 1940s and early 1970s. However, the river appears to be relatively stable since the 1970s, with some very recent (1977) evidence of the channel down-cutting and returning to near its original (1947) bed elevation. The bridge cross-section data for the middle and lower reaches of Rancheria Creek are sufficient to indicate the onset of bed aggradation. The bridge cross-sections (see Figures A-14 and A-15) however, do indicate that the middle and lower reaches of Rancheria Creek have been relatively stable since the mid-1970s, with some evidence of channel downcutting, similar to the mainstem Navarro River. Interview of long-time residents suggest that noticeable changes in the Navarro River and Rancheria Creek occurred after the 1955 and 1964 floods.

Between 1965 and 1992, channel widths in confined reaches (mainstem Navarro River and most of middle and lower Rancheria Creek) decreased by 10-to-20 percent, such that channel widths in those reaches in 1992 are similar (Rancheria Creek) or slightly larger (mainstem Navarro River) than they were in 1952 (see Table A-39). Partial recovery of the channel is also evident in, upper Rancheria Creek. At some of these locations, young willows and alders have begun to colonize bank-fringing lateral bars. Highway 128 bridge cross-sections over Indian, Mill, and Flynn Creeks also document pool scour of 1-to-2 feet between 1992 and 1996 (see Figures A-9 through A-11). Substantial pool scour during the winter of 1995 at the USGS stream gage on the Navarro River near Navarro[17], has caused the USGS to establish a new gage datum (elevation marker) that is about 2 feet lower than the former datum that had been in use since 1969. Recent pool scour at the Highway 128 bridge cross-sections on Indian Creek, Mill Creek, and Flynn Creek,

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[17] Scour here since March of 1995 may also be attributable to the remnants of the Floodgate Creek landslide dam which ponds water and causes bedload input from upstream reaches to be deposited in the pond.

Table A-39. Reach-Wide Average Changes in Active Channel Width.

and the pool scour at the USGS gage, when considered together suggest that there may be a trend, in recent years, toward deepening of pools in the mainstem Navarro River. As discussed earlier however, it appears that present-day depths are probably still somewhat shallower than historical depths. The cross-section in mainstem Navarro River at Greenwood Road Bridge appears to illustrate this situation (see Figure A-12).

Little average decrease in channel width has occurred in Anderson Creek subsequent to widening which occurred between 1952 and 1965. In fact, bars in Anderson Creek continued to increase in average width through 1981. Given the magnitude and persistence of increases in channel width, we also estimated the amount of sediment that has accumulated in the study reach of Anderson Creek between 1952 and 1992. This involved measurement on air photos of changes in the areas of unvegetated to poorly vegetated gravel bars, and assuming that typical bar heights in 1952 and 1992 were similar to heights measured in 1996. Using this approach, we estimate that about 195,000 metric tons of sediment accumulated in bars (in the study reach) between 1952 and 1992, or about 50 metric tons per km^2 per year (Table A-40).

Considering the magnitude of the sedimentation in Anderson Creek between 1952 and 1992, it is quite important to understand present-day and future trends in channel-sediment storage in this reach because of the ramifications for channel stability and restoration potential. However, based upon the lack of high flows between 1987 and 1992, and limited cross-section data for Anderson Creek, it is difficult to determine present-day and likely future trends in channel-sediment storage. To determine this, it would be useful to establish and survey repeatedly (over a period of years) a network of channel cross-sections in Anderson Creek in the Anderson Valley, and to perform pebble counts at the cross-section sites and sites located short distances downstream on Anderson Creek and mainstem Navarro River. Given those data, it should be possible to forecast accurately future trends in channel-sediment storage in Anderson Creek within the Anderson Valley. Based upon channel attributes observed in the summer of 1996, we conclude that evidence of present-day aggradation in Anderson Creek appears to be strong, and therefore, we believe that attempts to re-establish a flood-plain riparian forest would be mostly unsuccessful at this time.

A.4.4 CHANNEL CONDITION STUDY

"In forested regions, channel form reflects inter-relationships between watershed inputs to the channel (sediment, wood, and water) and the ability of the channel to either transport or store these inputs" (Sullivan *et al.* 1987). Because channels convey watershed inputs, channel condition provides a direct measure of present-day channel function and of the health of the watershed. Channel condition studies involved detailed description and interpretation of several channel attributes that can be used to assess: a) physical suitability and processes influencing aquatic and riparian habitat conditions; b) water quality attributes (sediment load and temperature); and c) likely channel responses to future watershed disturbances.

Table A-40. Changes in Anderson Creek Sediment Storage 1952-1992.

Considering that the primary goals of the Navarro watershed restoration plan are to restore water quality and salmonid habitat conditions, we selected field survey sites where we believed coho salmon and steelhead trout occur at present or occurred historically. In order to assess land-use activities and physical setting by stream reach type, fish distribution, and channel conditions, we attempted to include a broad array of stream reach, sub-basin, land use, and geological types in the sample of stream reaches surveyed.

A.4.4.1 Methods

Our assessment of channel condition in the Navarro River watershed is based upon:

1. interpretation of aerial photographs and topographic maps to develop a reconnaissance-level classification of stream reach types throughout the watershed, and to describe historical changes in channel width and canopy opening (1952 to 1992); and

   Large to moderate scale (1:20,000 to 1:31,640) time-sequential aerial photographs (1952, 1965, 1981, 1992) were reviewed to discern changes in channel width and riparian canopy opening through time. Time sequential changes in channel width and canopy opening were noted for several representative sub-basins and/or stream reaches which included a wide array of stream reach types and stream order, geological settings, and vegetation/land-use types. Easy to relocate features, such as tributary junctions, gravel bars, distinctive channel meanders, bridges, etc., were selected to define consistent reach sampling boundaries and cross-section locations for channel width and riparian opening measurements between surveys. Typically, few measurements of actual channel width or canopy opening were made. Instead, time sequential photos of a reach were visually inspected to discern qualitatively a trend (increase, decrease, no significant change), and the magnitude of changes (as a percentage of previous channel width or canopy opening) through time.

2. field studies to describe present-day channel conditions, sediment supply, and processes controlling physical aspects of salmonid habitat. Field surveys focused on: a) channel dimensions, b) streambed morphology, c) channel confinement, d) pool attributes, e) LWD loading and distribution, f) riffle sediment texture, g) bar attributes, and h) flood plain and terrace attributes.

We classified and surveyed approximately 16 miles of stream channels occurring in a wide array of sub-basin conditions (Table A-41). Table A-41 is a matrix which classifies the stream reaches surveyed based upon their slope, channel bed morphology, and degree of channel confinement (defined as ratio of channel width to valley width). Stream reaches surveyed varied in size, gradient, confinement, and bed morphology from steep and confined headwaters reaches to large and low-gradient streams, including the mainstem of the Navarro River (Table A-42).

Table A-41. Matrix Classifying Stream Reaches Surveyed.

UNCONFINED VW[a] > 4CW[b]	Ray's Gulch				**not applicable**
MODERATELY CONFINED 2 CW < VW < 4CW	SBNF 1 SBNF 3b NBNF b Navarro dsNF Navarro usNF Upper John Smith	North Fork Indian Lower J. Smith	Beasley Lower Beasley upper a Marsh 1a Marsh 3a Mill 4b Upper Con a	Beasley Upper b Marsh 1b Marsh 3b	
CONFINED VW < 2CW	NBNF a	SBNF 2 SBNF 3a Mill 3 Little North Fork	Mill 4a	Marsh 2a Bear Wallow Upper Con b	Marsh 2b
SLOPE:	< 1.0	1.0 - 2.0	2.0 - 4.0	4.0 - 8.0	8.0 - 20.0
CHANNEL BED MORPHOLOGY:	Pool-Riffle forced pool-riffle	Pool Riffle, Plane-Bed forced pool-riffle	Plane-Bed, Forced Pool-Riffle	Step-Pool	Cascade

(a) VW - Valley Width
(b) CW - Channel Width

adapted from: *Stream Classification System: Washington State Forest Practices Board (1994)*

Table A-42. Geometry, Dimensions, and Streambed Morphology of Stream Reaches Surveyed.

A.4.4.1.1 Channel Condition Field Surveying Technique/Protocol

Each stream segment surveyed was divided into sub-reaches (hereafter referred to as reaches). Every other reach was sampled. Reaches, typically, were approximately 10 active channel widths in length, although longer or shorter reaches were adopted in some instances for surveying expediency. Discharge was estimated in each reach by measurement of wetted channel width, depth, and average surface velocity (float method). Mean bankfull width and depth were estimated by measuring the apparent bankfull width and depth at riffle crests in several locations in the reach. A range of values are provided rather than a single average value in some instances when dimensions varied substantially.

Channel Bed Morphology

Stream reaches were defined by channel confinement, the ratio of channel width to valley width, and by channel bed morphology or "the nature and organization of channel bed material" (Montgomery and Buffington 1993). Channel bed morphology types include: regime, pool-riffle, forced pool-riffle, plane-bed, step-pool, cascade, colluvial, bedrock, and braided. Because our surveys focused on streams likely to support anadromous salmonids, no colluvial, bedrock, or regime channel bed types were noted. When a reach appears to be transitional (or alternates) between bed types, two types of channel bed morphology are listed.

Pool-riffle, forced pool-riffle, and plane-bed morphologies were most common in the reaches we surveyed. Plane-bed channels appear to be fairly flat or "flume-like". Free formed bars do not occur in plane-bed channels, pool spacing is quite high and riffles are the dominant habitat unit. Pool-riffle channels consist of regularly spaced bars and pools, most of which are free formed (e.g., not forced by large obstructions such as bedrock bank projections, boulders, large woody debris). When more than half of the pools and bars in a reach are forced, bed morphology is classified as forced pool-riffle. Step-pool morphology is defined by channel spanning steps formed by bedrock, boulders or large woody debris. Cascade bed morphology "is characterized by continuously tumbling flow" (Grant 1990). Confinement was estimated on an unconfined-to-moderately confined-to-confined scale, with "confined" meaning steep inner gorge slopes define on both side of the channel, and "moderately confined" meaning a slightly wider valley bottom with a small floodplain or terrace with hillslopes above. Low confinement suggests a wide valley bottom with a substantial floodplain or terrace. Channel pattern was defined as straight to sinuous with qualitative gradations (slight, very, etc.). In cases where large bends in streams are noted, these generally reflect entrenched meanders originally developed in a wide, low gradient valley bottom by a meandering stream. Since that time, the landscape has been uplifted to entrench these bends.

We defined riffles as those portions of the bed characterized by shallow, high velocity flow and local gradient increases. The dominant substrate in these areas was nearly always cobble to coarse pebble in size. Fine sediment deposits (sand and fine pebbles) rarely occurred in these locations, even when they were common in other portions of the channel bed.

The first bar observed in the reach greater in length than one active channel width was sampled to classify bar type (lateral, point, mid-channel, step, or single obstruction), bar dimensions (average height, length, width), and activity level (based on type of vegetation and percentage cover). Subsequent bars in each reach were tallied; attributes of subsequent bars were also recorded in cases when the first bar in the reach was not representative or in cases when subsequent bars were somehow noteworthy. Under the column "bar type," more than one number may be noted. The first number listed describes the sampled bar, while subsequent numbers refer to other bars in the reach if they are of a different type than the first. Two numbers may also be listed if the sampled bar is transitional between 2 bar types, for example 1,2 would refer to a bar that was transitional between being a lateral or a point bar, as often occurred in channels with very low sinuosity. Length and width of each sampled bar were estimated by pace; height was estimated visually or with a surveyors hand-level and a stadia rod. Dimensions noted are typically averages for the sampled bar, although ranges are noted for bars in which height and/or width varied substantially.

Only bars within the active channel were considered and tallied. Areas that historically may have been bars but that now supported well-developed vegetation and were not in the active channel (relict point bars, for example) were not counted as bars. Bars without vegetation or with only grass growth were typically considered "active," while bars that supported willows or other vegetation but contained a substrate of alluvial material were generally classified as "semi-active."

Pool Forming Factors

The first pool in each reach was sampled to discern the factors causing it to form (pool formation factors), dimensions, bed sediment sizes, and grain size and distribution of fine sediment deposition. Subsequent pools in the reach were tallied on field survey forms. More than one pool formation factor was typically listed on the survey forms (e.g., log jam, rootwad, boulder); the first number describes the dominant factor. Length and width were measured by pace or visual estimate; maximum and residual depth were measured using a stadia rod. The recorded dimensions reflect wetted dimensions at the time of the survey, rather than dimensions at bankfull stage. The extent of fine sediment deposition (< 2 mm) was visually estimated and classified on an ordinal scale of 1 (local occurrence in hydraulically sheltered locations) to 3 (widespread).

Large Woody Debris (LWD)

The data collected was intended to be useful for qualitative description of the abundance and functional importance of LWD in different reaches, rather than for quantitative description of the exact amount of LWD or stored sediment by LWD in reaches. The primary LWD function (i.e., pool scour, step formation, sediment storage, etc.) was identified, followed by a determination of secondary functions. In the field survey forms under number of pieces, only LWD pieces ≥1.5' in diameter were counted regardless of their individual lengths. This tally either represents the number of pieces in a log jam or the number of pieces occurring in the first LWD accumulation in a reach. In reaches with only one LWD site, the tally is indicative of the reach-wide total. When multiple LWD accumulations occurred within a reach, we attempted to note this.

Visual estimates of the average length, width, and height of the first log jam occurring in a reach were recorded. The presence of subsequent jams was noted in comments. The estimates of jam dimensions are unlikely to offer an accurate means of estimating jam volume and do not provide an estimation of volume of channel stored sediment behind log jams. They do, however, offer a general idea of the size of jams present on a given stream reach.

Bank Erosion Factors

Estimates of the percentage of each reach length with active erosion were made by visual observations, and are therefore, at best a rough approximation. All estimates were made according to the same relative scale, however, and therefore they provide a means of qualitative comparison between reaches as to whether active erosion rates are low, medium, or high. Notes in the comments section provide further means of comparison, and indicate the frequency of recent landslides. Typical bank height was recorded as an estimate of the height of a flood plain or terrace bank above the channel bed at its inside edge, and/or the heights of scarps at the base of a slope. We also recorded the types of features which predominately afford protection (if any) from bank erosion, including roots, boulders, cohesive clays, etc.

Floodplain and Terraces

Most channels lacked distinct floodplains and terraces and were instead inset within inner gorge slopes. In those cases, flood plain and terrace attributes were not noted. Where bank material was exposed, an attempt was made to determine whether or not it was alluvial, colluvial, or bedrock in origin based on layering of deposits, sorting, imbrication, rounding, etc. Typical overstory vegetation types and species, and diameters at breast height were noted, as were old-growth redwood stumps in growth position, when these were present.

Cross-sections and Sketch of Valley Flat Sections

We surveyed one to two cross-sections per reach as time permitted. Cross-sections were located at riffle crests. Cross-section was surveyed by stretching a measuring tape level across the channel and taking elevation measurements with a stadia rod at breaks in slope or otherwise notable points along each cross-section. Efforts were made to survey cross-sections at sites representative of the broader study reach. Sketches were made at each cross-section. In reaches where no cross-sections were surveyed, sketches represent typical channel, valley, and hillslope characteristics.

A.4.4.2 Results

Based on analysis of field data (Channel Descriptions and summary presented in Tables A-43 and A-44), we conclude that there is evidence of:

a) substantial wood loss in most stream surveyed

b) chronic fine sediment deposition in nearly all of the streams that we surveyed; and

channel aggradation in three of the reaches surveyed: North Fork Indian Creek, and North Branch North Fork Navarro River in reaches a and b between Dutch Henry and Cook Creeks. Channel aggradation is not evident in the other reaches surveyed.

Fine sediment deposition in channels was manifest as widespread accumulation of fines in pools, large quantities of sand and finer grains filling interstitial spaces between coarse sediment grains in riffles, and in some cases by extensive sheets of sand and/or finer material covering pools, runs, and glides.

Based on observed conditions, recent streamside landslides (0-to-10 years old) and/or active terrace bank erosion appear to be most common in steep streams ($S \geq 0.02$) underlain by semi-coherent units of the Coastal Belt, the melange of the Franciscan Complex, and valley fill deposits. Active stream bank erosion and streamside landsliding were typically infrequent in streams underlain by coherent Coastal Belt units. One notable exception was in reaches A and B of the North Branch North Fork Navarro River, which we believe are currently aggrading. Historical gullying, past management actions which resulted in stable accumulations of large woody debris being removed from channels, erosion caused by abandoned streamside roads, and conversion of vegetation cover from forest to scrub/grassland appear to be the most important factors influencing bank erosion and shallow landsliding in melange, semi-coherent Coastal Belt, and valley fill settings. Higher natural erosion rates in these settings, and sometimes harsher site conditions (for re-establishment of forest vegetation) probably explain most of the differences in bank erosion and/or shallow landsliding observed.

Based on review of time-sequential air photos (1952, 1965, 1981, 1992), we documented substantial increase in riparian canopy opening and/or channel width for a wide variety of stream reach types and sub-basin geological settings that peaked on the 1965 photos. High road densities or high proportions of recently logged (0 to 10 years ago) hillslopes on the 1952 and 1965 photographs are strongly associated with substantial increases in downstream canopy opening and stream width. Some reduction in channel width and riparian opening is evident on the post 1965 photography, but in most low-gradient stream reaches ($S < 0.02$), riparian canopy opening and channel width are still substantially greater in 1992 than in 1952.

Previous research suggests that low-gradient streams (slope < 3 %) are primary sites for long-lasting responses to watershed disturbances (Montgomery and Buffington 1993; Pitlick 1988). Streams with moderate to steep slopes (3-to-20%) transport sediment

Table A-43. Condition of Pool-Riffle Channels in the Navarro River Basin.

	IMPACT						
	Fine Sediment Deposition	**Wood Loss**	**Wood Accumulation**	**Coarse Sediment Deposition**	**Bank Erosion**	**Aggra-dation**	**Dam Break Flood and/or Debris Flow Deposition**
Stream/Reach							
Ray's Gulch	✓✓		✓✓		nd		
SBNF1	✓✓	✓✓					
SBNF 3b		✓✓					
NBNF a	✓✓	✓✓				✓	
NBNF b	✓✓	✓✓			✓✓	✓✓	
Mainstem Navarro usNF	✓✓	✓✓					
Mainstem Navarro dsNF	✓✓	✓✓					
Upper John Smith	✓	✓✓			✓		
North Fork Indian		✓✓		✓✓	✓	✓✓	✓
Lower John Smith		✓✓					
SBNF 2	✓	✓✓					
SBNF 3a		✓✓					
Mill 3	✓✓	✓✓					
Little North Fork		✓✓					

footnotes and symbols:
✓ - moderate evidence of impact
✓✓ - high evidence of impact
nd - no data, reach survey was reconnaissance level
note: no checks indicate that impact is not present

Table A-44. Condition of Forced Pool-Riffle, Step-Pool, and Cascade Channels in the Navarro River Basin.

	IMPACT				
	Wood Loss	Fine Sediment Deposition	Coarse Sediment Deposition	Bank Erosion	Catastrophic Events
Stream/Reach					
Beasley lower	✓(1)	✓✓		✓✓	DB
Beasley upper a	✓(1)	✓		✓✓	DB
Marsh 1a	✓(2)				
Marsh 3a	✓(2)				
Mill 4b	✓✓	✓✓		✓✓	DB or FL
Upper Con a	✓(1)	✓✓	✓	✓✓	
Mill 4a	✓✓	✓✓			
Beasley upper b	✓(1)	✓		✓✓	DB
Marsh 1b	✓(2)				
Marsh 3b	✓(2)				
Marsh 2a	✓(2)				
Upper Con b	✓(1)	✓✓		✓✓	
Bear Wallow	✓	✓		✓✓	DB or FL?
Marsh 2b	✓(2)				

footnotes and symbols:
✓ - moderate evidence of impact
✓✓ - high evidence of impact
nd - no data
(1) moderate-high amount relative to other channels surveyed; pool spacing/influence of LWD on pool formation suggests woody debris loading is low.
(2) woody debris is rotting, step storage capacity is filled suggesting little recent recruitment.
DB = Dam Break Flood, DFD = Debris Flow Deposition, FL - Large Flood, DFS = Debris Flow Scour

more efficiently, and hence, may recover more quickly from disturbances (given similar sediment input rates). Streams steeper than about 20 percent are thought to be formed primarily by mass wasting processes, and also to be important sources of sediment input to downstream reaches (Benda and Cundy 1990). A first step in the channel condition study, therefore, was to delineate the distribution of low gradient (response), moderate gradient (transport), and high gradient (source) reaches throughout the Navarro River basin. This was accomplished by measurement and delineation of stream longitudinal profile (slope) on 1:24,000 scale topographic maps (see Navarro watershed maps - not included in this technical appendix). Recent large scale aerial photographs (black and white aerial photographs taken in 1981 at 1:20,000 scale) were used to further subdivide the streams into reach types based on more narrowly defined stream slope categories (estimated on the topographic maps), and using the aerial photographs to estimate channel confinement category (e.g., channel width-to-valley width ratio).

A.4.4.3 Description of Channel Conditions in Reaches Surveyed

A.4.4.3.1 Bear Wallow Creek

Reach Locations

Bear Wallow Creek was surveyed from Honey Creek to Rancheria Creek, a distance of approximately 1.0 miles. Throughout the reach surveyed, the channel is confined and has a step-pool bed morphology.

Evidence Evaluated to Assess Fine and Coarse Sediment Deposition, Bank Erosion, Channel Aggradation

The dominant substrate sizes comprising the framework in riffles are cobble and gravel; and occasionally boulders. Sand and silt are usually abundant in the interstitial spaces between the framework clasts. Typically, streambed material is very poorly sorted. Accumulation of fine sediment is widespread in pools. Most boulders present in the stream are organized into channel spanning steps. Given the average gradient of the reach surveyed (Slope = 0.05), boulders forming steps are expected. Throughout the reach, the channel is confined within a steep inner gorge. Channel width-to-depth ratio is typically ≤ 10. Reach-wide average for active bank erosion is about 40 percent (range = 20-to-70 percent), among the highest values observed in any reach surveyed. Bank erosion is continuous along both banks or extensive along one bank; erosion is expressed, typically, as shallow landslides and slumps.

Considering these attributes, we believe that evidence for fine sediment deposition is strong. Evidence for coarse sediment deposition and/or channel aggradation is not evident. Evidence of accelerated bank erosion rate is moderate to high.

Evidence Evaluated to Assess Wood Loss and/or Wood Accumulation

Pool spacing is about 6.4 channel widths per pool, which is very high for a step-pool stream. Only about 35 percent of the pools in the reach surveyed are associated with large woody debris (LWD). Few data regarding typical percentage of pools formed by LWD in undisturbed step-pool, forest streams are available, and therefore, it is hard to say what pre-logging percentage may have been. Survey reveals, however, that LWD load is quite low and that old-growth size LWD is lacking. Given these factors, and very low pool spacing, we conclude that there is strong evidence of wood loss.

A.4.4.3.2 Con Creek: Reaches A and B

Reach Locations

Con Creek was surveyed 1250 feet downstream and approximately 2000 upstream of an unnamed tributary that enters from the north side of Conn Creek. The mouth of this tributary is located approximately at the 13W/14W range boundary (see Boonville, CA 7.5 minute topographic map). Reach A is a moderately confined, forced pool-riffle stream. Reach B is a confined, step-pool stream. Channel morphology alternates between these two reach types throughout the length of channel surveyed.

Evidence Evaluated to Assess Fine and Coarse Sediment Deposition, Bank Erosion, Channel Aggradation

Sub-angular coarse cobbles and boulders are the dominant substrate in riffles in Reach A near the junction with the unnamed tributary, and at many sites downstream. Medium to fine sub-rounded to rounded pebbles are dominant in bars. In Reach B, boulders are usually organized into channel spanning steps. In both reaches, fine sediment deposits in pools are widespread and among the highest values observed in any reach surveyed. Active bank erosion is typically quite high (> 40%), much of which is expressed as large recent landslides in both reaches, and terrace bank erosion in Reach A. Landslides appear to be related to an abandoned logging road located on a steep slope adjacent to the creek. Based upon these attributes, we believe that there is high evidence of coarse sediment deposition in Reach A, and high evidence of fine sediment deposition and accelerated bank erosion throughout both reaches.

Evidence Evaluated to Assess Wood Loss and/or Wood Accumulation

Over most of Reach A and parts of Reach B, LWD functions include step formation, sediment formation, and pool scour. Present-day LWD loading in Con Creek is high relative to typical amounts observed in streams surveyed. However, only about 35 percent of all pools in Reaches A and B of Con Creek are formed by LWD. We would expect that a higher percentage of pools were formed by LWD prior to logging of old-growth conifers. Average pool spacing over Reaches A and B is about 6.4 channel widths per pool. This is a very high value for a narrow, forest stream. Prior to logging of old-growth conifers, we would estimate that pool spacing was typically ≤ 2 channel widths per pool. Although present-day LWD loading is high relative to other channels surveyed, it appears that it is substantially lower than would be expected prior to logging.

A.4.4.3.3 John Smith Creek: Upper and Lower Reaches

Reach Locations

Upper John Smith Creek was surveyed from Johnson Creek confluence to a point approximately 0.5 miles downstream. Lower John Smith Creek was surveyed from Masonite Road to a point approximately 0.5 miles upstream.

Evidence Evaluated to Assess Fine and Coarse Sediment Deposition, Bank Erosion, Channel Aggradation

Cobbles are dominant and gravel is the subdominant substrate on riffles in both reaches. Riffles are infrequent in the upper reach. Bar area is low (10-15 %) in both reaches; dense grasses cover most gravel bars. Fines sediment deposits are widespread in pools in the upper reach and patchy in pools in the lower reach. The channel is typically moderately confined and has a low width-to-depth ratio in both reaches (W:D < 12). A streamside terrace forms one or both channel banks throughout much of the reach. Active bank erosion is highly variable with low rates throughout much of both reaches (10 %), and very high rates of active bank erosion (40 to 70%), on terraces and at recent landslides, located at the upstream end of the upper reach and the lower half of the lower reach.

Evidence for channel aggradation and coarse sediment deposition is not evident in either reach. Evidence for fine sediment deposition is moderate in the upper reach, and low in the lower reach. Accelerated bank erosion is apparent in some sub-reaches. Landslides and terrace bank erosion may be important contributors to high fine sediment deposition in pools in the upper reach.

Evidence Evaluated to Assess Wood Loss and/or Wood Accumulation

Much of the LWD forming pools in the lower reach was installed by the California Conservation Corps (CCC). If the CCC structures were not present, pool spacing would be much less frequent. Pool spacing is estimated as approximately 6 channel widths per pool in the upper reach; a very high spacing for a narrow forest stream. Channel cross-section was not measured in the lower reach, and therefore we cannot estimate pool spacing in the lower reach. Based on survey notes, LWD load appears to be somewhat higher in the upper reach. Approximately 8 of 15 pools occurring over both reaches are formed by LWD. LWD jams are infrequent. Evidence of wood loss appears to be moderate to high.

A.4.4.3.4 <u>Little North Fork Navarro River</u>

Reach Location

The Little North Fork of the Navarro River was surveyed from its confluence with John Smith Creek to a point approximately 1.0 miles upstream.

Evidence Evaluated to Assess Fine and Coarse Sediment Deposition, Bank Erosion, Channel Aggradation

Dominant substrate in riffles alternates between gravel and cobble sizes; fine sediment deposits occur locally in sheltered locations on riffles. Bars, typically, are unvegetated and cover approximately 35 % of the channel bed area; gravel is the dominant substrate on bars. Fine sediment deposits in pools are patchy to widespread. Active bank erosion is relatively low (25 %) and typically occurs at the outside of channel bends where bedrock is often exposed. Channel pattern is single thread and width-to-depth ratio is low (approximately 10-12). Accelerated bank erosion, coarse sediment deposition, and channel aggradation are not apparent. Evidence of fine sediment deposition is low.

Evidence Evaluated to Assess Wood Loss and/or Wood Accumulation

Pool spacing is typically low to very low (5 to 10 channel widths per pool) for a forest stream. Most of the reach has little or no LWD; only 3 of 13 pools are formed by LWD. We conclude that evidence of wood loss is moderate to high.

A.4.4.3.5 Mill Creek: Reach 3

Reach Location

Reach 3 of Mill Creek extends from Meyer Gulch confluence to a point approximately 0.5 miles upstream.

Evidence Evaluated to Assess Fine and Coarse Sediment Deposition, Bank Erosion, Channel Aggradation

Dominant substrate on riffles is cobble or gravel. A mixture of gravel and fines is common over glides and runs. Fine sediment in pools is widespread to patchy. Bars cover approximately 15-to-20 percent of the channel bed area; most bars are unvegetated or have a sparse cover of annual grasses. Frequency of active bank erosion is low (20-25 %) and typically occurs at the outside of channel bends. Coherent greywacke sandstone bedrock is often exposed in banks. Channel pattern is slightly sinuous and single thread. The channel is confined within a steep inner gorge, and channel width to depth ratio is low (< 10). Channel aggradation, accelerated bank erosion, and coarse sediment deposition are not apparent. Evidence for fine sediment deposition is moderate to strong.

Evidence Evaluated to Assess Wood Loss and/or Wood Accumulation

Large woody debris is almost entirely absent from this reach. pool spacing is very low (4 to 5 channel widths per pool); no pools in this reach appear to be formed by LWD. Evidence for wood loss is very strong.

A.4.4.3.6 Marsh Gulch

Reach Location

Marsh Gulch was surveyed from its confluence with mainstem Navarro River to a point approximately 1.0 miles upstream. The reach was subdivided into six reaches based on alternating pattern of streambed morphology (forced pool-riffle, step-pool, forced pool riffle) and channel confinement (moderately confined to confined).

Evidence Evaluated to Assess Coarse and Fine Sediment Deposition, and Bank Erosion

All reaches: Cobbles and/or boulders form the framework of most riffles and channel steps. Boulders are typically sub-rounded and covered by moss. The dominant substrate on bars is medium gravel to small cobble size. Bars constitute less than 10% of area of the channel bed in forced pool-riffle reaches (and smaller percentage area in step-pool reaches). Fine sediment deposits in pools are typically local to patchy. Active bank erosion is typically is very low (10 to 20 %); recent landslide scars are infrequent. Moss cover and rounding of boulders suggest stability and/or weathering in-place over a long period of time. Many of the boulders, apparently were delivered to the channel at the time that the older well-vegetated slides, observed in the reach, failed. Data collected for the survey are insufficient for bracketing the ages of these older slides, however, scarp morphology and revegetation of slides suggests a minimum age of 50 years or more.

<u>Opinions:</u> Sand is uncommon in bars, pools, and riffles; therefore we conclude that there is little evidence of fine sediment deposition. Timing of coarse sediment deposition does not appear to be recent as indicated by abundant moss growth and rounding of boulders. In steep gradient stream reaches, step-pool morphology and boulder substrate would be expected for in an undisturbed stream. Therefore we believe evidence for increase in coarse sediment deposition is low.

Evidence Evaluated to Assess Wood Loss

Marsh Gulch has the highest LWD loading of any stream that we surveyed. LWD in Marsh Gulch causes pool scour, contributes to streambank and bar stability, provides sites for sediment storage, and forms steps (debris jams) in the profile of the streambed. Most of the LWD in Marsh Gulch, however, appears to rapidly decaying and/or rotten. Most of the channel steps created by debris jams are now filled to storage capacity. These features suggest that most of the LWD in the channel may be long-lived, and that recent rate of LWD input has been low. Old-growth stumps are common on streamside terraces and slopes; at present, however, most streamside trees are young, second-growth redwoods with diameter at breast height of less than 1.0 foot. LWD is a primary and/or secondary control on pool formation in approximately 75% of the pools counted in reaches where bed morphology alternates between forced pool-riffle and step-pool. In step-pool reaches, nearly all of the pools counted were formed primarily by boulders steps which bridge the channel bed.

A.4.4.3.7 <u>Mill Creek: Reaches 4a and 4b</u>

Reach Locations

Reach 4a extends from Red Hill Gulch to a point approximately 0.5 miles downstream. Reach 4b extends from Red Hill Gulch upstream approximately 0.8 miles approximately to the confluence with Hungry Hollow.

Evidence Evaluated to Assess Coarse and Fine Sediment Deposition, Channel Aggradation, and Bank Erosion

In reach a, cobbles are the dominant substrate and gravels are subdominant on riffles; in reach 3b, the relationship is reversed. Fine sediment deposits are extensive over runs, glides, and pools in both reaches. Pools in both reaches, nearly always have widespread accumulations of fines (very high amounts relative to most stream reaches surveyed). Sand commonly fills the framework of coarse grains on bars in reach 4b; vegetation cover is sparse on bars in both reaches. Active bank erosion is quite high (50-70%) throughout reach 4a and the lower half reach 4b. In reach 4a, recent landslides are quite common. In reach 4b, active bank erosion occurs on terrace and/or flood plain banks, typically on the outside of channel bends. Channel width to depth ratio is low to moderate in reaches 4a and 4b; the channel is typically confined in reach 4a and moderately confined in reach 4b. Channel aggradation, and coarse sediment deposition are not apparent. Evidence for fine sediment deposition and accelerated bank erosion is strong.

Evidence Evaluated to Assess Wood Loss

reaches 4a and 4b: pool spacing is low for a forest channel (approximately 5 channel widths per pool); only 10 of 28 pools are formed by LWD. LWD is more widespread than in reach 3, however, LWD dams are rare, and therefore, little sediment storage is associated with LWD. Prior to clear-cut logging, we would expect that pool spacing would be less than 2 channel widths, and LWD steps would be frequent, and important sediment storage sites. Evidence of wood loss is moderate to high.

A.4.4.3.8 North Branch North Fork Navarro River

Reach Location

North Branch North Fork Navarro River (NBNF) was surveyed from Dutch Henry Creek confluence to a point approximately 300 feet downstream of Cook Creek confluence (1.0 miles). NBNF is pool-riffle stream throughout the survey area. For 1000 feet at the upstream end and 500 feet at the downstream end, the channel is moderately confined (reach a); between these segments, a distance of approximately 3800 feet, the channel is confined (reach b).

Evidence Evaluated to Assess Fines Sediment and Coarse Sediment Deposition, Channel Aggradation, and Bank Erosion

Reaches a and b: Surface flow is discontinuous with multiple sub-reaches, several hundred feet in length, where flow is subsurface. Gravel bars cover approximately 50 % of the channel bed; dominant substrate is typically pebble size (4 to 16 mm) in reaches a and b. Large mid-channel bars occur over most of reach a. Standing, dead willows cover point bars in the lower portion of reach b; dense grasses and willows are common along the margins of bars near the edges of the wetted channel. Channel width-to-depth ratio was estimated at two sites in reach b, and one site in reach a; It was very high (W:D > 24) at each of these sites. The channel is braided throughout the downstream portion of reach a. Fines sediment deposits in pools are widespread throughout reaches a and b; fine sediment deposits in riffles, however, typically, occur only in sheltered locations. Bank erosion rates are typically low (< 25 %) except for a few recent landslides which occur near Dutch Henry and Cook Creeks and over a short stretch (500 feet) in the middle of reach b. Bank erosion typically occurs on the outside of channel bends and occasionally independent of channel geometry. We conclude that evidence for channel aggradation is strong in reach a, and moderate in reach b. Evidence for fine sediment deposition is moderate in reaches a and b. Channel is susceptible to an increase in bank erosion and landslide activity in sub-reaches where the channel is aggrading.

Evidence Evaluated to Assess Wood Loss and/or Wood Accumulation

Pool spacing is approximately 4 channel widths per pool in reach b and 3 channel widths per pool in reach a; prior to clear-cut logging (and/or management related removal of LWD from the channel) this reach probably would have been forced pool-riffle with pool spacing of less than 2 channel widths. Only 4-of-15 pools in reaches a and b have LWD as a primary or secondary factor for pool formation. LWD has limited functional importance in the reach except for pool scour, and the reach is nearly devoid of LWD except for the jam near Cook Creek confluence. Based on these attributes, we believe there is moderate to strong evidence of wood loss.

A.4.4.3.9 North Fork Indian Creek

Reach Location

North Fork Indian Creek was surveyed from a road crossing located near its downstream end to a point approximately 1.5 miles upstream.

Evidence for Evaluation of Fine and Coarse Sediment Deposition and Channel Aggradation

Typically, cobbles are the dominant substrate in riffles; fine sediment is not common. Bars cover approximately 60 % of the streambed; gravel and cobbles are alternately dominant and subdominant substrate in bars. Little fine sediment (sand) is deposited on bars. Few mid-channel bars were observed, and most bars are poorly vegetated to partially vegetated with annuals and/or small shrub as cover. Fine sediment deposits in pools are local or patchy (and very low relative to other reaches surveyed). Occasionally, old-growth redwood stumps, appearing to be in growth position, are found within the active channel; rootswells of these stumps are often partially buried by coarse substrate. Elevations of rootswell of stumps indicates aggradation of at least a few meters. Based on review of 1952 photographs, it appears that in 1952, redwoods were growing on a well-vegetated flood plain. Channel width-to-depth ratio is approximately 24:1.

During a reconnaissance survey of North Fork Indian Creek in February of 1996, we located debris lines (high-water marks) associated with recent bankfull discharge and large flood (e.g., estimated recurrence interval of 10-to-15 years) events. We then compared typical sediment sizes observed in riffles (predominately cobbles) to the grain sizes (medium sand to coarse pebble sizes) that were loosely packed and imbricated on the upper surfaces of high bars overtopped by the bankfull, and January of 1995 flood. Much finer texture of loose sediment on the bars overtopped in January of 1995 (medium sand to coarse pebble) suggests that the coarse cobbles forming the framework of many riffles are very infrequently mobilized.

<u>Opinions:</u> There is strong evidence of coarse sediment deposition and persistent channel aggradation. Fine sediment deposition does not appear to be a problem.

Wood Loss and/or Wood Accumulation

LWD loading is very low in this reach. Old-growth rootwads (described above) are a primary source. Pool spacing is approximately 3.7 channel widths per pool; about half of all pools have LWD as a primary and/or secondary control on pool formation. Field notes and observations document that LWD is rare outside of pools, and that loading is at the low end of that observed in reaches surveyed. Prior to disturbance, we would expect most pools to be formed by LWD, and pool spacing to be less than 2 channel widths per pool.

<u>Opinions:</u> There is moderate to strong evidence of wood loss in this reach.

Evidence for Evaluation of Bank Erosion

Active bank erosion is moderate to low (25-to-30 %); much of which occurs on outside bends. Bank erosion and landsliding appear to have been more frequent historically (≥ 15-30 years ago). "Older appearing" landslides are especially common where the outside bend of the creek comes into contact with a steep, inner gorge slope.

<u>Opinion:</u> strong evidence of historical bank erosion problems; low evidence of present-day bank erosion.

A.4.4.3.10 <u>Ray's Gulch</u>

Reach Location

Ray's Gulch was "visually" surveyed from its confluence with Rancheria Creek to its confluence with Roller Gulch. Throughout the reach, the channel is unconfined and has a pool-riffle morphology.

Evidence Used to Assess Fine and Coarse Sediment Deposition, Bank Erosion, Channel Aggradation, Wood Loss and/or Accumulation

We classified this reach as an unconfined, pool-riffle stream because the channel gradient is very low (slope << 0.01), and it is entrenched 6-to-8 feet below a wide terrace that forms both banks of the stream throughout the reach. The channel is clogged with woody debris, and silt and clay deposits are nearly ubiquitous over the surface layer of the streambed. Aquatic vegetation is abundant inside the channel giving it a "marsh-like" appearance. The streamside terrace contains numerous slash piles and this area appears to have been recently logged. The survey did not continue above Roller Gulch confluence due to the fish biologists' opinion that under present-day conditions, Ray's Gulch does not provide suitable habitat for salmonids.

There is very strong evidence to suggest that fine sediment deposition and wood loss are extensive. Based upon the observations recorded, it is difficult to conclude whether the channel is now aggrading or degrading.

A.4.4.3.11 <u>South Branch North Fork Navarro River: Reaches 1 and 2</u>

Reach Locations

Reach 2 extends from Bailey Gulch to a point approximately 1.3 miles downstream. Reach 1 extends from the downstream boundary of Reach 2 downstream to a point approximately 0.2 miles upstream of the summer dam at the mouth of the South Branch North Fork Navarro River (SBNF).

Evidence of Coarse and Fine Sediment Deposition, Bank Erosion

Cobble and/or coarse pebble are alternately the dominant and subdominant sediment grain sizes in riffles throughout both reaches. In many locations, sand appears to be filling the spaces between large grains forming the framework of the stream bed at riffles. An extensive fine sand, sediment cap was observed on many bars located in reach 1 in February 1996. Fine sediment is patchy-to-widespread in pools throughout reaches 1 and 2. Active bank erosion is typically low (10-25 %) throughout both reaches. There is no evidence to indicate coarse sediment deposition or accelerated bank erosion. We believe there is moderate evidence of fine sediment deposition in reach 1, and high evidence of fine sediment deposition in reach 2.

Evidence of Wood Accumulation/Wood Loss

In reach 1, only 10 of 28 pools in the reach have LWD as a primary or secondary control on pool formation; pool spacing is low for a forest stream (4.2 channel widths/pool) implying moderate evidence of wood loss over most of the reach; most LWD is in two extensive debris jams which appear to be sites of wood accumulation.

In reach 2, pool spacing is very low for a forested stream (5.7 channel widths/pool) implying wood loss; prior to reduction in wood loading, this reach probably would have been a forced pool-riffle stream with pool spacing of less than 2 channel widths; only 2 of 7 pools in the reach have LWD as a primary or secondary control on pool formation.

In reach 2, there is moderate evidence of wood loss and of moderate wood accumulation at two very large debris jams. In reach 1, there is high evidence of wood loss.

A.4.4.3.12 <u>South Branch North Fork Navarro River: Reaches 3a and 3b</u>

Reach Locations

Reach 3a extends from McGarvey Creek confluence downstream to Shingle Mill Creek confluence (1.0 miles). Reach 3b extends from Shingle Mill Creek confluence to Bridge Creek confluence, approximately 1.0 miles downstream.

Evidence Used to Evaluate Fine and Coarse Sediment Deposition; Bank Erosion, Channel Aggradation

Reach 3a: Typically, cobbles are the dominant substrate in riffles, and pebbles are subdominant. Sand is uncommon in the surface layer of riffles (in the lee of some large clasts). Pebbles and cobbles are alternately the dominant and subdominant substrate in bars; bar area is low to moderate (25-30%). Nearly all bars are lateral bars; no mid-channel bars were observed. Based on vegetation cover, bars alternate between active, little or no vegetation cover, to semi-active, > 50 % vegetated with annual grasses and/or sedges. Channel width to depth ratio, typically, is very low (W:D < 12). Gravel is the dominant grain size in pools. Fine sediment deposition in pools is typically local to patchy, and low relative to the amount observed in most of the streams we surveyed. Channel pattern is single-thread; the channel is confined to moderately confined throughout its length. Active bank erosion is typically low (10-25 %).

Reach 3b: as per reach 3a except, pebbles are dominant substrate in riffles (cobbles are subdominant) and fine sediment deposition in pools is somewhat higher (typically patchy and occasionally widespread).

<u>Opinions:</u> In reaches 3a and 3b, coarse and fine sediment deposition do not appear to be problems; there is no evidence of channel aggradation and accelerated bank erosion.

Evidence for Evaluation of Wood Loss and Accumulation

Reach 3a: Pool spacing is very high (8.6 channel widths/pool); considering channel gradient, we would expect that pool spacing was less than 2 channel widths per pool prior to clear-cut logging. Less than 50 percent of all pool are forced by large woody debris (LWD). Typically, LWD pieces are infrequent throughout the reach. Large woody debris does not contribute to substantially to bar stability (island formation) or to side channel development.

Reach 3b: pool spacing is high (7.2 channel widths/pool). LWD appears to be much less common in reach 3b, as indicated by field notes, frequency of LWD counted, and percentage of pools formed by LWD (6-10%).

<u>Opinions:</u> substantial reduction in LWD loading appears to be indicated in reaches 3a and 3b.

Evidence for Evaluation of Bank Erosion

Reaches 3a and 3b: Relative frequency of active bank erosion is low (approximately 20 %). Coherent greywacke sandstone bedrock is commonly exposed in banks; recent landslides are uncommon.

<u>Opinions:</u> no evidence of present-day bank erosion problems; future susceptibility to bank erosion and landsliding appears to be low.

A.4.5 Channel-related Findings and Implications for Restoration

1. Most steep and/or confined streams in the Navarro River basin have "recovered" from historical channel aggradation and widening (e.g., channels filling in with sediment) which peaked on the 1965 photos. We use the term "recovered" to imply that stream-bed elevation and channel width are about the same today as they were in 1952. In a few steep or confined streams, aggradation has persisted through the present-day because those streams are not competent to transport much of the coarse sediment delivered to them during the 1964 flood. Even in streams which have "recovered" from historical channel filling, there is a fair amount of evidence to suggest that pool depths are shallower and pools are less frequent today (than they were prior to historical channel filling). Pool depths will not recover until the causes for fine sediment deposition have been treated (see below).

2. Historical aggradation and widening was much greater in large, gentle streams flowing through wide valleys (e.g. unconfined streams) than in steep and/or confined streams; examples of large, gentle, unconfined streams include: discontinuous reaches of mainstem Rancheria Creek along and upstream of highway 128; and Anderson Creek in Anderson Valley. Although bed scouring and channel narrowing have been on-going (since 1965) in Rancheria Creek, it still is in-filled with sediment and wider today than it was in 1952. On Anderson Creek in the Anderson Valley, historical aggradation and widening (measured as a percentage of 1952 channel width) is on-

going. Aggradation and widening in Anderson Creek in Anderson Valley is caused primarily by accelerated sediment production from upstream areas (primarily melange bedrock areas in the upper Anderson creek basin). Until meaningful reduction in sediment production from these sources is achieved, it appears likely that Anderson Creek in Anderson Valley will continue to aggrade. Actions taken to control bank erosion along Anderson creek and/or to increase streamside canopy will likely be unsuccessful until accelerated delivery from upstream sediment production is addressed.

3. Nearly all stream reach types found in the Navarro River basin are adversely affected at present by chronic fine sediment deposition which is manifest as pool shallowing and fine sediment filling in the interstitial spaces between coarse grains in riffles. To achieve a meaningful reduction in fine sediment deposition in channels, it may be necessary to achieve substantial reduction in total (fine and coarse) sediment production to channels because coarse sediment that is delivered to channels is rapidly broken down into fine sediment as it is transported through the channel network.

4. Wood loss is widespread in forested streams throughout the Navarro River basin (see channel condition analysis). This occurred as a result of: a) historical logging salvage operations; b) removal of large jams from streams by CDFG personnel in the 1950's and 1960's because the jams were thought to be fish passage barriers; and c) because stream-side forests have been converted from seral old-growth to young even-age stands. This is important because LWD in old-growth forests creates frequent and very deep pools, considerable sediment storage potential, and diverse channel morphologies which provide excellent anadromous fish habitat. Old-growth forests would need to be re-established along stream corridors in order to achieve increases in LWD loading in channels in the Navarro River basin.

5. Considering that most streams have recovered from aggradation and widening, and that wood loss is widespread in forested channels, it may be appropriate to install in-stream structures composed of LWD into some types of forested stream channels. Such actions may be useful for improving aquatic habitat conditions at the stream reach scale Factors which would effect such a decision include: local availability and size of LWD in comparison to stream size, and specific priorities for aquatic habitat improvement. Given the fact that the largest LWD in most streams today is less than 2 feet in diameter, it appears that in-stream structures composed of LWD would probably be most effective in small streams (width < 15 feet). In larger streams, this caliber of LWD would only remain stable at or near the margins of the channel limiting its usefulness for achieving aquatic habitat improvements.

6. As of 1952, most small to medium size forested tributaries of the Navarro River (i.e., John Smith Creek, South Branch North Fork Navarro River, etc.) had complete canopy closure over most of their lengths. By 1965, canopy opening on many of these streams had increased substantially as a result of channel aggradation and widening. Although stream canopy closure has been increasing since that time, today

many of these streams still have discontinuous canopy closure. This causes stream temperatures to be much more responsive to changes in air temperature and exposes them to direct solar heating. Where small and medium size forested streams are located in close proximity to the coast, increases in stream temperature as a result of canopy opening has been moderated. At inland locales (e.g., Anderson Valley and further upstream), stream temperature increases as a result of canopy opening have been much greater because maximum air temperatures are typically higher than in the coastal areas. Considering trends in canopy closure since 1965, it appears that canopy closure in many small and medium size forested streams will recover, at some future time, to conditions present in 1952. Because stream canopy closure is proceeding "naturally" in most small to medium size forested streams there does not appear to be any reason to emphasize the planting of riparian trees as a restoration action in these locations.

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APPENDIX C

STREAM HABITAT SUMMARIES

APPENDIX D

AGRICULTURAL WATER STORAGE PONDS POLICY

APPENDIX E

NAVARRO RIVER AND TRIBUTARIES SUMMER STREAM TEMPERATURES, STREAM FLOWS, AND WATER QUALITY, 1995-1997

APPENDIX F

OBSERVATIONS OF SALMONID USE, WATER QUALITY, AND CHANNEL MORPHOLOGY OF THE NAVARRO RIVER ESTUARY/LAGOON

APPENDIX G

SMALLER SCALE (1:195,000) VERSION OF OVER-SIZED (1:24,000) WATERSHED MAPS

APPENDIX H

LANDOWNER SURVEY