North Fork/Middle Fork American River Sediment Study

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Front cover: The photograph on the left was taken from Forest Hill Divide Road looking upstream (northeast) into the North Fork American River canyon. Onion Creek is visible in the uppermost middle left hand portion. The Royal Gorge wall is visible just to the left of Onion Creek and is partially obscured by the tree tops in the left foreground. The immediate foreground is Sailor Canyon, and the midground is Wildcat Canyon. The photograph on the right was taken from Mosquito Ridge Road looking downstream (east) at the characteristically steep canyon walls of the Middle Fork American River just below the Ralston Afterbay Reservoir.

Back cover: Downstream (east) view from Mosquito Ridge Road of the steep, forested, and brush-covered canyon walls of the North Fork of the Middle Fork American River just above its confluence with the Middle Fork American River. The flat-topped and formerly continuous plateau formed by the Mehrten Formation is visible on both sides of the canyon.

ABSTRACT

The North Fork/Middle Fork American River Sediment Study uses a coarse-filtered, geographic information system (GIS)-based, subwatershed relative potential risk screening model for soil erosion and sedimentation. It synthesizes relevant information using a map-based approach to support decision-making, and provides a spatial model that prioritizes the relative risk of erosion and sedimentation by subwatershed, regardless of land ownership. Watershed indicators are used to characterize potential erosion and sedimentation hazards. The knowledge-based modeling and risk-based prioritization achieves a consistent treatment of the individual subwatersheds that make up the watershed assessment area. The outcomes of the watershed modeling and prioritization process are used to prioritize and target management strategies (i.e., best management practices, disturbance minimization, and active restoration) for higher potential risk areas (relative to erosion and sedimentation under bare soil conditions) to enhance or maintain watershed health by minimizing potential sediment-related impacts to key resources. The prioritization can also be used as a framework for the development and implementation of a watershed monitoring plan. The opportunities for watershed protection and restoration, with emphasis in priority category 1 and 2 subwatersheds (7th-level hydrologic unit code [HUC]), are voluntary in nature with no intended land owner mandates or land-use related regulations. For successful implementation of the management strategies and priorities, a coordinated and collaborative process (including education and outreach for information sharing) among stakeholders is needed. With existing gaps in knowledge or data, an adaptive resource management approach (using inventory, monitoring, research, and adjustment) is essential for the implementation of the subwatershed-based management strategies.

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TABLE OF CONTENTS

Chapter/Section **Page**

APPENDICES

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LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

CHAPTER 1: INTRODUCTION

1.1 Study Authority and Prior Studies

An informal partnership of interested parties known as the American River Watershed Group (ARWG) has undertaken the North Fork/Middle Fork American River Sediment Study. The ARWG was founded in 1996 to collaborate on resource management issues in the North Fork/Middle Fork American River watershed. The California Department of Water Resources (DWR) supported the watershed assessment with Proposition 50 (Chapter 7) funds dedicated for the California Bay-Delta Authority (CBDA or CALFED) watershed grant program. The American River is a key watershed in the Bay-Delta system.

The ARWG formed a Technical Advisory Committee (TAC) to collaboratively work with Tetra Tech EC, Inc. (TtEC), a third-party environmental consulting firm, and to oversee all technical aspects of the North Fork/Middle Fork American River Sediment Study. The watershed assessment project was performed under the DWR Contract No. 4600003570 between the California Department of Water Resources and Sierra College. Under a Memorandum of Agreement (MOU, signed March 3, 2004), the project administration was undertaken by Sierra College (Economic Development Division). Placer County Water Agency (PCWA) and Placer County Resource Conservation District (RCD) representatives supported as the project manager and facilitator, respectively. The roles and responsibilities of various parties, including the ARWG TAC, were specified in the MOU to formalize the governance and structure for the contract.

In 2002, a study report titled *American River (North and Middle Forks) Integrated Watershed Plan and Stewardship Strategy* was completed under CALFED Category III Grant98E14. This report was the result of 3 years of collaborative work among the members of the ARWG and other interested parties to collect data on the watershed, evaluate current conditions, and suggest potential strategies for improving watershed health in the North/Middle Fork American River watershed.

1.2 Purpose and Scope

The ARWG pursued funding for this project to better understand erosion and sedimentation problems, the potential sources of sediment, the nature of erosion and sediment routing, and the potential effects of soil erosion and sedimentation on key resources in the North Fork/Middle Fork American River watershed. Based on the results of that improved understanding, appropriate management strategies for the highest priority subwatersheds and possible monitoring frameworks were also to be formulated. Key resources defined for this study include aquatic organisms and habitats, water and power infrastructure, and water quality.

Based on a work plan (dated March 18, 2005) developed collaboratively by the ARWG TAC and TtEC team, the ultimate outcome of the study is a risk-based watershed erosion and sedimentation assessment that prioritizes and targets areas of the watershed for future management efforts. Using geographic information systems (GIS) and digital data, a knowledge-based prioritization and targeting approach for optimization of management practices was developed. Watershed indicators were used to characterize potential erosion and sedimentation hazards. The weight of the evidence approach, which integrates various types of data to make an overall conclusion of potential risk (Hull and Swanson 2006), was used for adaptive watershed management and related strategic priorities.

Resource and land managers in the North Fork/Middle Fork American River watershed face a number of strategic challenges, including: (1) management across a hierarchy of scales; (2) management across a diverse set of land-use types; and (3) management across a diverse set of public and private land ownerships. The North Fork/Middle Fork American River Sediment Study addresses these challenges by:

- Synthesizing relevant information using a map-based approach to watershed assessment to support decision-making, and providing a spatially explicit model that prioritizes the relative risk of erosion and sedimentation by subwatershed regardless of land ownership;
- Identifying the ways that erosional and sediment delivery processes may affect key resources by indicating responsiveness of river reaches in relation to relative erosion potential of subwatersheds;
- Stratifying subwatersheds to allow land owners and managers to identify potential erosion and sedimentation hazards and design monitoring and evaluation plans for adaptive resource management; and
- Developing and prioritizing management strategies at a subwatershed level, and proposing actions for further analysis.

This watershed assessment report is not a decision document; no landowner mandates or regulations are intended to result from the recommendations.

1.3 Study Area Location and General Description

The American River originates in the high Sierra Nevada west of Lake Tahoe, in the Tahoe and Eldorado National Forests. The three main forks of the American River – the North, Middle, and South – flow through the Sierra foothills and converge east of Sacramento. Near Sacramento the American River drains into the Sacramento River, which eventually reaches the San Francisco Bay and the Pacific Ocean.

This study focuses on the North and Middle forks of the American River watershed and their respective subwatersheds (Map 1-1). The North Fork/Middle Fork American River watershed is approximately triangular in shape. It is bordered by the crest of the Sierra Nevada and Lake Tahoe basin on the east, by the Yuba and Bear River watersheds on the north, by the South Fork American River watershed on the south, and by the Folsom Reservoir on the west. The North Fork/Middle Fork American River watershed study area begins at the upstream extent of Folsom Reservoir and encompasses approximately 625,500 acres (977 square miles).

The U.S. Geological Survey has developed a standardized system of delineating watersheds throughout the United States and classifying them by hydrologic unit code

(HUC). A watershed represents an area of land that drains to a common point. To achieve a uniform range in sizes, composite watersheds are also delineated. Composite watersheds include areas that drain to more than one point but that are grouped together based on similar physical characteristics. Local agencies continue the process by delineating finer-scaled subwatersheds by HUC. In this study area, CalWater has delineated the finest-scaled subwatershed boundaries.

The entire North Fork/Middle Fork American River watershed is one 4th-level HUC, so called because it is uniquely identified by the fourth set of two-digit numbers (18020128). In the HUC system, the name of this 4th-level HUC watershed is North Fork American. Within the 4th-level HUC watershed are smaller 5th-level HUC subwatersheds, smaller 6th-level HUC subwatersheds, and still smaller 7th-level HUC subwatersheds. Smaller subwatersheds nest within the larger watersheds so that they share common boundaries. The North Fork/Middle Fork American River watershed contains six 5th-level HUC subwatersheds, including two that eventually drain to the North Fork American River and four that eventually drain to the Middle Fork American River. Nested within these 5th-level HUC subwatersheds are 20 6th-level HUC subwatersheds, including 7 that eventually drain to the North Fork American River, 12 that eventually drain to the Middle Fork American River, and the North Folsom Reservoir at the mouth of the watershed. Nested within the 6th-level HUC subwatersheds are 90 7th-level HUC subwatersheds, which serve as the basic map units for the subwatershed prioritization and targeting process in this study (Map 1-2). Of the total, 32 7th-level HUC subwatersheds eventually drain to the North Fork American River, 57 7th-level HUC subwatersheds eventually drain to the Middle Fork American River, and one 7th-level HUC is the North Folsom Reservoir at the mouth of the watershed.

The North Fork/Middle Fork American River watershed traverses a range of physical settings, including variations in geology, topography, hydrology, climate, soil, and land use. The Web site "The North Fork of the American River" provides an excellent overview of the area, including high-quality photographs (Towle 2007; http://home.inreach.com/rtowle/NorthFork/North_Fork_American.html). The watershed is part of the northern Sierra Nevada, which is generally composed of metamorphic rocks intruded by isolated granites. The Mehrten Formation and the Shoo Fly Complex each underlie nearly one-quarter of the watershed. The Mehrten Formation consists of volcanic and reworked rocks that are prone to mass wasting at the contact with the underlying Valley Springs Formation. The Shoo Fly Complex primarily underlies the middle portion of the watershed and consists of metasedimentary rocks considered to be among the oldest in the Sierra Nevada (570 to 440 million years old). Granitic rocks make up approximately 14 percent of the North Fork/Middle Fork American River watershed, primarily underlying the headwaters of the Rubicon River. The lower portion of the North Fork/Middle Fork American River watershed is dominated by the Calaveras Complex (metavolcanic rocks), Mariposa Formation (metavolcanic, metasedimentary, and metamorphic rocks), and Clipper Gap Formation (sedimentary rocks probably formed by ancient debris flows). Together, these three geologic units make up approximately 14 percent of the entire watershed.

Elevations in the North Fork/Middle Fork American River watershed range from over 9,900 feet at the headwaters of the Rubicon River to less than 500 feet at Folsom

Reservoir. Deep river canyons occur throughout the watershed where the North Fork and Middle Fork American Rivers have entrenched into the underlying bedrock. Metamorphic rocks, which tend to be less resistant to erosion than the granitic rocks that dominate other watersheds in the Sierra Nevada, underlie much of the watershed. Most of the watershed (over 60 percent) includes hillslopes between 11 and 50 percent. Slopes 70 percent or greater make up just over 10 percent of the North Fork/Middle Fork American River watershed.

The average annual precipitation for the North Fork/Middle Fork American River watershed is just under 60 inches (California Rivers Assessment 1997). The watershed generally experiences warm, dry summers and cold, wet winters. Weather can change rapidly during all seasons of the year, and elevation influences temperature and precipitation. At elevations less than 3,500 feet, the majority of precipitation falls as rain. Between 3,500 and 6,000 feet, precipitation may fall as either rain or snow. Above 6,000 feet precipitation falls mainly as snow (USDA Forest Service 1998). Most precipitation falls from October through April annually. At higher elevations, thunderstorms occur during summer months.

Soils form the basis of much of the analysis of erosion and sedimentation potential in this study. Soil characteristics vary throughout the North Fork/Middle Fork American River watershed depending on parent materials, relief, climatic conditions, biological activity, and time. In the lowest portion of the watershed, soils are generally deep, reddish-brown, fertile, and permeable (USDA Forest Service 2004a). Agricultural uses occur in these soils. As elevations rise to about 2,500 feet, soils tend to become more shallow, rockier, and redder. These soils have been used for rangeland grazing, residential development, and, to a lesser extent, agriculture. Throughout much of the rest of the watershed, the land is broken and rocky, with ridges of deep, clay-rich soils. The deeply weathered volcanic soils on the Foresthill and Georgetown Divides are productive timberlands. Higher-elevation soils are generally used for timber management and outdoor recreation.

The North Fork/Middle Fork American River watershed includes a range of public and private land ownerships. Within the eastern two-thirds of the watershed (the higher elevations), a mix of public land managed by the U.S. Department of Agriculture (USDA) Forest Service and large private landowners appears as a checkerboard. This ownership pattern arose because every other section of the land was granted to railroad companies in the 1800s. Since that era additional land exchanges, purchases, disposals, and remnants from mining claims have resulted in many isolated sections or partial sections of private lands within blocks of public land. The Tahoe and Eldorado National Forests make up approximately 37 and 21 percent of the watershed, respectively. The western third (the lower elevations) is a mix of private ownership and public lands mostly managed by the U.S. Department of the Interior (USDI) Bureaus of Land Management and Reclamation. Forestry is identified as the dominant land use (approximately 87 percent) in the North Fork/Middle Fork American River watershed. Another 7 percent is rural residential, 4 percent is open space, 1 percent is agriculture, and the remaining 1 percent is a mix of other land uses.

1.4 Report Organization

The report structure of the North Fork/Middle Fork American River Sediment Study follows the general chronology of the project development. The report is organized as follows:

- Chapter 1– Introduction;
- Chapter 2– Overview of Study Approach;
- Chapter 3– Watershed Characteristics and Processes;
- Chapter 4– Watershed Indicators, Modeling, and Prioritization;
- Chapter 5– Management Strategies and Priorities;
- Chapter 6– Monitoring Framework for Adaptive Management;
- Chapter 7– Opportunities and Next Steps;
- Appendix A– Literature Cited;
- Appendix B– GIS Data Sources and Gaps;
- Appendix C– C-1: Site Photographs and C-2: Field Review Report; and
- Appendix D– Detailed GIS Methods, Spatial Analysis, and Modeling.

Maps using existing and/or derived GIS data layers are presented throughout this report at the end of the chapters.

In general, this report begins by summarizing watershed characteristics at a relatively coarse scale and moves progressively to finer scales with each chapter. The overview presented in Chapter 2 covers the entire North Fork/Middle Fork American River watershed. In Chapter 3, details are provided by the finer-scaled 5th-level HUC subwatersheds nested within the entire North Fork/Middle Fork watershed. The first half of Chapter 4 moves to the next level, the 6th-level HUC subwatersheds, and the second half of Chapter 4 focuses on the even smaller 7th-level HUC subwatersheds. Chapter 5 identifies management strategies and priorities for watershed enhancement opportunities (including disturbance minimization and active restoration). Chapter 6 describes a possible framework for a watershed-scale erosion and sedimentation monitoring program in an adaptive management, collaborative, and non-regulatory context. Chapter 7 presents management opportunities and next steps based on the report's key findings.

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CHAPTER 2: OVERVIEW OF STUDY APPROACH

2.1 Conceptual Framework

The analysis framework for the North Fork/Middle Fork American River Sediment Study is consistent with the U.S. Environmental Protection Agency (EPA) Watershed Analysis and Management Project (EPA 2000). This coarse-filtered, GIS-based, watershed relative risk model at the subwatershed level is the first step (the Level 1 Assessment in Figure 2-1) in the overall phased process. The current study also documents the Synthesis and Recommendations component illustrated in Figure 2-1. This study will allow the ARWG to continue progressing toward the ultimate goal, the Level 2 Assessment and the Implementation of a Watershed Management Plan, as illustrated in Figure 2-1. The Level 2 Assessment or the Watershed Management Plan is not part of the currently funded North Fork/Middle Fork American River Sediment Study.

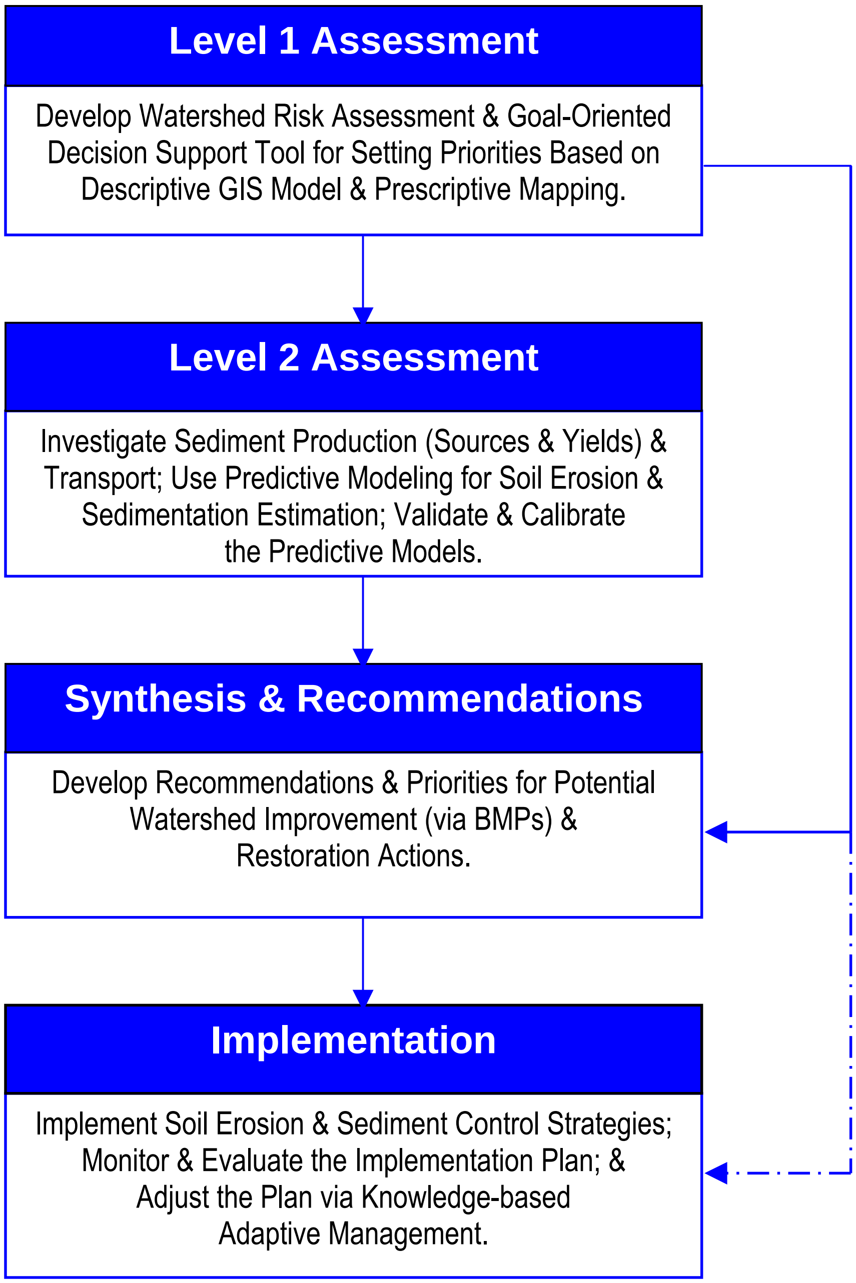
Fundamentally, the “systems approach” used in this study addresses watershed erosion and sedimentation potential by using multi-thematic GIS overlays of soil properties, slope steepness, sensitive geologic and geomorphic types (where available), road and stream networks, precipitation sensitivity (the combination of precipitation zones and intensities), aquatic species/habitats, and land-use. In this context the potential for more eroded soil to be delivered to the stream system is a function of individual factors, which are additive. With each additional factor the potential that a given subwatershed may deliver sufficient sediment downstream to affect a key resource increases.

The North Fork/Middle Fork American River watershed assessment approach focuses primarily on the GIS-based, watershed relative risk screening model for soil erosion and sediment delivery at the subwatershed level. The study used resource condition and vulnerability indicators to assess watershed hazards and risks. This GIS-based approach to watershed assessment is intended as a coarse filter for screening and prioritization of subwatersheds that may have inherent risks of erosion potential and sediment delivery conditions due to sensitive lands and road impacts. Using a systematic approach for the entire study area provides a framework that improves decision-making for watershed enhancement or maintenance and adaptive resource management.

2.2 Information Needs, Assembly, and Integration

With input from the ARWG TAC, TtEC compiled a list of geospatial and other data needed to complete the North Fork/Middle Fork American River Sediment Study. Data assembly focused on collecting base layers necessary to analyze potential erosion and sediment delivery to key resources. TtEC contacted several agencies, organizations, and individuals that maintain data for the watershed to request specific GIS data layers. In addition, existing data previously assembled by the USDA Forest Service and the ARWG were reviewed, and relevant data were incorporated into this study. While compiling GIS data layers and other information, TtEC collaborated with the ARWG TAC to ensure that the most representative data sources were consulted and that the best available information was included. Appendix B documents the “state of the data” (a review of data sources and gaps) for GIS coverages and other information used to create maps and perform spatial analyses.

Figure 2-1. Contextual Overview of Watershed-Scale Erosion and Sedimentation Assessment, Implementation, and Monitoring Framework: A Phased Approach. [1]



[1] This study represents the Level 1 Assessment and Synthesis and Recommendations.

In cases where more detailed data existed for some portions of the North Fork/Middle Fork American River watershed (e.g., contour-crenulated stream networks and geomorphic types on the Tahoe and Eldorado National Forests), the more detailed GIS data layers were utilized. These were incorporated into the watershed assessment with careful consideration of potential differences in scale, resolution, and extent between the different datasets. TtEC digitized selected data deemed critical to the outcome of the study, including finer-scaled geologic information for sensitive lands prone to mass wasting. In cases where GIS data layers from various sources were used for different areas in the North Fork/Middle Fork American River watershed, particular attention was devoted to documenting data resolution and scales of capture.

Data were also compiled for key resources, which for this watershed assessment are aquatic organisms and habitats, water and power infrastructure, and water quality. TtEC developed a list of fish and aquatic species considered as key resources in the North Fork/Middle Fork American River watershed, which the ARWG TAC subsequently approved. Similarly, information related to water and power infrastructure was gathered from available sources and presented to the ARWG TAC for approval. After researching available water quality data, TtEC and the ARWG TAC concluded that sediment-related water quality data are scarce.

Data related to known erosion sites were also gathered for the North Fork/Middle Fork American River watershed. Specifically, TtEC incorporated information on areas of placer mining debris, known major placer and hardrock mines, areas of glacial deposits such as moraines and alluvial terraces, and mass wasting sites. Each of these has a relatively high potential for sedimentation that may contribute coarse- and fine-grained sediment to stream systems.

In the interest of using the best available information and appropriately managing data quality, TtEC used the following four-step procedure for the data compilation and analysis:

1. Review of data needs and identification of data sources;
2. Selection of data sources based on review of data quality and extent (data acceptability or fitness of use);
3. Documentation of data availability, gaps, and limitations; and
4. Data extraction, analysis, and synthesis.

In addition to compiling digital data, TtEC also reviewed previous studies and reports, existing scientific literature, and field notes and surveys relevant to the North Fork/Middle Fork American River and surrounding watersheds.

2.3 Analysis Process and Limitations

The North Fork/Middle Fork American River watershed assessment used existing data to depict known or potential erosion and sedimentation hazards, and to develop a knowledge-based relative risk model for subwatershed screening and prioritization.

Selected GIS submodels were developed using specific risk indicators to characterize watershed vulnerability. These submodels were integrated to assess the relative risks of soil erosion and sediment delivery by subwatershed. The key indicators used in the GIS submodels were derived from a single GIS data layer, or from the intersections of two or more GIS data layers. The assessment of potential risk followed relevant assumptions based on professional judgment or empirical information supported by theory or experience.

A brief field review to selected subwatersheds was performed to better understand the dominant hillslope and channel erosion processes, major sediment sources, and sediment delivery and transport processes. During the reconnaissance visits, TtEC validated the approach by assessing the specific risk factors included in the GIS-based modeling of potential erosion and sedimentation hazards.

The approach used in this North Fork/Middle Fork American River Sediment Study has the benefit of applying similar methods in a systematic manner across the entire landscape using baseline condition information with a similar degree of detail. It also provides a series of potential risk indicators that can highlight variations by subwatershed in the study area. For example, an individual risk indicator associated with the percent of area in potentially highly erodible soils may be very low in one 7th-level HUC subwatershed and very high in another 7th-level HUC subwatershed, allowing direct comparison between the two subwatersheds.

The accuracy of the subwatershed screening and prioritization presented in this study depends on the quality, accuracy, and reliability of the available geospatial data. TtEC worked with the ARWG TAC to ensure that the best available information is incorporated, to the extent feasible. However, as organizations continue to collect new information and improve the existing knowledge base, the GIS-based models can be updated to more accurately reflect on-the-ground conditions and vulnerabilities. Similarly, this GIS-based relative risk model provides a coarse-scaled analysis of soil erosion and sedimentation processes, which can be supplemented with finer-scaled, site-specific studies, as they are conducted.

For the North Fork/Middle Fork American River Sediment Study, the watershed risk assessment is based on bare land potential of the area. Bare land potential is defined as the maximum erosion potential for an area of land that has no vegetative cover. With the exception of roads, evaluation of the effects of human land use is generally not part of the current study. Similarly, potential disturbance by wildfire or flooding are not considered in this watershed risk evaluation.

2.4 Applications of the Results

The methodology described in this report was designed specifically to meet the objectives of the North Fork/Middle Fork American River Sediment Study. Several quantitative spatial analyses and models were developed to characterize the potential risks of soil erosion and sedimentation in the watershed. The TtEC team used an iterative process during the GIS-based model development to incorporate literature research, the best available spatial data, and input from stakeholders and the ARWG TAC. The overall approach achieves a consistent treatment of the subwatersheds (90 7th-level

HUCs) that make up the watershed assessment area. At the same time, it explores the variability in these subwatersheds and ultimately highlights the areas where future efforts can focus to accomplish the greatest benefits with limited financial resources.

This is a reconnaissance-level (Level 1) analysis using watershed hazard indicators (specifically for erosion and sedimentation potential) and not a detailed, fieldwork-based analysis (Level 2) of hillslope erosion and stream channel sedimentation. However, future adaptive management strategies (including inventory, monitoring, research, and plan adjustment process) can be tiered off of this spatially explicit, systematic subwatershed screening and prioritization approach.

The key findings of the watershed vulnerability evaluation in this study can serve as the basis for an ecosystem-based approach involving prioritization, targeting, and optimization. This approach can be used to formulate specific management practices and strategic priorities. The results of this watershed assessment can be used to design and implement a monitoring and evaluation strategy, using geomorphic predictors to evaluate disturbance sensitivity and recovery potential, or conduct subwatershed-specific sediment studies to investigate sediment sources and yields. It can be used to examine sediment delivery and transport, and to develop and validate predictive or process-based models for soil erosion, runoff, and sediment delivery.

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CHAPTER 3: WATERSHED CHARACTERISTICS AND PROCESSES

3.1 Introduction

The purpose of Chapter 3 is to characterize the current landscape conditions and watershed processes related to soil erosion and sedimentation. This watershed characterization establishes the ecological baseline and provides the relevant context for the prioritization and recommended next steps that follow in subsequent chapters. The best available information, including GIS data layers, was assembled, reviewed, integrated, and synthesized to characterize the watershed resources, human land uses, and environmental conditions at multiple scales.

In Chapter 3, data summaries and related discussions are based on 5th-level HUC subwatersheds (Upper Middle Fork American River, Rubicon River, North Fork Middle Fork American River, Lower Middle Fork American River, Upper North Fork American River, and Lower North Fork American River). Where appropriate, selected 7th-level HUC subwatersheds within the 5th-level HUC subwatersheds are highlighted in the landscape characterization. Photo documentation of the North Fork/Middle Fork American River watershed assessment area is presented as part of Appendix C.

3.2 Drainage Basins/Hydrologic Units

Of the total 625,144 acres in the North Fork/Middle Fork American River watershed, approximately one-third (Table 3-1) is contained within the Rubicon River 5th-level HUC subwatershed along the southern extent of the study area. This subwatershed, together with the Upper Middle Fork American River and the North Fork Middle Fork American River subwatersheds, drains the headwaters of the Middle Fork American River (Map 3-1). These three subwatersheds converge at the Lower Middle Fork American River subwatershed, which drains directly to the North Fork American River. Just over one-quarter of the North Fork/Middle Fork American River watershed falls within the Upper North Fork American River, along the mainstem of the North Fork American River in the northernmost portion of the watershed. This subwatershed drains into the Lower North Fork American River subwatershed, which extends to the lowest elevation and westernmost extent of the North Fork/Middle Fork American River watershed.

Table 3-1. North Fork/Middle Fork American River Watershed by 5th-level HUC Subwatersheds (see Map 3-1).

5th-level HUC	Hydrologic Unit Name	Area (acres)	Area (sq. miles)	Extent (% of total area)
1802012801	Upper Middle Fork American River	70,890	110.8	11.3
1802012802	Rubicon River	201,818	315.3	32.3
1802012803	North Fork Middle Fork American	59,190	92.5	9.5
1802012804	Lower Middle Fork American River	62,067	97.0	9.9
1802012805	Upper North Fork American River	162,280	253.6	26.0
1802012806	Lower North Fork American River	68,899	107.7	11.0
	Total	625,144	976.9	100.0

3.3 Land Ownership, Land Use, and Population

The North Fork/Middle Fork American River watershed includes a mix of public and private lands (Map 3-2). Almost 35 percent of the watershed belongs to private landowners, including over half of the Lower North Fork and Lower Middle Fork American River watersheds (Table 3-2). Most of the private land occurs in the lowest third of the watershed or is interspersed with National Forest System lands in a checkerboard pattern. The largest public land manager is the USDA Forest Service, which manages almost 60 percent of the watershed (361,708 acres). This federal agency manages over 80 percent of the North Fork Middle Fork American River 5th-level HUC subwatershed (primarily in the Tahoe National Forest), almost 75 percent of the Upper Middle Fork American River (primarily in the Tahoe National Forest), and over 70 percent of the Rubicon River subwatershed (primarily in the Eldorado National Forest). The next-largest public land manager is the USDI Bureau of Land Management with 25,826 acres along the North and Middle Fork rivers, followed by the USDI Bureau of Reclamation with 21,577 acres along the mainstem rivers in the lowest portion of the watershed in the vicinity of Folsom Reservoir, and the State of California with 2,808 acres along the Georgetown Divide. The different land owners and managers follow different approaches to watershed resource management.

The majority (almost 90 percent) of the North Fork/Middle Fork American River watershed is covered by forest (Map 3-3 and Table 3-3), including all or almost all of the Upper Middle Fork American River subwatershed, the Rubicon River subwatershed, the North Fork Middle Fork American River subwatershed, and the Upper North Fork American River subwatershed, and nearly half of the remaining Lower Middle Fork American River subwatershed and the Lower North Fork American River subwatershed. In general, portions of the watershed above approximately 3,000 feet in elevation are dominated by forest. The next largest land use is rural residential, which makes up approximately 7 percent of the North Fork/Middle Fork American River watershed, primarily in lower elevations. Open space land use (or recreational use) encompasses about 4 percent of the watershed, also primarily in lower elevations. The remaining land uses account for less than 1 percent each of the watershed (Table 3-3). Different land uses can affect hillslope, hydrologic, and channel processes. Human activities and associated disturbance regimes can change ecological processes and resource conditions and contribute to accelerated erosion and sedimentation.

Rural residential development is rapidly occurring throughout Placer and El Dorado counties (Busch 2001). Auburn, California, located in Placer County, is the largest city in the study area. The city had an estimated population of 12,912 in 2005, a 3 percent increase from the 2000 census (U.S. Census Bureau 2006) (Table 3-4). In total, the estimated population of both El Dorado and Placer counties was 493,869 in 2005, an increase of 22 percent from the 2000 census. The combined county population projection for 2050 is estimated to be 939,716 (State of California Demographic Research Unit 2004). As of 2000, El Dorado County, which encompasses 1,711 square miles, averaged 91.4 persons per square mile; Placer County, encompassing 1,404 square miles, averaged 176.9 persons per square mile (U.S. Census Bureau 2006).

Table 3-2. Land Ownership/Management by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Maps 3-1 and 3-2).

5th-level Hydrologic Unit Name	Bureau of Land Management		Bureau of Reclamation		Eldorado National Forest		Private		State		Tahoe National Forest		Total	
	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)
Upper Middle Fork American River	0	0	0	0	6,712	9.5	18,015	25.4	0	0	46,163	65.1	70,890	100.0
Rubicon River	0	0	0	0	113,751	56.4	54,863	27.2	2,664	1.3	30,541	15.1	201,818	100.0
North Fork Middle Fork American	299	0.5	0	0	0	0	10,216	17.3	0	0	48,675	82.2	59,190	100.0
Lower Middle Fork American River	6,479	10.4	7,572	12.2	11,019	17.8	32,909	53.0	0	0	4,089	6.6	62,067	100.0
Upper North Fork American River	10,484	6.5	1,341	0.8	0	0	61,324	37.8	122	0.1	89,008	54.8	162,280	100.0
Lower North Fork American River	8,564	12.4	12,664	18.4	0	0	35,899	52.1	22	<0.1	11,750	17.1	68,898	100.0

Table 3-3. Land Uses by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Maps 3-1 and 3-3).

Land Use	Upper Middle Fork American River		Rubicon River		North Fork Middle Fork American		Lower Middle Fork American River		Upper North Fork American River		Lower North Fork American River	
	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)
Agriculture	0	0	26	<0.1	2	<0.1	15	<0.1	2,352	1.4	3,043	4.4
Community/Neighborhood Commercial/Office	0	0	8	<0.1	0	0	123	0.2	55	<0.1	243	0.4
Forest	70,882	100.0	201,318	99.8	58,976	99.6	28,011	45.1	153,206	94.4	33,311	48.3
Industrial	0	0	0	0	0	0	283	0.5	0	0	172	0.2
Low-Density Residential	0	0	2	<0.1	49	0.1	210	0.3	575	0.4	865	1.3
Medium-Density Residential	0	0	0	0	0	0	12	<0.1	0	0	87	0.1
Open Space	8	<0.1	0	0	32	0.1	12,143	19.6	591	0.4	13,045	18.9
Public/Quasi-Public	0	0	0	0	0	0	56	0.1	87	0.1	52	0.1
Rural Residential	0	0	441	0.2	131	0.2	20,672	33.3	3,809	2.3	17,540	25.5
Other	0	0	23	<0.1	0	0	542	0.9	1,604	1.0	541	0.8
Total	70,890	100.0	201,818	100.0	59,190	100.0	62,067	100.0	162,280	100.0	68,898	100.0

Table 3-4. Population (A) Trends and (B) Projections by State, County, and City in the North Fork/Middle Fork American River Watershed.

(A)

Population by County and Incorporated Place 1990, 2000, and 2005							
Geographic Area	Population			1990 to 2000		2000 to 2005	
	1990	2000	2005	Absolute Change	Percent Change	Absolute Change	Percent Change
State:							
California	29,811,427	33,871,648	36,132,147	4,060,221	13.6	2,260,499	6.7
County:							
El Dorado	125,995	156,299	176,841	30,304	24.1	20,542	13.1
Placer	172,796	248,399	317,028	75,603	43.8	68,629	27.6
City:							
Auburn	10,592	12,462	12,912	1,870	17.7	450	3.6

Source: U.S. Census Bureau 2006.

(B)

Population Projections 2010 and 2050							
Geographic Area	Population			2000 to 2010		2010 to 2050	
	2000	2010	2050	Absolute Change	Percent Change	Absolute Change	Percent Change
State:							
California	33,871,648	39,246,767	54,777,700	5,375,119	15.9	15,530,933	39.6
County:							
El Dorado	156,299	188,471	282,331	32,172	20.6	93,860	49.8
Placer	248,399	349,113	657,385	100,714	40.5	308,272	88.3

Source: State of California Demographic Research Unit 2004.

3.4 Elevation and Topography

The topography of the North Fork/Middle Fork American River watershed includes some of the deepest canyons in the United States. Elevations range from over 9,900 feet at the headwaters of the Rubicon River to less than 500 feet at Folsom Reservoir (Map 3-4). The 5th-level HUC subwatersheds with the greatest relief (i.e., difference between the highest and lowest elevations) are the Upper Middle Fork American River, the Rubicon River, and the Upper North Fork American River, which range from about 1,000 feet to over 8,000 feet (Table 3-5). At Royal Gorge on the North Fork American River, the rock wall is over 4,000 feet high. The 5th-level HUC subwatersheds with the lowest relief are the Lower Middle Fork American River and the Lower North Fork American River, which range from less than 1,000 feet to almost 5,000 feet. In terms of sediment production and delivery, relief offers an estimate of the overall potential energy in a watershed. Soil erosion and sediment transport by gravity is more likely in a high-relief watershed than a low-relief watershed.

Table 3-5. Elevation by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Maps 3-1 and 3-4).

	Upper Middle Fork American River		Rubicon River		North Fork Middle Fork American		Lower Middle Fork American River		Upper North Fork American River		Lower North Fork American River	
Elevation Classes (feet)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)
≤1,000	0	0	0	0	0	0	3,463	5.6	101	0.1	3,660	5.3
1,001-2,000	983	1.4	1,764	0.9	1,615	2.7	18,184	29.3	5,334	3.3	19,450	28.2
2,001-3,000	3,328	4.7	6,345	3.1	5,420	9.2	26,965	43.4	21,893	13.5	21,295	30.9
3,001-4,000	6,782	9.6	16,987	8.4	10,293	17.4	12,369	19.9	23,644	14.6	17,354	25.2
4,001-5,000	10,599	15.0	44,656	22.1	20,009	33.8	1,085	1.7	26,003	16.0	7,139	10.4
5,001-6,000	23,014	32.5	45,292	22.4	17,124	28.9	0	0	33,702	20.8	0	0
6,001-7,000	18,326	25.9	43,204	21.4	4,670	7.9	0	0	38,376	23.6	0	0
7,001-8,000	6,436	9.1	33,377	16.5	58	0.1	0	0	11,374	7.0	0	0
8,001-9,000	1,420	2.0	9,502	4.7	0	0	0	0	1,853	1.1	0	0
≥9,001	0	0	693	0.3	0	0	0	0	0	0	0	0
Total	70,890	100.0	201,818	100.0	59,190	100.0	62,067	100.0	162,280	100.0	68,899	100.0

Similarly, the extent of steep slopes within a watershed offers an estimate of the potential for sediment transport. Soil erosion by water and/or gravity is more likely to occur on steep slopes. However, on exceedingly steep slopes (beyond the angle of repose), soil formation is difficult and existing soils are more likely to have eroded during earlier runoff events. Mass wasting processes, including falls (e.g., rock falls, rock avalanches), slides (e.g., rock slides, slumps), and flows (e.g., debris flows, earth flows, creep), may occur episodically on steep hillslopes, particularly those near or steeper than the angle of repose. As a result, slope gradient can be used as a tool for locating potential sites of mass wasting (Shaw and Johnson 1995). The distribution of slope steepness within the North Fork/Middle Fork American River watershed is shown on Map 3-5 and Table 3-6. The distributions of slope steepness follow the same general trend across each 5th-level HUC subwatershed. Slopes 11 to 30 percent make up the majority of each subwatershed, with hillslopes ranging from 31 to 50 percent also commonly occurring. Relatively sheer slopes greater than 70 percent predominate in deep canyons along the mainstem rivers.

Slope aspect, another topographic attribute of the watershed, can affect sediment production and delivery. South-facing slopes in the northern hemisphere generally experience more solar radiation. In the Sierra Nevada, more solar radiation translates into more frequent freeze-thaw cycles, lower soil moisture, thinner and rockier soils, and less vegetative cover than on generally shadier, more moist north-facing slopes. As a result, south-facing slopes may be more susceptible to mass failure events and less susceptible to surface erosion or soil creep than north-facing slopes. Within the 5th-level HUC subwatersheds of the North Fork/Middle Fork American River, slope aspects are fairly evenly distributed (Map 3-6 and Table 3-7). The extent of northerly-facing (northeast-, north-, or northwest-facing) slopes ranges from 30 to 35 percent of the 5th-level HUC subwatersheds, and the extent of southerly-facing (southeast-, south-, or southwest-facing) slopes ranges from 38 to 43 percent of the 5th-level HUC subwatersheds. The North Fork Middle Fork American River subwatershed has the greatest ratio of southerly- to northerly-facing slopes (with 25,729 acres of southerly- and 17,583 acres of northerly-facing slopes). The Upper North Fork American River subwatershed has the lowest ratio of southerly- to northerly-facing slopes (with 62,277 acres of southerly- and 57,409 acres of northerly-facing slopes).

3.5 Geology, Geomorphology, and Soils

3.5.1 Geology

The geology of the North Fork/Middle Fork American River watershed is complex and includes many units (Map 3-7 and Table 3-8). In general, they range from metamorphic rocks formed during the Jurassic (approximately 206 to 144 million years old); to volcanics and plutonic rocks dating 115 to 87 million years old; to recent glacial deposits as old as 2.5 million years; to modern landslide, scree, and other mass wasting deposits and water-lain alluvium. At the surface, three-quarters of the North Fork/Middle Fork American River watershed consists of the following geologic units: Mehrten Formation (24 percent), Shoo Fly Complex (24 percent), granitic rocks (14 percent), Calaveras Complex (8 percent), and glacial deposits (5 percent). Of these, the Miocene to Pliocene (24 to 2 million years ago) Mehrten Formation in particular has been correlated with mass wasting at the contact with the underlying

Table 3-6. Slope Steepness by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Maps 3-1 and 3-5).

5th-level Hydrologic Unit Name	≤10 percent		11-30 percent		31-50 percent		51-70 percent		>70 percent		Total	
	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)
Upper Middle Fork American River	8,007	11.3	26,303	37.1	21,564	30.4	8,500	12.0	6,516	9.2	70,890	100.0
Rubicon River	39,693	19.7	77,359	38.3	50,565	25.1	20,835	10.3	13,366	6.6	201,818	100.0
North Fork Middle Fork American	7,006	11.8	17,237	29.1	15,139	25.6	9,926	16.8	9,882	16.7	59,190	100.0
Lower Middle Fork American River	10,276	16.6	19,805	31.9	15,176	24.5	9,566	15.4	7,245	11.7	62,067	100.0
Upper North Fork American River	18,275	11.3	51,192	31.5	42,817	26.4	26,669	16.4	23,327	14.4	162,280	100.0
Lower North Fork American River	15,980	23.2	25,260	36.7	13,862	20.1	8,447	12.3	5,350	7.8	68,898	100.0

Table 3-7. Slope Aspects by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Maps 3-1 and 3-6).

Aspect	Upper Middle Fork American River		Rubicon River		North Fork Middle Fork American		Lower Middle Fork American River		Upper North Fork American River		Lower North Fork American River	
	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)
Flat	1,022	1.4	2,305	1.1	0	0	14	<0.1	336	0.2	156	0.2
North	7,649	10.8	23,660	11.7	4,986	8.4	6,943	11.2	19,550	12.0	7,647	11.1
Northwest	11,543	16.3	29,196	14.5	8,997	15.2	7,476	12.0	24,149	14.9	9,119	13.2
West	10,571	14.9	29,394	14.6	9,444	16.0	9,479	15.3	25,158	15.5	10,274	14.9
Southwest	8,554	12.1	27,743	13.7	7,609	12.9	8,940	14.4	20,074	12.4	10,920	15.8
South	9,710	13.7	28,487	14.1	8,661	14.6	8,947	14.4	22,090	13.6	10,390	15.1
Southeast	10,623	15.0	24,476	12.1	9,459	16.0	7,860	12.7	20,113	12.4	8,089	11.7
East	6,911	9.7	17,998	8.9	6,434	10.9	6,514	10.5	17,100	10.5	7,012	10.2
Northeast	4,307	6.1	18,560	9.2	3,600	6.1	5,896	9.5	13,710	8.4	5,291	7.7
Total	70,890	100.0	201,818	100.0	59,190	100.0	62,067	100.0	162,280	100.0	68,899	100.0

Table 3-8. Geologic Types by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Maps 3-1 and 3-7).

	Upper Middle Fork American River		Rubicon River		North Fork Middle Fork American		Lower Middle Fork American River		Upper North Fork American River		Lower North Fork American River	
Geologic Unit	**Area (acres)**	**Extent (%)**	**Area (acres)**	**Extent (%)**	**Area (acres)**	**Extent (%)**	**Area (acres)**	**Extent (%)**	**Area (acres)**	**Extent (%)**	**Area (acres)**	**Extent (%)**
Alluvium	1,654	2.3	4,133	2.0	36	0.1	160	0.3	1,620	1.0	0	0
Andesite	0	0	1,621	0.8	0	0	124	0.2	197	0.1	283	0.4
Andesite Conglomerate	0	0	0	0	0	0	217	0.4	451	0.3	572	0.8
Auriferous Gravels	72	0.1	44	<0.1	263	0.4	321	0.5	1,522	0.9	603	0.9
Basalt	1,739	2.5	1,564	0.8	0	0	0	0	484	0.3	0	0
Calaveras Complex	0	0	0	0	0	0	22,116	36.6	17,442	10.7	10,333	15.0
Chert	0	0	456	0.2	0	0	0	0	318	0.2	2,439	3.5
Clipper Gap Formation	0	0	0	0	0	0	7,965	12.8	0	0	13,325	19.3
Diorite	0	0	3,132	1.6	0	0	0	0	3,221	2.0	0	0
Gabbro	85	0.1	3,184	1.6	0	0	831	1.3	1,798	1.1	0	0
Glacial Deposits	4,104	5.8	20,186	10.0	1,045	1.8	104	0.2	8,118	5.0	0	0
Granite	4,766	6.7	69,556	34.5	0	0	0	0	12,893	7.9	34	0
Lake Combie Complex	0	0	0	0	0	0	374	0.6	0	0	1,995	2.9
Lake Tahoe Sequence	0	0	3	<0.1	0	0	0	0	0	0	0	0
Landslide Deposits	151	0.2	165	0.1	0	0	0	0	123	0.1	0	0
Limestone	0	0	27	<0.1	0	0	93	0.1	47	<0.1	0	0
Logtown Formation	0	0	0	0	0	0	1,031	1.7	0	0	217	0.3
Mariposa Formation	0	0	0	0	0	0	1,958	3.2	1,194	0.7	10,765	15.6
Mehrten Formation	*27,196*	*38.4*	*49,643*	*24.6*	*14,746*	*24.9*	*9,657*	*15.6*	*32,882*	*20.3*	*17,315*	*25.1*
Metamorphic Rocks	0	0	72	<0.1	0	0	585	0.9	482	0.3	0	0
Mine Tailings	0	0	0	0	0	0	159	0.3	0	0	0	0
Rhyolite	0	0	0	0	8	<0.1	1	<0.1	0	0	0	0
Sailor Canyon Formation	3,462	4.9	9,404	4.7	0	0	0	0	8,258	5.1	0	0
Scree or Talus Deposits	67	0.1	180	0.1	0	0	0	0	1,712	1.1	0	0
Serpentinized Ultramafic Rocks	0	0	0	0	248	0.4	2,923	4.7	3,014	1.9	5,317	7.7
Shoo Fly Complex	20,496	28.9	27,410	13.6	42,790	72.3	11,898	19.2	43,128	26.6	932	1.4
Sierra Buttes Formation	0	0	0	0	0	0	0	0	1,000	0.6	0	0
Taylor Formation	0	0	5	<0.1	0	0	0	0	306	0.2	0	0
Tuttle Lake Formation	525	0.7	633	0.3	0	0	0	0	0	0	0	0
Ultramafic Rocks	0	0	0	0	24	<0.1	300	0.5	1,020	0.6	0	0
Unassigned Meta. Sed/Vol	64	0.1	3,067	1.5	21	0	959	1.5	12,311	7.6	4,471	6.5
Valley Springs Formation	*5,386*	*7.6*	*5,752*	*2.9*	*0*	*0*	*224*	*0.4*	*6,799*	*4.2*	*269*	*0.4*
Volcanic Rocks	0	0	1,484	0.7	0	0	0	0	148	0.1	0	0
Volcaniclastic Sediments	0	0	0	0	0	0	0	0	1,206	0.7	0	0
Other	1,123	1.6	94	<0.1	7	<0.1	66	0.1	586	0.4	28	<0.1
Total	70,890	100.0	201,818	100.0	59,190	100.0	62,067	100.0	162,280	100.0	68,898	100.0

Note: Mehrten and Valley Springs Formations highlighted because of their importance in mass wasting processes in the North Fork/Middle Fork American River watershed.

Oligocene to Miocene (37 to 5 million years ago) Valley Springs Formation (which encompasses 3 percent of the total watershed area). Because of their importance in generating sediment, the Mehrten and Valley Springs formations were digitized from finer-scaled geologic maps as shown on Map 3-7 (Busch 2001; Loyd 1995). The Mehrten and Valley Springs formations by 5th-level HUC subwatersheds are highlighted in Table 3-8.

The Valley Springs Formation originated from around 20 to 30 million years ago, during a long sequence of volcanism in the Sierra Nevada (Loyd 1995). During this episode, rhyolitic ash erupted and spread westward. Some of the ash consolidated into the welded tuffs found today at higher elevations. Much of it settled, filling the Eocene valleys and covering the Eocene landscape with ash layers of 400 feet or more. These ash layers were eroded by overland flow and fluvial transport, which redistributed them farther to the west and downslope. Outcrops of redeposited ash can be seen throughout the North Fork/Middle Fork American River watershed, such as along roads in the Onion Creek 7th-level HUC subwatershed and the south side of the French Meadows Reservoir dam. The Valley Springs rhyolitic ash series appear as layers of white, grey, or tan sandstone or clay.

Following the rhyolitic eruptions, from about 3 to 10 million years ago a more mafic, iron-rich sequence of volcanic activity began, including a series of andesitic mudflows (lahars) that inundated the pre-existing landscape and buried many ridges and valleys. This andesitic mudflow series makes up the Mehrten Formation and appears as beds of gray andesitic ash embedded with cobbles and boulders of andesite (Loyd 1995; Page and Sawyer 2001). The resulting volcanic plateau covered much of the North Fork/Middle Fork American River watershed. The remnants of this plateau occur in the mid- to high-elevation, flat-topped features that form at least part of the topographic divides between the 5th-level HUC subwatersheds. The Foresthill Divide and Georgetown Divide are prominent examples of this plateau surface formed by the burial of the landscape by these extensive volcanic mudflows (Page and Sawyer 2001). The present river system was formed by erosion into this buried landscape during the last 5 million years (Wakabayashi and Sawyer 2001). Headward erosion into the Mehrten deposits at the upper parts of watersheds continues to this day. At the upper parts of these watersheds the edges of these Mehrten deposits often form steep cliffs, which dominate mass wasting processes in several 7th-level HUC subwatersheds, including Upper North Shirttail Canyon, Humbug Creek, Sailor Canyon and Wildcat Canyon (on the North Fork American River), Grouse Creek and Peavine Creek (on the North Fork Middle Fork of the American River), Upper Duncan Canyon and Headwaters, Middle, and Lower Long Canyon (Map 3-7).

The Auriferous gravels (i.e., gold-bearing gravels) cover a very small area in the watershed (Table 3-8). However, the hydraulic mining of these deposits washed enormous quantities of sediment into the North and Middle Fork American rivers (James 1997, 1999; Laddish 1996). These gravels were deposited in an Eocene-age (55 to 34 million years ago) river system that drained the Sierra Nevada area at that time (Konigsmark 2002; Lindgren 1911).

The contact between the Mehrten and Valley Springs formations is prone to mass wasting events, particularly where roads intersect this plane (Koler, personal communication, 2005; USDA Forest Service 2003a). A study of the adjacent Yuba River watershed determined that 70 percent of the sediment attributable to mass wasting occurred on the Mehrten and Valley Springs formations (Curtis and others 2005). In the

North Fork/Middle Fork American River watershed, mass wasting occurs in areas of discontinuous, poorly consolidated ash in the Valley Springs Formation, at the contact between the Valley Springs and Mehrten formations, and at the lower contact of the Mehrten Formation (USDA Forest Service 2003a). Chronic failures are associated with ash layers within the mudflow units, as the ash layers alter to low permeability clay layers during post-depositional weathering. Saturation of these clays during wet years can trigger widespread mass wasting. High landslide susceptibility occurs on the Mehrten and Valley Springs formations on slopes ranging from 20 to 40 percent, and extreme susceptibility occurs on slopes of 40 to 60 percent (USDA Forest Service 2003a).

Other prevalent geologic units associated with sediment production include granite and glacial deposits. Granitic rocks, which predominate in the Rubicon River subwatershed, deteriorate into grus with physical (e.g., exfoliation and freeze-thaw) and chemical (e.g., hydrolysis) weathering. Grus includes relatively coarse-grained sands and gravels that lack clay or fine sediment. The lack of matrix makes this material susceptible to surface erosion.

Glacial deposits occur at elevations above approximately 3,650 feet, the lowest probable Pleistocene ice terminus (Scott and Gravlee 1968), in the eastern portion of the North Fork/Middle Fork American River watershed. The upper portion of the watershed exhibits a variety of classic glacial sculpting features, such as U-shaped valleys and cirques (Guyton 1998). The younger (Tahoe- and Tioga-stage) glacial deposits are about 14,000 to 50,000 years old (Guyton 1998), while the older (Donner Lake- and Sherwin-stage) glacial deposits are about 250,000 years old or older. The upper part of the watershed was inundated by glacier ice named the Yuba ice field. This glacier ice mass was contiguous with the one that covered the Yuba River drainage basin to the north (James 2003; James and others 2002; Wahrhaftig and Birman 1965). The Yuba ice field extended to near the South Fork American River but was separate from the Mokelumne ice field to the south. The older glacial deposits are extensively weathered. These deposits include ice-contact till and ice-margin moraines, which are typically poorly sorted, and fluvial and outwash deposits left by water. These deposits can contain materials ranging from very fine silt and clay to large boulders. Relatively small-scaled, localized surface erosion of glacial deposits also occurs in the North Fork/Middle Fork American River watershed.

In addition to the geologic units described above, several major fault zones extend along north-south trends through the Sierra Nevada, along with many smaller shears. For the most part, these are deep-seated, high-angle structures that were active millions of years ago. The role of geologic fault planes in current landscape stability is difficult to evaluate with the available GIS datasets. Detailed, watershed-specific studies are needed in the North Fork/Middle Fork American River to establish the relationships between fault and shear zones and areas prone to mass wasting.

3.5.2 Geomorphology

The Tahoe and Eldorado National Forests have mapped geomorphic units for National Forest System lands throughout the North Fork/Middle Fork American River watershed (Map 3-8). In general, geomorphic units were identified by aerial photographic interpretation with limited field review. Included in this USDA Forest Service mapping process was an assessment of the relative risk of mass wasting in each geomorphic unit. Active mass wasting was identified in all of the following geomorphic units: colluvial aprons and hillslopes; mass wasting complexes; debris flows and slides; frost action; human influence; inner gorges; meadows, runout zones, and transport zones related to snow avalanches; rock slides and rock falls; and undifferentiated stream channels. The most common geomorphic types mapped in the North Fork/Middle Fork American River watershed are colluvial hillslopes and eroding hillslopes, as shown in Table 3-9.

Table 3-9. Geomorphic Types in the North Fork/Middle Fork American River Watershed (mapped on National Forest System lands only; see Map 3-8).

Geomorphic Unit	Area (acres)	Extent (%)
Colluvial apron	45,615	7.3
Colluvial hillslope	176,542	28.2
Complex, mass wasting	27,317	4.4
Debris flow	13,200	2.1
Debris slide	1,558	0.2
Debris slide basin	2,940	0.5
Eroding hillslope	132,681	21.2
Fluvial deposition	130	<0.1
Frost action	25,322	4.0
Human influence	3,031	0.5
Inner gorge	42,159	6.7
Meadow	3,288	0.5
Mountain-valley fan	994	0.2
Rock slide-rock fall	12,916	2.1
Runout zone, snow avalanche	8,208	1.3
Slump earth flow	50	<0.1
Transport zone, snow avalanche	89	<0.1
Undifferentiated stream channel	12,256	2.0
Water	5,344	0.9
Not classified (outside National Forest)	111,504	17.9
Total	625,144	100.0

Key geomorphic units responsible for generating sediment (via mass wasting and fluvial erosion) within the National Forest System lands include inner gorges and channel erosion (USDA Forest Service 1998). Inner gorges result from rapid stream incision and undercutting of slopes adjacent to streams. Landslides, rock fall, rockslides, slope wash, soil creep, and dry ravel (i.e., downslope movement of dry, noncohesive soil or rock particles under the influence of gravity) are all active processes within the inner gorge. In the North Fork/Middle Fork American River watershed, the largest areas of inner gorge develop on large streams that cut through metasedimentary rock at lower elevations dominated by rain. The channel erosion geomorphic unit includes aggradation, degradation, and lateral scour or bank erosion, which occur throughout the North Fork/Middle Fork American River watershed.

3.5.3 Soils

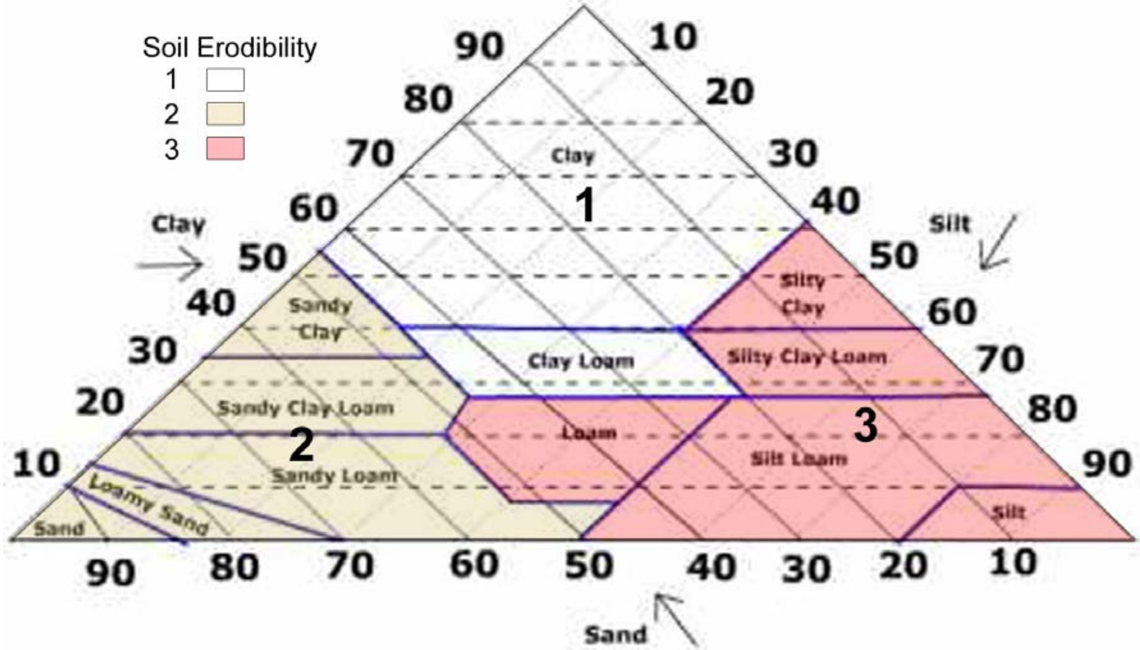
The geologic units of the North Fork/Middle Fork American River watershed form the parent materials for the soils found in watershed. The Natural Resource Conservation Service (NRCS) mapped soil map units in the lower portion of the watershed in western Placer and El Dorado counties (Placer County Map 1980; El Dorado County Map 1974). The Tahoe and Eldorado National Forests mapped soils on their respective National Forest System lands. These soil surveys were added to the NRCS SSURGO database (Tahoe National Forest Map 1980; Eldorado National Forest Map1984). In general, soils in the North Fork/Middle Fork American River watershed tend to be moderately deep to deep and productive between 2,500 and 5,000 feet in elevation. Below that elevation range, soils tend to be impacted by historical land uses (USDA Forest Service 2004a). Above that elevation range, frost activity increases, and soils shift from a mesic to frigid temperature regime and tend to be less developed. At the highest elevations of the watershed, soils are mostly shallow and poorly developed.

Many soils in the Middle Fork American River are rated with high or very high maximum erosion hazard ratings, a factor that estimates the risk of accelerated surface erosion on soils with no protective vegetative cover (USDA Forest Service 2003a). Areas of rock outcrop, very rocky soils, and shallow soils can generate runoff and concentrate surface water flow that can increase the risk of erosion. Most of the soils in the Middle Fork American River have high rock content (USDA Forest Service 2003a). Surface rock fragments can increase the risk of erosion by channeling surface water flow. Rock fragments in the soil can decrease the effective rooting depth of the soil, the nutrient holding capacity, and productivity of the soil.

A wide range of surface soil textures are mapped in the four soil surveys that cover the North Fork/Middle Fork American River watershed. They range from clay loam (as in the Sites clay loam) to very cobbly sandy loam (as in the Tallac-cryumbrepts, Wet association) to very bouldery sand (as in riverwash) and include many loamy textures. The erodibility of the silty textures (such as silt loams) is highest, followed by sandy textures (such as sandy loams); clay-rich textures are most resistant to surface erosion (Figure 3-1) (Finney, personal communication, 2005).

Soils are classified by the NRCS into hydrologic soil groups (i.e., Group A, B, C, and D) based on their runoff potential under similar storm and cover conditions. Hydrologic soil groups in the North Fork/Middle Fork American River watershed range from A to D. Soils classified as Group A have low runoff potential and high infiltration rates when thoroughly wet. These mainly consist of deep, well drained to excessively drained sands or gravelly sands. Soils classified as Group B have moderate infiltration rates and consist of moderately deep or deep, moderately well-drained to well-drained soils with moderately fine texture to moderately coarse texture. Soils classified as Group C have slow infiltration rates and often have a layer that impedes the downward movement of water. Soils classified as Group D have high runoff potential and very slow infiltration rates. These consist of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material.

Figure 3-1. Relative Soil Erodibility, based on Surface Soil Textures, Related to Hillslope Surface Erosion Processes.



Notes: Erodibility Group: 1 = lowest erodibility; 2= intermediate erodibility; and 3= highest erodibility
Source: Finney, personal communication, 2005.

For this study, soil parameters (i.e., surface soil texture and hydrologic soil group) and terrain steepness were used to determine an erosion hazard rating system. More detailed information on erosion hazard ratings in the North Fork/Middle Fork American River watershed is presented in Chapter 4.

3.6 Climate and Surface Water

3.6.1 Climate

Local climatic variations of the western Sierra Nevada are great because of local relief, but some generalizations are possible. The climate of the North Fork/Middle Fork American River watershed is typically Mediterranean, with moist, relatively mild winters and dry, warm summers (National Research Council 1995). The area is characterized by a pattern of summer drought, punctuated by thunderstorms, and winter rain related to changes in the general circulation caused by migrating Pacific Ocean pressure centers (Scott and Gravlee 1968). Mean annual precipitation ranges from about 25 inches near Folsom Reservoir to about 60 inches at Hell Hole Reservoir. The difference in precipitation total reflects orographic effects in the region. Most of the total annual precipitation occurs during the period November through March (Scott and Gravlee 1968).

A rapid increase in precipitation with elevation results from rising and cooling of moist air masses having prevailing west-to-east movement as they reach the Sierra Nevada (Dettinger and others 2004; National Research Council 1995). The orientation and exposure of an area with respect to the direction of air movement also affect the quantity of precipitation received. In general, at elevations less than approximately 3,500 feet, the climate of the North Fork/Middle Fork American River watershed is similar to the typical Sierra Nevada foothill with mild weather and little frost (USDA Forest Service 2004a), and the majority of precipitation falls as rain (Map 3-9) (USDA Forest Service 1998). Between approximately 3,500 and 6,000 feet, precipitation falls as either rain or snow, and rain-on-snow events dominate (USDA Forest Service 1998, 2003a). Above 6,000 feet, most precipitation falls as snow. These three zones correspond to increasing mean annual precipitation (for example, 45 inches, 55 inches, and 62 inches, respectively, on the Eldorado National Forest) (USDA Forest Service 1998). In addition, discharge in the North Fork/Middle Fork American River watershed is contributed by approximately equal amounts of snowmelt and rainfall (Jeton and others 1996). River basins to the north are more rain dominated while basins to the south are more snow dominated (Dettinger 2005). This distribution of rain versus snow reflects the lower elevations of the watersheds to the north and the higher elevation of watersheds to the south. Air temperatures range from 19 to 80 degrees Fahrenheit at 5,000 feet and are slightly cooler at higher elevations and warmer at lower elevations.

In the North Fork/Middle Fork American River watershed, precipitation-related sensitivity is highest in the rain-on-snow zone and lowest in the snow zone (USDA Forest Service 1998). A watershed with a large portion of highly erodible soils on steep slopes in a rain-on-snow zone (a watershed with a high natural sensitivity index) has a low tolerance for watershed disturbance (USDA Forest Service 1998).

The two lowest subwatersheds, Lower Middle Fork and Lower North Fork American River, are rain-dominated (Map 3-9 and Figure 3-2). The centrally located North Fork Middle Fork American River subwatershed is rain-on-snow dominated. The remaining subwatersheds include both rain-on-snow and higher-elevation snow-dominated areas in nearly the same proportions. Similarly, because precipitation intensity generally increases with increasing elevation in the North Fork/Middle Fork American River watershed (Map 3-10), the same lower subwatersheds (Lower Middle Fork and Lower North Fork American River subwatersheds) are dominated by moderately low to moderate precipitation intensity, while the upper subwatersheds (Upper Middle Fork and Upper North Fork American River subwatersheds) are dominated by moderately high and high intensities (Figure 3-3).

Precipitation intensity classes were adapted from National Oceanic and Atmospheric Administration (NOAA) maps (100-year, 6-hour storm) of the area. NOAA maps of varying intensities were considered to depict the energies that generate sources of erosion and sedimentation. Lower intensities were considered to represent chronic sources of erosion and sedimentation, and the more episodic extreme events were considered to generate larger volumes of erosion and sediment. Upon review, the basic distribution patterns of varying intensities were similar to those of the 100-year, 6-hour storm. Overall, the storms that generate the largest floods are the warm and wet winter storms referred to as “Pineapple Expresses” which have high precipitation but also cause snowmelt and rain-on-snow events (Dettinger 2004, 2005).

Understanding precipitation patterns is an important part of watershed assessment and management planning. The amount, intensity, and duration of precipitation influence hydrologic processes (i.e., instream base and peak flows, overland flow), water management regimes, flood potential, and erosion processes.

Figure 3-2. Precipitation Zones by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Maps 3-1 and 3-9).

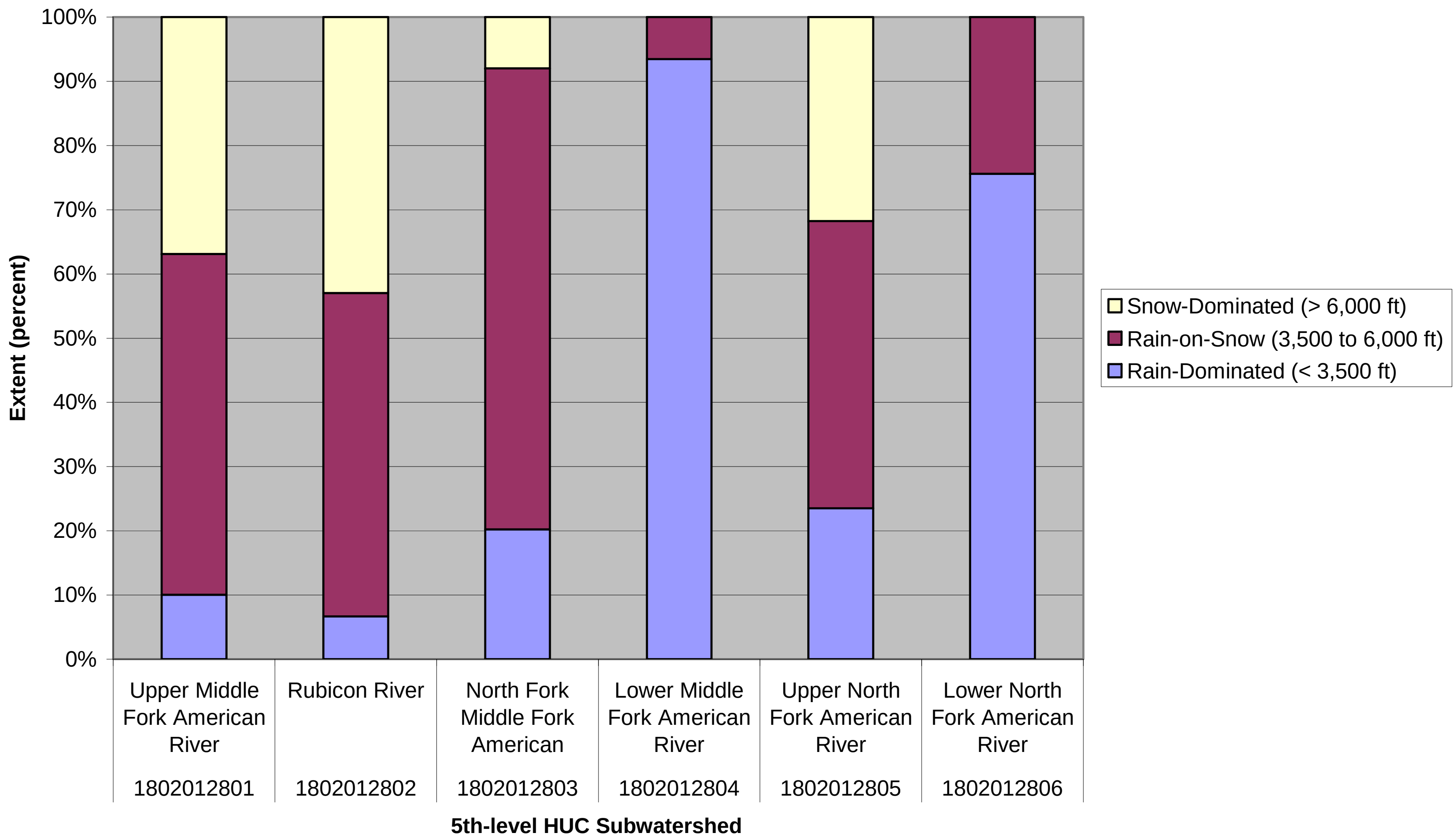
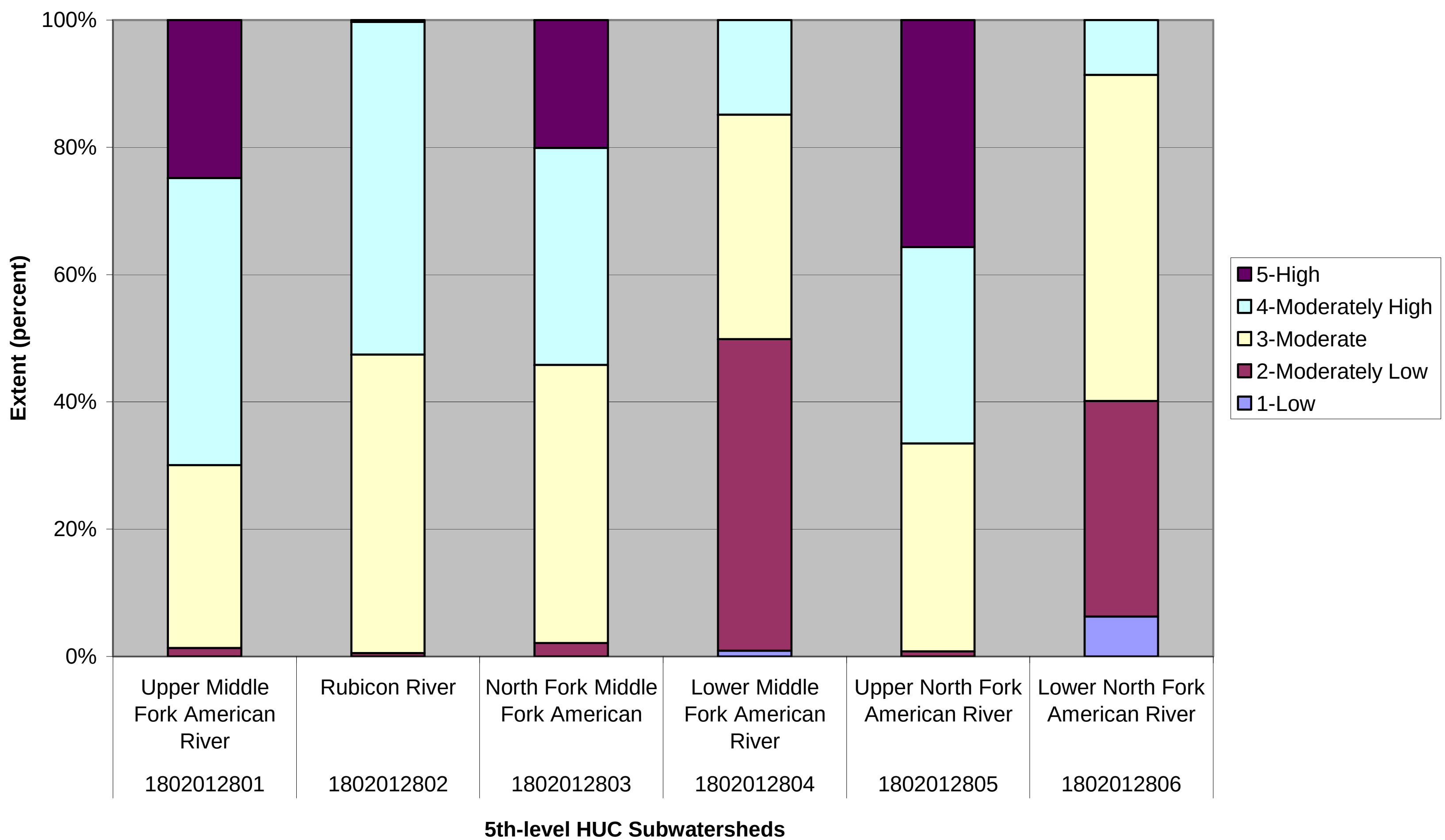


Figure 3-3. Precipitation Intensities by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watersheds (see Maps 3-1 and 3-10).



NOAA has recently installed a network of more than 30 weather sensors in the Upper and Lower North Fork American River 5th-level HUC subwatersheds, resulting in one of the most closely monitored water systems in the United States (National Oceanic and Atmospheric Administration 2006). This area was selected to learn more about storms that originate in the Pacific Ocean beyond Hawaii and trigger serious floods in the Sacramento (California) area. The study is an extension of work conducted in the California Coast Ranges evaluating the 'landfall' of concentrated zones of high moisture content air (atmospheric rivers) and their influence on precipitation patterns and river flooding (National Oceanic and Atmospheric Administration 2006; Ralph and others 2003, 2006). Researchers hope to learn more about these atmospheric rivers, which act like airborne pipelines that pull large amounts of rain across the Pacific Ocean from the tropics.

The North Fork/Middle Fork American River watershed serves as the headwaters to the American River through the Sacramento metropolitan region and is often directly in the path of Pacific storms. As a result, the region faces the greatest urban flooding risk in the country (Weiser 2006). Data collected by NOAA during the trial program (December 2006 through 2009) will be used to develop strategies to actively manage dams and flood defenses in response to sudden shifts in precipitation. The dynamic nature of the weather patterns in the American River watershed has made them difficult to predict. A 10- to 15-degree shift in wind direction can leave one canyon dry in a rain shadow while redirecting a storm elsewhere.

3.6.2 Surface Water

Alpine snow is an important water resource in California and the western United States. Three major features of alpine snowmelt are the spring pulse (the first surge in snowmelt-driven river discharge in spring), maximum snowmelt discharge, and base flow (low river discharge supported by groundwater in fall) (Peterson and others 2005). Geologic factors, base rock permeability and mean soil thickness, influence snowmelt flow pathways (Peterson and others 2005). Both surface and groundwater flows and water levels increase in wet years compared to dry years. The surface water flow increase is greater in watersheds with relatively impermeable base rock, while the groundwater flow increase is generally greater in watersheds with permeable rock (Peterson and others 2005). The surface flow increase is greater in watersheds with low mean soil thickness; whereas the groundwater flow increase is greater in watersheds with high mean soil thickness.

Runoff in Sierra Nevada watersheds like the North Fork/Middle Fork American River is typically generated by warm winter Pacific storms, spring snowmelt, or occasionally by convective storms generated in late summer or early fall by subtropical air masses from the Gulf of Mexico (Curtis and others 2005). Beginning as early as October, Pacific frontal systems bring winter precipitation into northern California, with approximately 85 percent of precipitation falling between November and April.

Above an elevation of 6,000 feet, the precipitation is usually in the form of snow, most of which is stored in mountain snowpacks. Consequently, annual peak discharges for streams draining the higher elevations generally occur in late spring during melting of the snowpack. The peak discharges of late spring are generally relatively small (Scott and Gravlee 1968). The infrequent severe floods occur during heavy, warm winter storms, commonly referred to as "Pineapple Expresses," when meteorological conditions result in rain at higher than normal elevations. Under these conditions, rain-on-snow events can produce the largest floods, like that of December 1964 (Dettinger 2004, 2005), 1986, and 1997. These floods have the most potential to cause major damage to human infrastructure.

In the Lower North Fork and Lower Middle Fork subwatersheds, the yearly cycle is dominated by rainfall (Lewis and others 2000, 2002). Studies in an oak woodland dominated watershed in Yuba County (California) indicate that stream flow in ephemeral streams is associated with three seasonal periods when the soil undergoes wetting, saturation, and drying (Lewis and others 2002). The wetting period occurs quickly with initial rainstorms, and thereafter stream flow follows the annual and individual storm system rainfall pattern (Lewis and others 2000). Runoff occurs between about September or October and June (Lewis and others 2000). By July the ephemeral streams contain no water.

Major floods on the American River system have occurred many times since flow records began to be kept (National Research Council 1995; Sacramento Area Flood Control Agency 2006). Large flood events were recorded in 1907, 1928, 1951, 1956, 1965, 1986, and 1997 (Sacramento Area Flood Control Agency 2006). The 1956 event filled the nearly completed Folsom Reservoir Dam in one week when the previous estimate for filling had been one year (Sacramento Area Flood Control Agency 2006). A torrential rainfall of 22 inches in 5 days concentrated upstream of the Hell Hole Dam site produced dramatic and unprecedented runoff that resulted in failure of the partly completed dam on December 23, 1964 (Scott and Gravlee 1968). The surge release produced peak discharges substantially greater than previously recorded flows along the entire 61-mile route downstream from the dam site, along the Rubicon, Middle Fork American, and North Fork American rivers. During the 1986 flood, the coffer dam built at the site of the then in-construction Auburn Dam on the North Fork American River collapsed, releasing substantial amounts of water and sediment into the system (National Research Council 1995).

3.7 Stream Network and Flow Regimes

The North Fork/Middle Fork American River watershed includes perennial, seasonal or intermittent, and ephemeral streams. Perennial and intermittent stream networks were mapped using the National Hydrography Dataset (NHD) for the entire North Fork/Middle Fork American River watershed (Map 3-11). According to the NHD, perennial streams "contain water throughout the year, except for infrequent periods of severe drought", and intermittent streams "contain water for only part of the year, but more than just after rainstorms and at snowmelt." On National Forest System lands, perennial, seasonal, and ephemeral stream data mapped by the Tahoe and Eldorado National Forests were used. These datasets define perennial streams as "essentially flowing year round. Streams generally associated with a stable water table in the locality through which they flow." Seasonal and intermittent streams are both defined as "streams that flow only at certain times of the year when they receive water from springs or surface sources such as snow. Channel is usually above the water table during the dry season." Ephemeral streams are defined as "streams that flow only in direct response to storm precipitation. Channel is at all times above the water table." Because of their similar definitions, we grouped the NHD intermittent streams and National Forest System seasonal streams together throughout this study under the term "intermittent." In total, approximately 1,749 miles of non-ephemeral streams are mapped in the entire watershed assessment area, including 1,173 miles of perennial and 576 miles of intermittent streams (Table 3-10). Ephemeral streams are discussed below.

Table 3-10. Stream Flow Types by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (mapped Perennial and Intermittent Streams; see Maps 3-1 and 3-11).

	Perennial Streams		Intermittent Streams		Total (non-ephemeral streams)	
5th-level Hydrologic Unit Name	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)
Upper Middle Fork American River	159.4	1.44	44.0	0.40	203.4	1.84
Rubicon River	324.0	1.03	131.5	0.42	455.4	1.44
North Fork Middle Fork American	163.0	1.76	40.0	0.43	203.0	2.19
Lower Middle Fork American River	95.6	0.99	115.6	1.19	211.2	2.18
Upper North Fork American River	308.6	1.22	147.4	0.58	456.0	1.80
Lower North Fork American River	122.6	1.14	97.4	0.90	219.9	2.04

As mentioned above, more detailed stream mapping of ephemeral streams from the Tahoe and Eldorado National Forests were incorporated. These more detailed datasets are presently becoming part of the NHD. The USDA Forest Service completed a process of manually digitizing ephemeral streams by interpreting contour crenulations on 1:24,000-scale topographic maps using the accepted Strahler (1957) method. The contour-crenulated stream networks on National Forest System lands add approximately 3,606 miles of ephemeral streams in the North Fork/Middle Fork American River watershed (Table 3-11). Based on ground truthing of similar stream mapping in other areas, the accuracy of the ephemeral streams is estimated as high as 85 percent (Mai, personal communication, 2007). Contour-crenulated ephemeral streams were not mapped for the area (17.9 percent of the study area) outside of National Forest System lands in this assessment.

TtEC compared drainage densities with and without contour-crenulated ephemeral streams in the 57 7th-level HUC subwatersheds that are completely within National Forest System lands. GIS mapping of contour-crenulated ephemeral streams completely covers these subwatersheds. On average, drainage densities of perennial, intermittent, and contour-crenulated ephemeral streams together are 3.6 times greater than drainage densities with perennial and intermittent streams only (without contour-crenulated ephemeral streams). The ratio of drainage densities with and without contour-crenulated ephemeral streams ranges from 2.1 times (in the Middle Fork American River-French Meadows Reservoir 7th-level HUC subwatershed) to 5.6 times (in the North Fork American River-Wildcat Canyon 7th-level HUC subwatershed). We chose not to extrapolate these ratios to areas without contour-crenulated ephemeral stream mapping because the geomorphology of the mapped and unmapped areas differs. In general, the mapped areas occur at higher elevations in forested areas with more relief. In contrast, the unmapped areas generally occur in the lowest, flattest portions of the North Fork/Middle Fork American River watershed. The occurrence of ephemeral streams may not be constant in these different areas.

Table 3-11. Stream Flow Types by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (mapped Perennial and Intermittent Streams, plus Contour-crenulated Ephemeral Streams on National Forest System lands; see Maps 3-1 and 3-11).

	Perennial Streams		Intermittent Streams		Ephemeral Streams		Total (all streams)	
5th-level Hydrologic Unit Name [1]	**Length (miles)**	**Density (mi/mi²)**	**Length (miles)**	**Density (mi/mi²)**	**Length (miles)**	**Density (mi/mi²)**	**Length (miles)**	**Density (mi/mi²)**
Upper Middle Fork American River (100%)	159.4	1.44	44.0	0.40	429.9	7.81	633.3	11.50
Rubicon River (100%)	324.0	1.03	131.5	0.42	1,185.6	22.95	1,641.0	31.74
North Fork Middle Fork American (98%)	163.0	1.76	40.0	0.43	511.2	10.92	714.2	15.29
Lower Middle Fork American River (40%)	95.6	0.99	115.6	1.19	361.7	7.65	572.9	12.04
Upper North Fork American River (77%)	308.6	1.22	147.4	0.58	1,020.0	21.05	1,476.0	29.95
Lower North Fork American River (23%)	122.6	1.14	97.4	0.90	97.1	1.77	317.0	7.45

[1] The percentage of each 5th-level HUC subwatershed on National Forest System lands (with contour-crenulated ephemeral stream mapping) is shown in parentheses. Comparing subwatersheds with less than 100 percent coverage of contour-crenulated ephemeral streams could result in misinterpretations. For example, lower densities may indicate lack of contour-crenulated ephemeral streams. Refer to Table 3-10 for a display of the same information without contour-crenulated ephemeral streams.

Drainage density is commonly used as an indicator of the resistance of rock and soil to erosion (USDA Forest Service 1998). In general, the drainage density of a watershed is highest where rocks are weaker or less resistant to erosion, soils are more permeable, or precipitation is highest. Drainage density in combination with relief ratio can be used as indicator for basin energy and transport efficiency (Simons and others 1980). Overall, the densities of non-ephemeral streams range from 1.44 miles per square mile in the Rubicon River subwatershed to 2.18 and 2.19 miles per square mile in the Lower Middle Fork and North Fork Middle Fork American River subwatersheds, respectively, within the North Fork/Middle Fork American River watershed (Table 3-10).

3.8 Channel Morphology and Water Quality

3.8.1 Channel Morphology

The mainstem rivers in the North Fork/Middle Fork American River watershed are deep bedrock gorges incised within a west-sloping erosion surface of Tertiary age (Page and Sawyer 2001; Scott and Gravlee 1968; Wakabayashi and Sawyer 2001). Incision that accompanied the Pliocene and Pleistocene uplift and tilting of the range allowed the major trunk streams to maintain a westerly course normal to the dominant structural lineaments. Various strath terrace levels on gorge sides represent fluctuations in the process of valley incision. Minor tributaries show a high degree of structural control, particularly along the western flank of the range where their flow is parallel to the north and northwesterly shear system (Scott and Gravlee 1968).

Based on detailed surveys of portions of the North Fork American River (Laddish 1996), the substrate consists of pebbles and cobbles with some sand and a small amount of silt. It is paved in some areas and unpaved in others. Grain sizes on bars (point bars, separation bars, etc.) range from cobbles to sand. Generally, bars are not paved and many display imbrication (i.e., pebbles tilted in the same direction, often with their flat sides dipping upstream). Along the Middle Fork American River, grain sizes of cobbles to gravels as well as finer materials are reported (Jones and Stokes 2002).

Headwater streams in the North Fork/Middle Fork American River watershed include a mixture of high-gradient (less than 0.2 or 20 percent slope) bedrock and boulder-dominated channels that are steep and highly confined, and that move large material (USDA Forest Service 2003a). Many of the stream banks have high rock content, and channels have high sediment transport capacity due to steep gradients and high levels of entrenchment. Short reaches of high-gradient gravel and cobble channels also occur among headwater streams (USDA Forest Service 2003a). These channels are more sensitive to increases in stream flow and sediment supply than the bedrock and boulder channels. Moderate-gradient (0.03 to 0.2 or 3 to 20 percent slope) channels with bedrock and boulder substrates are found where canyons open slightly and become less steep, such as the Middle Fork American River. The mainstem rivers within the North Fork/Middle Fork American River watershed are predominately low-gradient (less than 0.03 or 3 percent slope), gravel-bedded with bedrock-controlled pool-riffle morphologies (Rutten 1998). Many reaches exhibit areas of degradation and aggradation in response to sediment that was introduced to the river by hydraulic gold mining in the late 19th and early 20th centuries. The Rubicon River also displays relic scour and deposition features associated with the 1964 failure of Hell Hole Dam. Pool infilling with fine sediment is generally low, but tends to increase downstream (Rutten 1998).

Stream channels were classified using the system of source, transport, and response reaches described by Montgomery and Buffington (1993, 1997). To obtain the highest level of accuracy in stream channel classifications, Montgomery and Buffington (1993, 1997) recommend conducting extensive fieldwork. However, recognizing the time and resources required to complete extensive fieldwork, the authors recommend a second approach for assigning stream channel types. Their preliminary correlation of channel types and gradients suggests that classifying stream reaches using only a topographic map or digital elevation model results in sufficient accuracy to predict reach sensitivity at a scale appropriate for watershed-level assessments.

Stream segments of the North Fork/Middle Fork American River watershed were classified based on stream gradients. Stream gradients were calculated using ESRI® ArcInfo™ software and the 10-meter U.S. Geological Survey digital elevation model (DEM) of the North Fork/Middle Fork American River watershed. A similar process was used in Keithley (1999) to prioritize watersheds in need of short-term sediment risk reduction and long-term instream habitat protection.

In steeper headwater reaches, streams have sufficient stream power to erode the channel bed and bank materials, thereby serving as sediment “sources.” These streams act as receptor sites for colluvial material and debris flows. Source channels are common in headwater reaches throughout the North Fork/Middle Fork American River watershed and in small ephemeral tributaries to the mainstem rivers (Maps 3-12 and 3-13). Stream segments with intermediate slopes "transport" sediment from source reaches downstream without net sediment deposition. Transport channel reaches were further subdivided based on stream gradient. Wider, more sinuous alluvial streams with lower slopes (generally less than 3 percent) tend to accumulate sediment. These "response" channel reaches eventually receive most of the material that is eroded from uplands and delivered into source and transport reaches. The low-gradient, transport-limited channels encounter significant morphometric adjustment in response to increased sediment supply. Sediment bars, alluvial fans, and other deposits occur throughout the response channel reaches. The drainage densities of low-gradient streams can be used to identify and rate depositional areas.

Channel types in the North Fork/Middle Fork American River watershed are dominated by relatively high-gradient streams. Considering only mapped perennial and intermittent streams, the Rubicon River, Lower Middle Fork, and Lower North Fork American River subwatersheds have the highest densities of low-gradient response reaches with 0.42, 0.46, and 0.66 miles per square mile, respectively (Table 3-12). The subwatershed with the greatest density of moderate-gradient transport reaches is the North Fork Middle Fork American River with 0.94 miles per square mile of Transport I and 0.53 miles per square mile of Transport II. Several subwatersheds have high-gradient source stream densities greater than 0.50 miles per square mile, including the Upper Middle Fork American River, the North Fork Middle Fork American, and the Lower Middle Fork American. Table 3-13 presents stream lengths and densities that include the contour-crenulated ephemeral streams mapped on National Forest System lands. Because each of the 5th-level HUC subwatersheds includes non-National Forest System lands, care should be used to avoid misinterpreting these values.

Table 3-12. Stream Gradient-based Channel Types by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (mapped Perennial and Intermittent Streams; see Maps 3-1 and 3-12).

5th-level Hydrologic Unit Name	Response (<3% slope)		Transport I (3-10% slope)		Transport II (11-20% slope)		Source (>20% slope)	
	Length (miles)	Density (mi/mi^2)	Length (miles)	Density (mi/mi^2)	Length (miles)	Density (mi/mi^2)	Length (miles)	Density (mi/mi^2)
Upper Middle Fork American River	35.1	0.32	55.1	0.51	50.4	0.47	61.3	0.57
Rubicon River	131.0	0.42	150.8	0.49	78.4	0.25	92.5	0.30
North Fork Middle Fork American	21.3	0.23	84.8	0.94	48.1	0.53	48.0	0.53
Lower Middle Fork American River	43.2	0.46	68.1	0.72	46.2	0.49	52.9	0.56
Upper North Fork American	94.8	0.38	137.6	0.55	101.8	0.41	125.0	0.50
Lower North Fork American River	70.0	0.66	97.7	0.93	30.9	0.29	23.8	0.23

Table 3-13. Stream Gradient-based Channel Types by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (mapped Perennial and Intermittent Streams, plus Contour-Crenulated Ephemeral Streams on National Forest System lands; see Maps 3-1 and 3-13).

5th-level Hydrologic Unit Name [1]	Response (<3% slope)		Transport I (3-10% slope)		Transport II (11-20% slope)		Source (>20% slope)	
	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)
Upper Middle Fork American River (100%)	39.4	0.36	77.4	0.71	126.0	1.15	389.0	3.56
Rubicon River (100%)	175.6	0.56	318.3	1.02	398.5	1.28	745.9	2.40
North Fork Middle Fork American (98%)	27.0	0.30	111.5	1.22	136.6	1.50	437.8	4.80
Lower Middle Fork American River (40%)	46.8	0.49	93.9	0.98	132.2	1.38	299.1	3.13
Upper North Fork American (77%)	103.6	0.41	200.8	0.80	272.9	1.09	901.4	3.60
Lower North Fork American River (23%)	74.6	0.70	130.9	1.23	69.4	0.65	45.8	0.43

[1] The percentage of each 5th-level HUC subwatershed on National Forest System lands (with contour-crenulated ephemeral stream mapping) is shown in parentheses. Comparing subwatersheds with less than 100 percent coverage of contour-crenulated ephemeral streams could result in misinterpretations. For example, lower densities may indicate lack of contour-crenulated ephemeral streams. Refer to Table 3-12 for a display of the same information without contour-crenulated ephemeral streams.

3.8.2 Water Quality

Water quality does not appear to be a major concern within the North Fork/Middle Fork American River watershed (USDA Forest Service 2003a). Sedimentation is a concern in some areas, for example based on the frequent removal of excess material from behind Duncan Diversion and Interbay and Ralston reservoirs, although the amount of sediment transport to these sites appears to reflect natural processes. However, little information exists about the amount or sources of sediment in the watershed. Requests for digital water quality information (primarily for sediment pollutant), for the North Fork/Middle Fork American River watershed, from the USDI Geological Survey, U.S. Environmental Protection Agency, USDA Forest Service, California Department of Water Resources (including California Data Exchange Center), California Water Resources Control Board, California Department of Fish and Game, and El Dorado and Placer counties yielded few results.

Some information related to sediment and water quality in Folsom Reservoir is presented in LSA Associates (2003) and CDM and others (2006). The Basin Plan requires that turbidity be low except during periods of storm runoff. LSA Associates (2003) reported that water quality with respect to turbidity is good, although there are concerns with stormwater runoff associated with housing, roads, and commercial development in the immediate watershed draining to the reservoir. CDM and others (2006) reported that the average turbidity for Folsom Reservoir in samples taken in June 2005 were below the Basin Plan objectives.

The State of California designates beneficial uses of water for the largest rivers in the North Fork/Middle Fork American River watershed. Beneficial uses specific to the smaller subwatersheds are identified by water rights files, Federal Energy Regulatory Commission (FERC) project files, California Department of Water Resources administrative files, California Department of Fish and Game fisheries or aquatic species databases, and information in resource management plans, including those of the Tahoe and Eldorado National Forests and the Bureau of Land Management.

3.9 Aquatic Species and Channel Habitats

3.9.1 Focal Species and Species Accounts

Focal species include fish (both native and introduced), amphibians, and riparian-obligate reptiles (Table 3-14). They include special status species that are listed as federal threatened or endangered species, federal species of concern, California State threatened or endangered species, California State species of concern, and USDA Forest Service sensitive or management indicator species.

Table 3-14. Focal Species for North Fork/Middle Fork American River Watershed.

Amphibians and Reptiles		
Common Name	**Scientific Name**	**Management Status** [1]
Mountain yellow-legged frog	*Rana muscosa*	FSC, SSC
Foothill yellow-legged frog	*Rana boylii*	FSC, SSC
California red-legged frog	*Rana aurora draytonii*	FT, SSC
Western pond turtle	*Emys (formerly Clemmys) marmorata*	FSC, SSC
Giant garter snake	*Thamnophis gigas*	FT, ST
Northern leopard frog	*Rana pipiens*	FSS
Native Fish Species		
Rainbow trout	*Oncorhynchus mykiss*	MIS
Hardhead	*Mylophardodon concephalus*	SSC, FSS
Sacramento sucker	*Catostomus occidentalis*	
Sacramento pikeminnow	*Ptychocheilus grandis*	
Sacramento roach	*Lavinia symmetricus symmetricus*	SSC
Sculpin (prickly, riffle)	*Cottus* sp.	
Introduced Fish Species		
Cutthroat trout	*Oncorhynchus clarki*	
Brook trout	*Salvelinus fontinalis*	
Brown trout	*Salmo trutta*	
Smallmouth bass	*Micropterus salmoides*	
Kokanee	*Oncorhynchus nerka*	
Lake trout	*Salvelinus namaycush*	

[1] Status: FT= Federal Threatened; FE= Federal Endangered; ST= State Threatened; SE= State Endangered; FSC= Federal Species of Concern; SSC= State Species of Concern; FSS= Forest Service Sensitive; MIS= Forest Service Management Indicator Species.

Available species and habitat information were used for the aquatic resource assessment. The primary sources of information for focal species occurrences in the study area are the California Natural Diversity Database (California Natural Heritage Program), GIS coverages from the USDA Forest Service, PCWA fish surveys (unpublished data, 2006) for the Middle Fork American River watershed, and other documents such as Moyle and Davis (2001) and the Sierra Nevada Ecosystem Project (Regents of the

University of California 1996). Sufficient data were not available to characterize the watershed-specific aquatic species and habitat distribution or to evaluate the status and trends of the ecological resources at multiple scales.

Brief general descriptions of species' life history and occurrences are presented below. Documented aquatic species occurrences in the North Fork/Middle Fork American River watershed are presented on Map 3-14.

Mountain Yellow-Legged Frog
Life History: This frog is a native of the Sierran foothill and highland areas and is closely related to the foothill yellow-legged frog. This species inhabits river banks, meadows and isolated pools or ponds, and lake borders in the high Sierra and rocky streams. The frog seems to prefer sloping banks with rocks or vegetation to the water's edge, and generally stays near water. Mountain yellow-legged frogs breed from June to August (Stebbins 1966). Habitat elevation range is above 5,000 feet.

Species Occurrence: Mountain yellow-legged frogs have been documented in the Rubicon River (40 sightings) and Upper North Fork American River (5 sightings) subwatersheds.

Foothill Yellow-Legged Frog
Life History: Foothill yellow-legged frogs live in rocky or gravely streams and are seldom seen far from water. Habitat is generally in streams or rivers in forested areas and usually in riffles (Stebbins 1966). These animals are generally in the vicinity of permanent streams and are active in water temperatures from 7 to 21 degrees Celsius. Eggs are laid in the spring or early summer and are usually found attached to rocky substrate. The reproductive season is affected by flooding and may be delayed by high water. In California, tadpoles metamorphose in 3 to 4 months. Foothill yellow-legged frogs eat aquatic and terrestrial invertebrates, and are preyed upon by garter snakes (Nussbaum and others 1983). Habitat elevation range is below 5,500 feet.

Species Occurrence: Foothill yellow-legged frogs have been detected in all six 5th-level HUC subwatersheds. The highest number of sightings is in the Lower North Fork American River subwatershed (27 sightings), followed by the North Fork Middle Fork American River (22 sightings), Rubicon River (14 sightings), Upper North Fork American River (10 sightings), Upper Middle Fork American River (5 sightings), and Lower Middle Fork American River (3 sightings) subwatersheds.

California Red-Legged Frog
Life History: Red-legged frogs, of which the California red-legged frog is a subspecies, inhabit moist forests and valley riparian areas, although during the non-breeding season, these animals can exist at considerable distances (200 to 300 meters) from water. They are most common in woodlands along foothill areas and are attracted to places with cattails or other aquatic vegetation (Stebbins 1966). During the summer, frogs will move to stream and pond edges and will often hide in thick cover under banks. Breeding site selection is variable; however, the site must have slow flow and have water long enough for metamorphosis to occur. Underwater vegetation is also required for egg attachment. Eggs are generally deposited in January or February and

spawning usually lasts about 2 weeks. Early embryos are only tolerant of temperatures between 4 and 21 degrees Celsius. Red-legged frogs eat beetles, caterpillars, isopods, and other invertebrates (Nussbaum and others 1983). Habitat elevation range is below 5,000 feet.

Species Occurrence: California red-legged frogs are documented in the North Fork Middle Fork American River (3 sightings), Rubicon River (2 sightings), and Upper Middle Fork American River (1 sighting) subwatersheds. This species has been sighted within the Middle Fork American River subwatershed at a pond within a powerline corridor on Ralston Ridge, between the Middle Fork American and Rubicon rivers. The sighting occurred in the summer of 2001 and follow-up surveys of the pond and areas of the Middle Fork American River have failed to result in any additional sightings. A historical sighting, as well as a newly confirmed population first recorded in July 2006 (Mai, personal communication, 2007), also resides in a ponded area near Michigan Bluff. Surveys throughout the watershed have located dispersal habitat, and a few ponds provide low-quality breeding habitat.

Western Pond Turtle
Life History: The western pond turtle inhabits marshes, sloughs, ponds, and slow water areas in creeks and rivers. These turtles require basking sites, usually in the form of partially submerged logs or vegetation mats, or rocks or banks. These animals generally hibernate in the bottom mud during the winter. Female turtles leave the water in late May to July to find nesting sites in sandy banks or sunny fields. Western pond turtles appear to be omnivorous, consuming pods of water lilies, fish, worms, and other invertebrates. They also may consume carrion.

Species Occurrence: Western pond turtles have been documented in the Upper North Fork American River (three sightings), Lower Middle Fork American River (two sightings), and Rubicon River (two sightings) subwatersheds. This species has been located on Ralston Ridge and in the North Fork Middle Fork American River.

Giant Garter Snake
Life History: The giant garter snake, a species endemic to the Central Valley of California, requires riparian habitat with a permanent water source that also has vegetative cover and a large food source. The giant garter snake is often found in wetland areas, but can inhabit irrigation canals and diversion ditches. The snake feeds on frogs and tadpoles, and small fish as well as invertebrates (U.S. Fish and Wildlife Service 2006).

Species Occurrence: Garter snakes have been documented in the Rubicon River (36 sightings), Upper Middle Fork American River (11 sightings), Lower North Fork American River (6 sightings), North Fork Middle Fork American River (5 sightings), Upper North Fork American River (5 sightings), and Lower Middle Fork American River (4 sightings) subwatersheds. The giant garter snake is not on the species list for the Eldorado National Forest.

Northern Leopard Frog

Life History: Northern leopard frogs eat invertebrates including aquatic insects. This species breeds from March through June, and their egg masses are attached to aquatic vegetation. They generally inhabit freshwater sites that are heavily vegetated, but can also be found in brackish marshes (U.S. Geological Survey 2006). Habitat elevation range is up to 7,000 feet.

Species Occurrence: Northern leopard frogs are distributed throughout North America, excluding the west coast, but including the northeastern side of California, which likely includes some part of the North Fork/Middle Fork American River watershed.

Rainbow Trout

Life History: Rainbow trout prefer cool water (less than 70 degrees Fahrenheit) with plenty of dissolved oxygen. These fish will move to deeper water in lakes when surface waters are warmer than 70 degrees Fahrenheit, but are tolerant of a wide range of salinities. Growth is affected by temperature, water chemistry, and food supply. Water chemistry is, in turn, affected by the geology of an area. Generally, limestone or sandstone will produce water preferred by trout as compared to granite or lava rock. Rainbow trout generally spawn from February to June, depending on the water temperature and location. These fish feed on aquatic insects (i.e., dipterans, mayflies, stoneflies, and beetle larvae), amphipods, aquatic worms, and fish eggs. Some are known to also eat other fish (Wydoski and Whitney 1979).

*Species Occurrence***:** Rainbow trout are found in all six 5th-level HUC subwatersheds (Upper Middle Fork American River, Rubicon River, North Fork Middle Fork American River, Lower Middle Fork American River, Upper North Fork American River, and Lower North Fork American River). They are found along the foothills and in high elevations. The PCWA fish surveys (Placer County Water Agency, unpublished data, 2006) document resident rainbow trout throughout the Rubicon River, Upper Middle Fork American River, Lower Middle Fork American River, and Lower North Fork American River 5th-level HUC subwatersheds, including the mainstem rivers; Long Canyon Creek (including North and South forks); Duncan Creek; and Hell Hole, French Meadows, and Interbay reservoirs.

Hardhead

*Life History***:** Hardhead are generally found in quiet waters and forage for aquatic invertebrates and vegetation. These fish have been known to concentrate in surface waters and often are fed upon by avian predators. These fish spawn in the spring, but the activity may extend into August in the foothill areas. Gravel substrate is necessary for spawning. These fish prefer deep pools with gravel and sand substrate for holding habitat. Optimal temperature requirements are 24 to 28 degrees Celsius, but they are generally intolerant of low dissolved oxygen levels (Moyle and Davis 2001).

*Species Occurrence***:** The elevation range for hardhead is 30 to 4,600 feet and these fish exist in most of the major tributaries to the Sacramento River, likely including the North and Middle Fork American and the Rubicon rivers (Moyle and Davis 2001). The USDA Forest Service has documented hardhead sightings and suitable habitat in the Middle Fork American River downstream from French Meadows Reservoir and Ralston

Afterbay Dam (Mai, personal communication, 2007). The PCWA fish sampling (Placer County Water Agency, unpublished data, 2006) reports hardhead in the Rubicon River (Hell Hole to Ralston reach), Hell Hole Reservoir, and Middle Fork American River (French Meadows to North Fork American reaches).

Sacramento Sucker

Life History: The Sacramento sucker is an inland fish found throughout the Sacramento River and San Joaquin River systems. Suckers migrate from large bodies of water such as bays and deltas to streams for spawning. Fish spawn in gravel substrate generally from February through June at lower elevations and into August at higher elevations. Egg incubation is 3 to 4 weeks. Newly hatched larvae remain in interstitial spaces until their yolk sack is absorbed. Larvae feed primarily on early life stages of aquatic invertebrates. Juveniles are most common in tributary streams, and generally browse the bottom of streams (Moyle and Davis 2001; University of California Berkeley 2006).

Species Occurrence: Distribution is within the Upper North Fork American River, Rubicon River, and Lower Middle Fork American River subwatersheds. Observations of large numbers of sucker larvae indicate that spawning occurs in the American River below Nimbus Dam. The PCWA fish surveys (Placer County Water Agency, unpublished data, 2006) document Sacramento suckers throughout the Rubicon River, Upper Middle Fork American River, Lower Middle Fork American River, and Lower North Fork American River 5th-level HUC subwatersheds, including the mainstem rivers; Long Canyon Creek (including North and South forks); Duncan Creek; and Hell Hole, French Meadows, and Interbay reservoirs. They are suspected but not confirmed in the Middle Fork American River above French Meadows Reservoir.

Sacramento Pikeminnow

Life History: Pikeminnows are large fish in the minnow family in North America, and the Sacramento pikeminnow is limited in distribution to rivers in California. Pikeminnows are voracious eaters with a primary diet of other fish, and can consume juvenile salmonids where they co-occur. Pikeminnows are generally found in large lakes or reservoirs and in large river systems.

Species Occurrence: Sacramento pikeminnow are distributed in the Upper North Fork American River, Lower Middle Fork American River, Rubicon River, and a very small portion of the Upper Middle Fork American River subwatersheds. The PCWA fish sampling (Placer County Water Agency, unpublished data, 2006) reports pikeminnows in the Rubicon River; Middle Fork American River (French Meadows to North Fork American reaches); and Hell Hole, French Meadows, and Interbay reservoirs.

Sacramento Roach

Life History: Sacramento roach, a subspecies of the California roach, are omnivorous and feed primarily on algae, diatoms, invertebrates, and crustaceans. They are bottom feeders, so end up ingesting detritus as well. Growth occurs rapidly, especially during the summer months, likely due to greater food supply during this period. Reproduction occurs generally March to June and spawning has been noted to be determined by water temperature which must be at least 16 degrees Celsius (60 degrees Fahrenheit). Spawning takes place in gravel substrates and eggs hatch in 2 to 3 days. Roach are very tolerant of warm temperatures (30 to 35 degrees Celsius) and low oxygen levels (1 to 2 parts per million), but can also be found in colder streams. Studies in the Clear Lake region have shown that roach abundance correlates with water temperature, conductivity, gradient, and coarse substrates (Moyle and Davis 2001).

Species Occurrence: Sacramento roach have very limited distribution in the North Fork/Middle Fork American River watershed. There is one small segment of stream identified in the Lower North Fork American River subwatershed that is suspected to contain the species (Placer County Water Agency, unpublished data, 2006).

Riffle and Prickly Sculpin

Life History: The riffle and prickly sculpin are found in quiet waters and slow riffles in small streams in the backwaters of larger rivers. Generally, these fish are found on sand or gravel bottoms and prefer waters less than 60 degrees Fahrenheit, but have been found in waters up to 72 degrees Fahrenheit. Spawning generally occurs in March and April, and eggs are deposited in blind pockets in rotting logs. Male fish guard the eggs and actively protect the nest. Riffle sculpin feed on crustaceans, aquatic insect larvae, and snails. Riffle sculpin are thought to serve as a forage species for trout (Wydoski and Whitney 1979).

Species Occurrence: Sculpins are documented in the Upper North Fork American River, North Fork Middle Fork American River, Lower Middle Fork American River, and Rubicon River subwatersheds. The prickly sculpin generally occurs in the lowland and foothill areas, whereas the riffle sculpin occurs in the foothills and high elevations. The PCWA fish surveys (Placer County Water Agency, unpublished data, 2006) document sculpins in the Rubicon River, Middle Fork American River (Ralston to North Fork American reach), North Fork American River (Middle Fork American to Folsom reach), Long Canyon Creek (including North and South forks), Duncan Creek, and Interbay Reservoir.

Cutthroat Trout

Life History: Cutthroat trout are generally found in headwater streams that often have higher gradients than the habitat of other trout species. These fish spawn in clean small- to medium-sized gravels, generally at higher elevations than most other salmonids. Survival of embryos is inversely proportional to the amount of fine sediment in the stream. Juveniles feed mostly on aquatic insects, while adults have been noted to feed on other fish and salmon eggs. Optimal habitat has cool water and is well shaded, with high levels of instream cover (Moyle and Davis 2001).

Species Occurrence: Cutthroat trout is suspected to occur in the Rubicon River and Hell Hole Reservoir (Placer County Water Agency, unpublished data, 2006).

Brook Trout

Life History: Brook trout habitat is generally cool, clear headwater ponds, and spring-fed streams. These fish require cool water (less than 68 degrees Fahrenheit) and high dissolved oxygen levels. In fresh water, brook trout do not migrate far and generally stay within one-half mile of their home territory. They are most active in the early morning and late afternoon, and at other times can be found under banks, logs, or other cover elements. Few fish live beyond 4 years of age, and males are generally larger than females. Density-dependent responses occur in streams where there are low nutrients, and growth becomes stunted under these conditions. Brook trout spawn between August and December in water temperatures from 40 to 50 degrees Fahrenheit. Redds are dug by females in gravel substrate and are defended by both males and females (Wydoski and Whitney 1979). Compared to salmon, brook trout have a higher preference for cold, clear water, and will ascend small brooks to spawn (McClane 1978). As young juveniles in lakes, brook trout feed on zooplankton as well as on midges. Aquatic insect larvae (i.e., dipterans, mayflies, and caddisflies) make up the principal diet in stream habitats. Freshwater shrimp, worms, snails, and isopods are also consumed. In the summer, terrestrial insects provide important food resources, and some fish predation has been observed (Wydoski and Whitney 1979).

Species Occurrence: Brook trout are found in the Upper North Fork American River, Upper Middle Fork American River, and Rubicon River subwatersheds. In the Upper Middle Fork American River subwatershed, brook trout are known to occur in the Middle Fork American River above French Meadows Reservoir and Duncan Creek (Placer County Water Agency, unpublished data, 2006).

Brown Trout

Life History: Brown trout can survive in warmer waters (65 to 75 degrees Fahrenheit) than any other species of trout. In areas where forest cover has been removed, the brown trout is likely to replace other species of trout. This species also tolerates turbid waters and waters with low oxygen levels better than other trout. Brown trout feed late at night and early in the morning, and generally remain concealed in cover during the day. Spawning occurs from October to December in gravel substrate from one-quarter to 3 inches in diameter. Brown trout juveniles feed on aquatic invertebrates such as blackflies, mayflies, and stoneflies, and in winter they feed on freshwater shrimp and isopods. Larger fish feed on amphipods, isopods, aquatic insects, crayfish, snails, and small fish. Large brown trout feed significantly on other fish including sculpins, minnows, suckers, darters, lampreys, and other trout (Wydoski and Whitney 1979).

Species Occurrence: Brown trout are found in all six 5th-level HUC subwatersheds (Upper Middle Fork American River, Rubicon River, North Fork Middle Fork American River, Lower Middle Fork American River, Upper North Fork American River, and Lower North Fork American River). The PCWA fish surveys (Placer County Water Agency, unpublished data, 2006) report brown trout in the Rubicon River; Middle Fork American River; North Fork American River (Middle Fork American to Folsom reach); and Hell Hole, French Meadows, and Interbay reservoirs.

Smallmouth Bass

Life History: Smallmouth bass inhabit warmer waters (10 to 32 degrees Celsius) up to a depth of 23 feet. They are found in clear vegetated lakes, but also sometimes in more turbid water such as ponds or swampy areas. Food items include fishes, crayfish, and frogs for adults, and mostly crustaceans, insects, and some smaller fishes for juveniles (Fishbase 2007a). These fish will not feed in extreme water temperatures (above 32 degrees or below 5 degrees Celsius), and do not feed during spawning, which generally occurs in spring when the fish are 3 or 4 years old (Wydoski and Whitney 2003).

Predators for these fish include aquatic feeding birds such as herons and kingfishers (Fishbase 2007a).

Species Occurrence: Smallmouth bass have been introduced widely as a game fish. The species has been documented to occur in the North Fork/Middle Fork American River watershed in reservoir habitat. The PCWA fish surveys (Placer County Water Agency, unpublished data, 2006) document smallmouth bass in the North Fork American River (Middle Fork American to Folsom reach) and French Meadows Reservoir.

Kokanee

Life History: Kokanee salmon are landlocked populations of sockeye salmon, have a very similar general life history, and are often maintained by stocking hatchery fish. They are found in water around 50 degrees Fahrenheit, and will seek out that temperature layer in stratified lakes. They grow most rapidly in highly productive lakes with low fish density. Kokanee remain in fresh water for their entire lifecycle and generally mature (8 to 15 inches in length) between 3 and 5 years. Their food resources include aquatic insect larvae and zooplankton (mostly *Daphnia* and copepods) (Wydoski and Whitney 2003).

Species Occurrence: Kokanee salmon have been introduced in several areas of the United States (Wydoski and Whitney 2003). These fish are found in Hell Hole Reservoir, where they are still stocked annually (Placer County Water Agency, unpublished data, 2006).

Lake Trout

Life History: Lake trout are generally found in relatively deep waters in the southern part of the range, generally preferring temperatures around 50 degrees Fahrenheit. They generally feed on a variety of organisms including crustaceans, insects, fishes, and some plankton (Fishbase 2007b). Fish are generally solitary and may travel large distances within a waterbody. They are known to feed on kokanee salmon and other fish as adults, and on crustaceans, insects, and some fish as juveniles (Wydoski and Whitney 2003). These fish are highly susceptible to pollution, especially chemicals used in pesticides (Fishbase 2007b). The species can be long lived, and size at maturity can vary greatly. Spawning occurs in fall, generally over gravel, boulders or rubble, but occasionally over mud bottoms or in boulders in tributary streams (Wydoski and Whitney 2003).

Species Occurrence: Lake trout are a popular game fish and maintain a self-sustaining population in Hell Hole Reservoir (Placer County Water Agency, unpublished data, 2006).

3.9.2 Fish-Bearing Streams and Channel Habitats

Distribution of known fish-bearing streams in the North Fork/Middle Fork American River watershed is presented on Map 3-14. The fish-bearing streams were mapped using a combination of GIS coverages derived from multiple sources (including USDA Forest Service, California Department of Fish and Game, California Natural Diversity Database) and professional judgment by the ARWG TAC.

For the North Fork/Middle Fork American River watershed, the known fish-bearing stream densities range from 0.23 mile per square mile in the Lower North Fork American River subwatershed to 0.83 mile per square mile in the Upper Middle Fork American River and North Fork Middle Fork American River subwatersheds (Table 3-15). In comparing the total lengths of perennial streams (1,173.2 miles) and known fish-bearing streams (611.1 miles) (Table 3-15), we suspect that the amount of fish-bearing streams in the North Fork/Middle Fork American River watershed may be underestimated. The current mapping may be incomplete due to a lack of sufficient data available to classify all fish-bearing streams in the watershed. Typically, perennial streams have fish present unless passage barriers (such as waterfalls or improperly functioning road-stream crossings) are present. Fish-bearing streams mapped by the Tahoe and Eldorado National Forests are defined as those that have significant reproducing populations.

Table 3-15. Perennial Streams and Fish-Bearing Streams by 5th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Maps 3-1 and 3-14).

	Perennial Streams		Fish-Bearing Streams	
5th-level Hydrologic Unit Name	Length (miles)	Density (mi/mi^2)	Length (miles)	Densities (mi/mi^2)
Upper Middle Fork American River	159.4	1.44	91.9	0.83
Rubicon River	324.0	1.03	196.5	0.62
North Fork Middle Fork American	163.0	1.76	77.1	0.83
Lower Middle Fork American River	95.6	0.99	66.6	0.69
Upper North Fork American River	308.6	1.22	154.4	0.61
Lower North Fork American River	122.6	1.14	24.6	0.23
Total	1,173.2	1.20	611.0	0.63

The Middle Fork American River is a low-gradient system with mostly bedrock and boulder substrates. This river contains moderate fish habitat with high amounts of bedrock cover, but is lacking in spawning habitat due to the presence of three dams along the river. Conifers in the riparian corridor and steep hillslopes provide most of the shade to the river. Pool filling is generally low, but increases downstream. Land use in the uplands has affected the stability of tributary streams, which contribute sediment to the main channel. The fish-bearing streams within the Middle Fork American River watershed are the mainstem of Middle Fork American River and the following tributary streams: Big Mosquito Creek, Brushy Canyon, Canyon Creek, Duncan Canyon, Dolly Creek, Lower Long Canyon, North Fork Long Canyon, Otter Creek, Rice Creek, South Fork Long Canyon, Spruce Creek, and Wallace Canyon (Mai, personal communication, 2007). All of these streams are known to contain rainbow trout. Some sightings of brown trout occur in the Middle Fork American River, likely as a result of being stocked in the French Meadows Reservoir.

The North Fork of the Middle Fork American River is a large, moderate-gradient stream with boulder and bedrock substrate. The channel is stable with healthy riparian corridor vegetation. Mining in some areas has caused localized inchannel habitat damage.

Data on aquatic habitat conditions within the North Fork/Middle Fork American River watershed have been collected on a rotational basis in both the Tahoe National Forest and the Eldorado National Forest. Project files containing aquatic habitat surveys for reach-level assessments are available. However, these data are point estimates of channel habitat condition and cannot be extrapolated to represent the condition at the subwatershed- or watershed-level. The methods used for these aquatic habitat surveys historically were the Rosgen channel typing; recently the method used has transitioned to the USDA Forest Service Region 5 stream condition inventory. The data gathering in these approaches, if applied using a randomized, spatially representative sample design, could provide information on in-channel baseline conditions at the subwatershed- or watershed-level. In addition to the USDA Forest Service, PCWA is currently collecting data on aquatic species and habitats for the Middle Fork American River watershed.

3.9.3 Ecological Impacts of Accelerated Sedimentation

This section provides a brief contextual overview of ecological impacts on aquatic species and habitats from accelerated sedimentation resulting from human land uses. References related to the selected focal species in the Sierra Nevada are incorporated, as available.

Species Sensitivity to Sediment

Of the focal species (see Table 3-14), the fish species that are most sensitive to sediment inputs are the salmonids (i.e., rainbow trout, cutthroat trout, brown trout, and brook trout), which are less tolerant of high sediment levels, and which require clean gravels for spawning. The larval life stage of salmonids is the most sensitive to increasing concentrations of sediments in the form of total suspended solids (TSS). Salmonid eggs are slightly more tolerant, although after 2 months of exposure to TSS concentrations of 57 milligrams per liter, hatching success was reduced in rainbow trout eggs (Newcombe 1994). At higher concentrations (1,000 to 2,500 milligrams per liter), Campbell (1954) found 100 percent mortality in rainbow trout eggs.

The sculpin species are also somewhat sensitive because they are benthic species and large inputs of sediment directly affect where they can use the habitat. The other native fish species are less sensitive to sediment inputs, but can still suffer from behavioral and physiological effects of high sediment levels in aquatic systems.

Other aquatic species, including amphibians and reptiles that are riparian obligates, can also be affected by the same land use actions that increase the level of sediment in aquatic systems. Changes in land use such as logging, mining, grazing, urbanization, and agriculture may be sources of high TSS levels, and also result in the alteration of upslope and riparian vegetation, which reduces the available habitat for these species (Jennings 1996; Kauffman and others 2001). In addition, higher levels of sediment in streams can favor the establishment of invasive species, which is one of the leading threats to amphibians in the Sierra Nevada (Jennings 1996). One of the reasons for decline of amphibians in the Sierra Nevada is predation by introduced fish species and non-native amphibians, which are generally less sensitive to sediment inputs.

Potential Effects on Aquatic Species and Habitats

Fish and other aquatic species respond to increased levels of sediment in several ways. Behavioral effects include avoidance of areas with high TSS, reduced feeding in areas with high sediment levels, and loss of territoriality (or the ability to defend a territory) (Anderson and others 1996). Behavioral effects are generally temporary, and can be reversed (Newcombe 1994).

Physiological effects include impaired growth (generally in response to chronic exposure); gill trauma, which can result in changes to blood chemistry and oxygen levels; decreased immune resistance; and phogocytosis, or envelopment of sediment particles by cells and storage in fish tissue such as the spleen (Anderson and others 1996). Impaired growth may be due to reduced feeding and high TSS levels, which could be related to reduced visibility in the water column. Similarly, territoriality is based on the ability to observe others in a territory and to defend it from intruders (Berg and Northcote 1985). With reduced visibility, the ability to defend a territory is decreased proportionally. Gill trauma is generally due to gill abrasion and particle absorption into the gills. Decreased resistance to disease has been observed in rainbow trout, which had greater levels of fin rot when exposed for 121 days to TSS concentrations of 270 milligrams per liter of diatomaceous earth. Phagocytosis may also contribute to reduced resistance to disease (Newcombe and Jensen 1995).

The level of flow present when stream sedimentation occurs has a large effect on the changes to aquatic habitat and water quality (TSS levels). Other considerations are the timing (seasonally) of the sediment input as well as the habitat present where the sediment input occurs. Changes in habitat that occur as a result of sediment input include clogging of the interstitial spaces in gravels, which affects both egg and larval survival, as well as the invertebrates that are used as a food resource by many aquatic species. Channel morphology can also be affected by the reduction of pool depths, which decreases fish holding capacity (Bjornn and others 1977). Channels with high levels of anthropogenic sediment tend to be less stable and to have higher levels of in-channel erosion. Juvenile fish frequently use interstitial spaces for cover, and are negatively affected when these spaces are filled with fine sediment, especially in winter (Bjornn and others 1977). The effects of increased stress from high suspended sediment levels can have serious impacts on fish survival in winter due to the depleted energy reserves that fish species incur during the winter months (Anderson and others 1996).

Food resources available to fish can also be affected by high TSS levels. Levels of periphyton, zooplankton, and macro-invertebrates are often reduced or the community structure altered by high sediment levels. Downstream drift by invertebrates has been noted to be induced by high suspended sediment levels (Rosenberg and Weins 1978), as well as a natural dispersal method.

3.10 Road Network and Transportation

Since the Gold Rush, transportation routes have played a major role in the development of the North Fork/Middle Fork American River watershed. The current road network and partial coverage of trails are presented on Map 3-15. Interstate 80 remains a major travel route for commerce in California. Many of the smaller roads in the study area were built as mining towns developed in the 1800s. Roads and trails GIS datasets were compiled from several sources, including the Tahoe National Forest, the Eldorado National Forest, the Bureau of Land Management, and Placer and El Dorado counties. The overall density of roads (including all surface types) and trails in the North Fork/Middle Fork American River watershed ranges from 3.0 and 3.1 miles per square mile in the Upper North Fork American River and Rubicon River subwatersheds, respectively, to 5.1 miles per square mile in the Lower North Fork American River watershed (Table 3-16).

Table 3-16. Roads (by Surface Types) and Trails by 5th-level HUC Subwatershed in the North Fork/Middle Fork American River Watershed (see Maps 3-1 and 3-15).

5th-level Hydrologic Unit Name	Paved Surface		Gravel Surface		Native Surface		Trails		Total	
	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)
Upper Middle Fork American River	37.2	0.34	21.5	0.19	255.1	2.30	49.3	0.44	363.1	3.28
Rubicon River	117.1	0.37	1.0	0.00	642.1	2.04	209.7	0.66	969.8	3.08
North Fork Middle Fork American	41.1	0.44	36.1	0.39	279.2	3.02	46.0	0.50	402.4	4.35
Lower Middle Fork American River	138.1	1.42	7.7	0.08	272.6	2.81	43.2	0.45	461.6	4.76
Upper North Fork American River	159.1	0.63	3.1	0.01	463.2	1.83	135.7	0.54	761.1	3.00
Lower North Fork American River	164.0	1.52	22.3	0.21	316.8	2.94	47.5	0.44	550.6	5.11

As has been widely reported (Amaranthus and others 1985; Bilby and others 1989; Donald and others 1996; Kochenderfer and others 1997; Megahan and Kidd 1972; Reid and Dunne 1984; Rice and Lewis 1986; Rothacher 1971; Sullivan and Duncan 1981; Swanson and others 1981; Swift 1985, 1988), roads in managed forests can have significant impacts on rates of soil erosion, mass wasting, and sedimentation to streams. Road sediment production and delivery can be reduced by providing and maintaining frequent drainage structures, avoiding locations that generate more road surface and ditch runoff, and reducing the frequency of road grading (MacDonald and Coe 2005).

In the North Fork/Middle Fork American River watershed, current road maintenance on National Forest System lands focuses mainly on safety and upkeep on the arterial roads, collector roads, and high-use local roads. Local roads generally receive only custodial care, and repairs focus on correcting problems causing resource damage. Within National Forest System lands, cooperative agreements exist with other partners to share in the costs of maintaining roads (USDA Forest Service 2004a).

Road surface is another critical aspect of road management for sediment control. Roads surfaced with asphalt and bituminous chip seal provide the greatest stability, but are expensive to construct and maintain. Aggregate surfaces provide a lower degree of stability but are less expensive (Schiess and others 2000; Shilling and Girvetz 2003). Native surfaced roads are the most prevalent in the North Fork/Middle Fork American River watershed, with approximately 2,230 miles (Table 3-16). These roads tend to have limited infiltration, resulting in runoff of excess rainfall (Schilling and Girvetz 2003). Road placement, especially road proximity to streams, and road-stream crossings, can affect surface water flows and stream channel morphology. Because population growth has tended to occur on large parcels in the rural residential portions of the North Fork/Middle Fork American River watershed, the miles of road per person is very high when compared to more urban settings (Schilling and Girvetz 2003). Roadbeds and road-related infrastructure can impinge on the physical characteristics and processes of stream systems and reduce their ability to recover from land-use impacts.

The mean sediment production rate for unpaved roads in the Eldorado National Forest ranged from 0.2 to 0.81 kilograms per square meter during wet seasons (MacDonald and Coe 2005; MacDonald and others 2004). These levels were nearly an order of magnitude greater than those measured from skid trails, off-highway vehicle use, or burned areas (although high-severity burns resulted in relatively high rates). Sedimentation rates were reduced by at least an order of magnitude by placing approximately 10 centimeters of coarse gravel on the road surface. Road sediment production depends largely on road slope and grading. Midslope roads on shallow soils had higher sediment production rates than those on deeper soils, presumably because of the increase in surface runoff. One-quarter of the road segments surveyed were delivering runoff and sediment to stream channels.

Both the Tahoe and Eldorado National Forests have completed roads analyses that cover the portions of each National Forest within the North Fork/Middle Fork American River watershed (USDA Forest Service 2003b, 2004a). These analyses prioritize actions on National Forest System lands to ensure that the road network is essential for land use and resource management; that construction, reconstruction, and maintenance of roads minimize adverse environmental impacts; and that unneeded roads are decommissioned and restoration of ecological processes are initiated (USDA Forest Service 2003b).

3.11 Water Development and Mining

3.11.1 Water Development

Water flows in the North Fork/Middle Fork American River are regulated for a combination of urban consumptive, agricultural irrigation, and hydropower uses, as well as flood control. In part because of national security issues, few agencies were willing to disclose information about public works and water infrastructure. Publicly available information was obtained from the U.S. Army Corps of Engineers as part of the National Inventory of Dams, a program run in cooperation with the Federal Emergency Management Agency's National Dam Safety program. A total of 34 public water infrastructure (i.e., dams and reservoirs) locations were mapped in Map 3-16, including two on the Upper Middle Fork American River, four on the Rubicon River, two on the Lower Middle Fork American River, and three each on the Upper and Lower North Fork American River subwatersheds. In addition to these impoundments, 112 miles of ditches and pipelines used for water diversion were mapped in the North Fork/Middle Fork American River watershed, based on NHD. The majority of these were mapped in the North Fork American River and Rubicon River subwatersheds (with 37 and 28 miles, respectively). In general, diversions convey water within the watershed to users who are remote from the waterway and convey water to and from adjacent basins, including the Bear River (Shilling and Girvetz 2003) and the Yuba River (Snyder and others 2004). Water development and impoundments can affect the watershed hydrologic and channel processes, including instream flow regimes, channel morphology, and sediment transport and deposition.

Water development in the Middle Fork American River began in 1957 with the creation of the Placer County Water Agency (USDA Forest Service 2003a). The project consists of two storage and five diversion dams, five power plants, diversion and transmission facilities, five tunnels, and related facilities. Construction on the project was completed in 1967. Water flows in the Middle Fork American River are controlled primarily by the American River Project, managed by the Placer County Water Agency. The project was constructed during the 1960s to conserve and control water for irrigation, domestic and commercial uses, and electric generation. The project includes French Meadows Reservoir, Duncan Diversion, Interbay Reservoir, Ralston Reservoir, and Hell Hole Reservoir.

3.11.2 Mining

In 1848, James Marshall discovered gold at Coloma on the South Fork of the American River 8 miles north of Placerville (Busch 2001). Soon after, thousands of gold seekers worked placer mines throughout the North Fork/Middle Fork American River watershed, creating dredge tailings, a poorly sorted mixture ranging from clay to boulders. Evidence of historical mining occurs throughout the watershed in the form of abandoned mines, ditches, adits, and mining debris (USDA Forest Service 2004a). A number of active mining permits still exist in the watershed. Most of the activity involves dredging, although a small amount of placer mining continues. Initially, mining was by simple hand methods. Later, dredging, hydraulic mining, and drift mining techniques were employed. Placer County hosted some of the largest hydraulic mines and longest drift mines in the world (Loyd 1995). In 1851, mining for lode gold began in the area (Busch 2001). In later years, asbestos, chromite, clay, copper, diamonds, dimension stone, gold, lead, limestone, platinum, mercury, silica, silver, slate, soapstone, tungsten, zinc, and manganese have been recovered. Recently, the primary mineral commodity produced in the watershed has been industrial limestone, including the largest mineral producer in the El Dorado County, the Cool-Cave quarry north of Cool, California.

As a result of downstream impacts, hydraulic mining was enjoined in 1884. During the 1930s there was another episode of considerable placer mining activity in the American River watershed (Busch 2001). Mechanized placer mining operations used draglines and floating washing plants. Valid placer mining claims still exist along the American River and its tributaries. Two-thirds of all hydraulic mining in California took place in the Yuba, Bear, and American river watersheds, with most of the mining in the American River watershed occurring in the North Fork drainage. Hydraulic mining involved directing high-pressure water cannons at Eocene gravel exposures and washing excavated sediment through mercury-laden sluice boxes (Curtis and others 2005). Tailings were ultimately conveyed into adjacent watercourses leading to substantial increases in sediment loads and downstream channel aggradation. The amount of sediment displaced by early hydraulic mining is said to be eight times the amount of material moved in construction of the Panama Canal (Laddish 1996).

During the Tertiary, the American River occupied a different channel than it does today. Gold was concentrated in these ancestral channels (Konigsmark 2002; Lindgren 1911). Subsequent volcanism buried these channels under thick deposits of ash and debris. During the volcanic episodes the rivers were sometimes forced into new channels. The modern American River system developed in the last 5 million years (Wakabayashi and Sawyer 2001) and swept away much of the Tertiary volcanic cover. It incised deep canyons into bedrock, resulting in the concentration of heavy materials and accumulation of gold in the present streams.

Placer deposits are concentrations of heavy minerals that form from wave or current action of water or air. The mechanical action of these media selectively winnows away very fine and low-density materials and concentrates the remaining larger or higher-density mineral grains. Minerals concentrated in this manner are likely to be dense and resistant to weathering, solution, and abrasion. Although the auriferous deposits have historically been called “gravels,” they contain sand, silt, clay, and gravel- to boulder-sized materials. Compositionally, they include metamorphic, igneous, and quartz clasts (Loyd 1995). In the North Fork/Middle Fork American River watershed, both modern and paleoriver deposits have been mined intermittently since the early gold rush days. Over decades while mining activity flourished, extensive portions of the river system were dewatered, with significant impact to riverine resources.

Historical hydraulic mining has left Sierra Nevada rivers and watersheds with a legacy of locally eroded hillsides and excess sediment (Shilling and Girvetz 2003). Since the 1880s, Sierra Nevada rivers have been transporting sediment from sources, including lag deposits left by tailings, smaller-scale continued hydraulic mining, and erosion of hillslopes and other abandoned mines (James 1997, 1999; Snyder and others 2004).

Extensive remobilization of stored hydraulic mining sediment began in the late 1800s when large winter storms delivered substantial volumes of sediment to the Central Valley (Curtis and others 2005). This remobilization continues to affect sediment yields as low-order tributaries, aggraded with vast quantities of hydraulic mining sediment, continue incising to pre-mining channel bed elevations (Curtis and others 2005; Snyder and others 2004). Levels of mining-related sediment are thought to be lower in the North Fork/Middle Fork American River watershed than in the adjacent Yuba River watershed, which provided the largest source of mining-related sediment to the Sacramento River.

Since the late 1950s, the USDI Bureau of Reclamation periodically has investigated the sand and gravel resources of the North and Middle forks of the American River for the purpose of supplying required aggregate material for the construction of the proposed Auburn Dam. These investigations delineated over 13.5 million tons of sand and gravel deposited within and along a 7-mile segment of the Middle Fork of the American River between Mammoth Bar and Cherokee Bar (Loyd 1995). Of this amount, approximately 1.5 million tons are contained within the river channel itself, and 12 million tons fall within the following major gravel bars located adjacent to the channel. From west to east, these are Mammoth, Texas, Brown’s, Hoosier, Buckeye, Sardine, Maine, Philadelphia, Poverty, and Cherokee bars. Investigations by the USDI Bureau of Reclamation indicate the presence of between 2 and 4 million tons of sand and gravel in several river bars along 8 miles of the North Fork American River between Lake Clementine and the Ponderosa Bridge. Additional deposits are thought to be present within the channel now inundated by Lake Clementine.

Studies of the North Fork American River suggest approximately 213 million cubic yards of hydraulic gold-mining sediment filled the previously bedrock-lined channel (Laddish 1996; Rutten 1998). Despite this significant sediment load, widescale changes in stream morphology appear limited to localized aggradation and degradation (Laddish 1996). Sierra Nevada streams initially responded by aggrading in the tributaries near the sediment source. The floods of 1862 scoured the tributaries and transported much of the sediment into the mainstem channels downstream where it caused widespread aggradation and channel avulsion (Rutten 1998). At one time, the channel bed elevation of the levied lower American River was higher than the floodplain outside of the levees.

The North Fork American River is still recovering from hydraulic mining sediment (Laddish 1996). Long- and short-term survey data reveal a degrading, supply-limited reach upstream and an aggrading, transport-limited reach downstream (Rutten 1998). As the river recovers, sediment moves through the North Fork drainage as an asymmetric wave, similar to recovery in the Bear River (Laddish 1996). The river's historical terraces record temporary states of equilibrium during the regradation of the river channel. The presence of multiple terraces suggests that the receding limb of the sediment curve is not smooth but punctuated by several peaks representing either sediment reactivation caused by incision or episodes of aggradation followed by incision. After re-attaining a pre-mining longitudinal profile, the river will likely begin eroding laterally (Laddish 1996). Reworking of stored mining sediment in upland tributaries will likely occur throughout the next millennium. Mining sediment represents a significant sediment source that will continue to affect long-term sediment yield from watersheds in the Sierra Nevada (Curtis and others 2005). Gold mining also used substantial amounts of mercury to recover gold. Varying amounts of mercury contamination of sediment and aquatic organisms remain to this day in many Sierra Nevada watersheds (Alpers and others 2005).

A single database of active and abandoned mines in the North Fork/Middle Fork American River watershed does not exist. Different data sources with partial information include the Principal Areas of Mine Pollution (PAMP) system maintained by the California Office of Mine Reclamation, Topographically Occurring Mine Symbols (TOMS) digitized from the USDI Geological Survey 7.5-minute quadrangle maps, and the Abandoned Mine Lands databases maintained by the USDA Forest Service. Multiple locations are often shown for a single mine, and mine sites are likely repeated in these different data sources. The California Office of Mine Reclamation is conducting an inventory of the entire American River watershed, although their progress has been delayed by the higher-priority reclamation efforts at known mine sites. Using the existing data from multiple sources, almost 1,600 individual sites are identified in the North Fork/Middle Fork American River watershed (Map 3-17). Of the total, approximately 380 sites are identified as placer or hydraulic mines.

3.12 Erosion Processes and Sediment Dynamics

This section provides a general contextual overview of erosion and sedimentation processes with some specific references to the Sierra Nevada and the North Fork/Middle Fork American River watershed.

Erosion is the detachment of bedrock fragments or soil particles from a given area by the processes of wind, water, ice, or gravity. Sedimentation is the end result of several physical processes, including erosion; sediment production, transport, and deposition; and instream morphological processes. Sedimentation of surface water and effects on beneficial uses of water is the most common nonpoint-source pollution concern related to land management activities.

Erosion and sediment delivery are natural processes that can be affected by human-induced disturbances. Actions that produce bare soil or increase or concentrate water flow have a high potential for accelerated erosion and sediment delivery to streams. Increased sediment delivery to streams negatively affects water quality and the physical habitat for aquatic organisms. The effects on channel habitat by accelerated sedimentation may be shown by fine sediment infilling pools or infiltrating and clogging the pores between coarse sediment. Natural events such as wildfires and mass failures can cause these same effects in episodic pulses, and other smaller inputs from chronic erosion sources also can occur. Thus, demonstrating accelerated sedimentation requires careful documentation. Increased erosion and sediment delivery to streams can be reduced by increasing ground cover and by preventing the concentration of surface water runoff.

3.12.1 Sediment Production

For erosion to occur there must be material that can be eroded, which requires the weathering of pre-existing bedrock. Weathering is the physical and chemical disintegration of rock that breaks it into progressively smaller sizes and also alters the minerals of the original rock into clay minerals. Weathering progresses from the surface down into the rock. Because the surface has undergone weathering for longer periods, it is generally the most altered material and the alteration decreases with depth until eventually solid, unweathered bedrock is reached.

The uppermost weathered surface layer is converted into soil reflecting the site-specific components of parent material (i.e., the type of rock or deposited material), topography, climate, organisms (vegetation and burrowing animals), and time. Important parameters that affect soil erodibility include its texture (grain size) and the amount of vegetation cover. Generally, the larger (coarser) a particle is, the harder it is to erode. However, deposits of clay-sized sediment or soils with higher amounts of clay may be more difficult to erode than coarser particles because these very fine-grained particles tend to stick together. Conversely, soils dominated by loose sand-sized materials (such as those produced by the weathering of granitic rock) may be relatively easy to move because there is minimal tendency for the particles to stick together (Andre and Anderson 1961). The surface soil grain size was one of the parameters used to define the erosion hazard rating (see Chapter 4) for this watershed assessment.

Because watersheds have a geologic history, there are also a variety of depositional landforms that store sediment for long periods, undergo continued weathering and soil formation, and can supply sediment by erosion. In the North Fork/Middle Fork American River watershed these depositional landforms include:

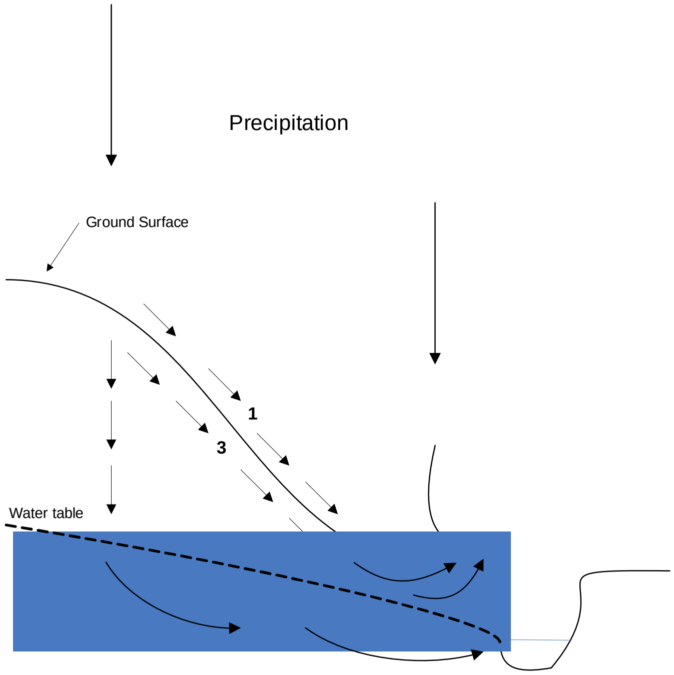
- stream terraces (older river deposits into which the stream or river has eroded),
- alluvial fans (a fan-shaped accumulation of river sediment deposited at the mouth of a ravine or at the junction of a tributary stream with a larger stream),
- slope deposits,
- deposits from former glaciers,
- hydraulic mining debris, and
- deposits left by the failure of the Hell Hole Dam on the Rubicon River in 1964.

Localized stream terrace deposits are found in the North Fork American River upstream of Lake Clementine (Laddish 1996) and along the Rubicon River (Scott and Gravlee 1968). Small alluvial fans are common where smaller drainages enter the North and Middle Forks of the American River and the Rubicon River. A variety of slope deposits occur along many of the major stream valleys throughout the watershed. Glaciation and the associated glacial deposits are restricted to approximately the upper one-third of the watershed. Substantial amounts of hydraulic mining debris are found along the middle to lower portions of the North Fork and Middle Fork of the American River (Busch 2001; James 1997, 1999; Laddish 1996).

3.12.2 Runoff Processes

For water erosion to occur on the ground surface or hillslopes, there must be sufficient water to actually runoff and move weathered bedrock fragments or soil particles. The possible paths that water may follow in moving downhill can be placed into four categories called (1) overland flow, (2) groundwater flow, (3) shallow subsurface stormflow, and (4) saturation overland flow (Figure 3-4). When rain falls on a ground surface it will initially infiltrate into the soil. If the rain continues for some length of time or with high intensity, at some point it may overcome the infiltration capacity of the soil and begin to flow over the ground surface as overland flow. *Overland flow* is relatively rare in forested environments because the trees and ground litter slow the water down, giving it more time to infiltrate. Overland flow tends to occur in natural areas with discontinuous vegetation coverage or in disturbed areas where the vegetation and litter have been removed and where the soil may have been compacted, reducing its infiltration capacity. Discontinuous natural vegetation cover tends to occur at elevations above approximately 5,000 feet including the higher elevations of the montane forest, subalpine forest, and alpine zones in the upper part of the North Fork/Middle Fork American River watershed. Overland flow is more common in shrub and grassland environments, but even here the rainfall must continue for some length of time before it overcomes the soil's infiltration capacity. Additionally, Kavvas and others (2000) report overland flow occurring beneath the snow pack during peak melt periods in the Lake Tahoe basin.

Figure 3-4. Water Pathways on a Hillslope.



Note: Path 1 is overland flow. Path 2 is groundwater flow. Path 3 is shallow subsurface flow. Path 4 is saturation overland flow composed of direct precipitation on saturated area plus the infiltrated water that returns to the ground surface.
Source: Modified from Figure 9-1 of Dunne and Leopold 1978.

The infiltrated water may continue down into the weathered zone and become *groundwater*. Groundwater moves through the pores in the weathered zone, and in the North Fork/Middle Fork American River watershed it may be stored at depth or move towards the stream channels. In portions of the watershed that are dominated by shallow bedrock, this groundwater reaches the relatively impermeable bedrock and moves towards the stream channels fairly quickly. In disturbed areas, particularly road cuts, this groundwater (as well as shallow subsurface flow) may emerge and cause erosion of the soil.

Some of the infiltrated water moves downslope just beneath the ground surface—this is called *shallow subsurface flow*. Lastly, during longer rainstorms the shallow subsurface flow comes to the surface near stream channels. Direct rainfall is added to this emerged water and the combination is called *saturation overland flow* to differentiate it from normal overland flow.

The ability of water to infiltrate the soil depends on properties such as soil texture. The coarser the soil texture the more water can infiltrate the soil; conversely, the finer the soil texture the less water can infiltrate the soil. Soil texture similarly influences how fast water can infiltrate the soil. These variations in soil infiltration capacity and rate are important for evaluating both soil erosion and water runoff characteristics (volume and timing). Consequently, as part of the process of mapping and investigating the soils in any area, they are assigned to a hydrologic soil group (group A, B, C, or D; described in

Section 3.5) that reflects their runoff potential and infiltration rates under similar storm and cover conditions. Soils have increasing erodibility potential from hydrologic soil group A to D. The hydrologic soil group was one of the parameters used to define the Erosion Hazard Rating (EHR, see Chapter 4) for this watershed assessment.

The amount of runoff is also affected by the precipitation zones that occur in the North Fork/Middle Fork American River watershed. As described in Section 3.6, the precipitation zones change in the west-to-east direction as the elevation increases. The lower elevations are predominantly rain, the intermediate elevations can have rain-on-snow zone events, while the highest elevations are predominantly a snow zone.

3.12.3 Sediment Sources and Transport, and Erosion Processes

Sediment sources and transport processes can be divided into those that occur on hillslopes (hillslope processes—both surface erosion and mass wasting) and those that occur in stream channels (channel processes) (see Table 3-17). Table 3-17 lists and defines many of the processes that can occur in the North Fork/Middle Fork American River watershed. The following discussion does not attempt to be an all-inclusive evaluation of this wide range of processes. Rather, the discussion concentrates on the dominant processes that are important for a general understanding of erosion and sediment dynamics in the watershed. Mount (1995) provides a more detailed review of these processes from a California context.

Hillslope Erosion – Mass Wasting

Landslides occur where slopes are sufficiently steep that gravity can overcome the internal friction that holds the weathered material on the slope. Loose sediment that is simply piled up will have a stable slope angle of approximately 65 to 70 percent (33 to 35 degrees)—called the angle of repose. This angle of repose tends to approximate the steepest slopes on which loose material is found. The stability of natural weathered materials on slopes lower than 33 degrees depends on the internal friction and is influenced by characteristics such as grain size, permeability, and local topography. Water is the primary driver for landslides because the internal friction is reduced as water is added to the mixture and fills the internal pore spaces. As the pore spaces fill, the water exerts a buoyant effect that tends to push the grains apart. Commonly, landslides occur when soil moisture accumulates over a winter period and is followed by long, intense rainstorms. Rain-on-snow events also contribute to landslides. Often local slope configurations cause subsurface water to concentrate in very specific locations which are then susceptible to failure in a landslide. As an example, numerous landslides occurred in the Sierra Nevada during the 1997 New Year storm.

Table 3-17. Sediment Sources and Transport Processes.

Specific Process	Definition or Comment
Hillslope Processes—Surface Erosion	
Frost shattering	The production of rock fragments by the freezing of water within cracks and joints within rocks.
Wind	Wind can erode fine soil particles.
Rainsplash	The impact of raindrops on bare soil splashes small soil particles into the air and some of them are displaced downslope.
Sheetwash	The flow of sheet of water over a soil surface displaces some soil particles downslope. The sheet flow can be from overland flow or saturation overland flow.
Subsnowpack	Subsnowpack (or subnival) erosion occurs when melting snow produces sheetwash on the soil surface but beneath the snow pack.
Rilling	As sheetwash becomes concentrated it forms rivulets that erode small channels into the soil surface. Rills are usually considered to be less than 10 to 15 inches deep. In agricultural terms, rills are small enough to be obliterated by the pass of a plow. If larger than this, they are considered gullies.
Gullying	As water flow increases downslope rills become larger and form gullies. Gullies may be greater than 10 to 15 inches deep to tens of feet deep.
Tunnel erosion (soil pipes)	Shallow subsurface stormflow can sometimes become concentrated along pre-existing subsurface channels in the soil (e.g., in channels formed by decayed tree roots). These subsurface channels can enlarge downslope and exit to the surface usually at stream banks or road cuts. At these sites these “soil pipes” can disgorge notable amounts of sediment.
Animal burrowing	Various burrowing animals excavate soil for their burrows. When pushed to the soil surface, some of this soil moves downslope.
Trampling	Animals walking on slopes displace some soil down the hillside with their foot steps.
Treethrow	The displacement of soil by the falling over of a tree and its root mass. The soil attached to the tree roots is pulled from the ground; when the soil falls from the roots a small amount of it is displaced downslope.
Dry ravel	Loose accumulations of rock fragments on relatively steep angles that move downslope under the influence of gravity.
Soil creep	The slow downslope movement of soil on slopes. Shown by tilted fence posts or tree trunks that are straight above but curve upslope at their base.
Hillslope Processes—Mass Wasting	
Rockfall	The falling of an individual loose rock, commonly from a steep near-vertical rock face.
Rock slide	The falling of a mass of rock that shatters and continues downslope, sometimes at great speed. Water or snow is not a significant component of the mixture of materials.
Debris avalanche	Debris avalanches are moving masses of rock, soil and snow that occur when the flank of a mountain collapses and slides rapidly downslope.
Earthflow	Slope material liquefies and flows out forming a bowl at the head and depositing the liquefied material on the slope below.
Slump	Commonly a rotational slide where a coherent mass of material moves downslope along a subsurface rupture surface. The rotated mass undergoes various types of deformation.

Table 3-17. Sediment Sources and Transport Processes (Continued).

Specific Process	Definition or Comment
Channel Processes	
Debris flows	A channelized flow composed of a slurry or mixture sediment (boulders, cobbles, gravel, sand, silt, clay) and water where the sediment is supported by the viscous matrix of sediment.
River (fluid flow, fluvial) transport	The movement of sediment (boulders, cobbles, gravel, sand, coarse silt) by stream flow. The sediment may move as bedload or suspended load (see below).
Dredging	Human excavation of sediment from streams, lakes, or reservoirs.
Gravel mining	The removal of gravel from stream beds for use as aggregate or fill.
Bedload	Bedload is the movement of sediment by river flow by rolling, bouncing, or intermittent suspension along the bed of a stream. Bedload is usually considered to be coarser than sand size but includes gravel, cobbles, and boulders.
Suspended load	Suspended load is sediment that is transported by suspension above the bed of the stream in the middle to upper portion of the stream flow. Suspended load is generally silt or clay size, although fine to coarse sand may be carried in suspension during a stream's peak discharge.

Source: Modified from Reid and Dunne 1996; California Division of Mines and Geology 1999; U.S. Geological Survey 2004.

The Eldorado National Forest received Emergency Relief for Federally Owned Roads (ERFO) funds to address 34 mass wasting sites within the North Fork/Middle Fork American River watershed after the 1997 New Year storm. Of these, 5 were identified as landslides, 1 as a slump, and 15 as site-specific erosion sites; 12 were associated with culvert failures and 1 with a bridge failure. Most of these ERFO sites were located along the Eleven Pines Road in the Rubicon River 5th-level HUC subwatershed. With the exception of one erosion site and the bridge site, all 1997 ERFO sites in the North Fork/Middle Fork American River watershed were located within the Rubicon River 5th-level HUC subwatershed, where the majority of the lands in the watershed managed by the Eldorado National Forest fall (Table 3-2). The Long Canyon landslide was initiated during a large precipitation event and continues to reactivate during other large events. Several smaller mass wasting events have affected access to utility facilities in the watershed (Mai 1997). Outside of the North Fork/Middle Fork American River watershed, landslides occurred along Highway 50 when the cumulative precipitation in the area was 235 percent of normal and the high-intensity rain of the New Year storm fell on and melted the snowpack (Hilton 2001; Wagner and Spittler 1997). Other landslides occurred in the Highway 50 corridor in 1983 when the 1982-1983 precipitation was 176 percent of average (Wagner and Spittler 1997). Similarly, the Sourgrass landslide above the Stanislaus River occurred when the cumulative precipitation was 200 percent of average followed by the New Year storm (DeGraff 2001).

Because of their dependence on high precipitation, landslides tend to be episodic; that is, a site may not move for many years and then the right weather conditions occur and the slope fails. When landslides occur adjacent to stream channels, their sediment may be delivered directly to the stream system. Though landslides vary in size, they can be large and therefore during major landsliding events very large amounts of sediment can be input into the river system. For example, the Mill Creek landslide complex triggered by the 1997 New Year storm was large enough to briefly block the South Fork American River (Hilton 2001; Wagner and Spittler 1997). In the North Fork/Middle Fork American River watershed, landslides tend to be common in the steep inner gorges of the main canyons (North Fork American River, North Fork of the North Fork American River, Middle Fork American River, and Rubicon River) and where the Mehrten and Valley Springs formations are exposed as relatively steep slopes by stream incision (see Sections 3.4 and 3.5). Many of the steep inner gorges also have steep stream channels and failure can occur along these streams with direct influx of sediment into the steep tributary stream and then downslope to the main channels. Such failures are often debris flows, which are considered a channel process in Table 3-17.

Hillslope Erosion – Surface Erosion

Processes that produce surface water runoff are necessary for erosion to occur. As noted, such erosion tends to be more dominant when the vegetative ground cover is reduced or non-existent. In these conditions rainsplash erosion (Table 3-17) also occurs. Rainsplash moves particles and makes them available for transport by overland flow. Rainsplash can also cause the surface to be sealed, reducing infiltration and increasing runoff and erosion. As overland flow occurs (including saturation overland flow), it produces sheetwash erosion. As this flow concentrates, it can erode rills into the surface and, if the flow continues to concentrate, then larger gullies may form. Rills and gullies may deliver sediment to the stream system.

Channel Erosion

Erosional streams flow within the valleys that they erode. This is very evident in the North Fork/Middle Fork American River watershed where the stream systems erode into the plateau-forming Mehrten Formation. Examples of these systems are Upper North Shirttail Canyon, Humbug Creek (North Fork American River) and Grouse Creek and Peavine Creek on the North Fork Middle Fork of the American River. In addition, the steep inner gorge canyons of the larger rivers reflect long-term erosion into the landscape inundated by the Mehrten Formation volcanic lahars (see Section 3.5). Wakabayashi and Sawyer (2001) indicate that up to 3,200 feet of stream incision has occurred in the last 5 million years.

Stream channels transport (or deposit) the water and sediment that is supplied to them from upstream. Additional sediment is produced by local channel erosion. This erosion occurs by the transport of sediment from the channel bottom as well as erosion and transport of sediment from the channel banks. The material forming the channel banks may be river deposits in short-term storage, older stream terraces, or, in the North Fork and Middle Fork American River, hydraulic mining debris. Stream density is also an indicator of the general amount of stream erosion that is occurring. That is, the more streams that exist in a given area, the greater potential for sediment to be eroded and transported downstream.

The general classification of stream channels used in this watershed assessment is that of Montgomery and Buffington (1993, 1997); i.e., source, transport and response reaches (see Section 3.8). All these stream channels transport sediment. However, in general, the source reaches are steeper streams that serve as a primary source of sediment for the stream system. Transport reaches tend to be adjusted to transport the sediment supplied to them so that there is little deposition along these reaches. Response reaches tend to be those where sediment will be deposited. Because of the long-term (geologic time) landscape incision, all of these streams are incising into their underlying bedrock. However, that erosion is only identifiable on the scale of thousands of years. The sediment transport addressed here occurs on the yearly, multi-year, decadal, and up to approximately 100-year timeframe.

Sedimentation involves the deposition of eroded materials in areas on site, or off site on adjacent lands. The particles eroded from the upland landscape may only be moved short distances, may be deposited, or may not be delivered to a stream. Only sediment delivered to a stream can affect water quality with respect to sediment. Unpaved forest roads are a widespread concern with respect to erosion and sediment delivery to stream systems. Coe (2006) evaluated forest roads in the central Sierra Nevada in the South Fork American River and Cosumnes River watersheds. He found that 25 percent of the surveyed road length was connected to a stream channel and could deliver sediment to the stream, indicating that 75 percent of the road system did not deliver sediment to stream channels.

As noted above, sediment can be derived by processes on the hillslopes or within the channel. It requires detailed evaluations to determine the percentage of sediment contributed by hillslope versus channel processes. In general, channel processes are likely dominant. For example, an investigation of the Lake Tahoe Basin based on modeling and some stream channel investigation found that approximately 70 percent of the sediment load was derived from the stream channel, and approximately 30 percent from the hillslopes (Simon and others 2003). However, in more highly disturbed watersheds that relationship could be reversed (Simon and others 2003).

Bedload and Suspended Load

Once sediment is in the stream system, it is transported either as bedload or suspended load (Table 3-17). Bedload moves by rolling, bouncing, or intermittent suspension along the bed of a stream. It consists of a wide size range from sand through gravels, cobble, and boulders. Suspended load is transported in suspension above the bed in the middle or upper portion of the stream flow. Suspended load is generally silt or clay size, although fine to coarse sand may be carried in suspension during high stream discharges.

For any given grain size, the stream flow has to reach a certain threshold before the sediment will move. In general, the coarser the sediment the higher the stream flow must be to move it. In lowland river systems, the bedload may be less than 25 percent of that moving as suspended load (Wohl 2000). However, in mountain rivers bedload generally constitutes a higher percentage of the total sediment load (Wohl 2000). Because of its size, bedload requires higher flows to move than suspended load, and sufficiently large flows do not occur often. For example, in Sagehen Creek, draining the eastern Sierra Nevada approximately 12 miles north of the present study area, Andrews (1994) found that 47 percent of all bedload transported during 38 years of record occurred in just 6 years. During 10 years of the total 38 years, essentially no bedload transport occurred. Similarly, Curtis and others (2006) evaluated sediment transport at two locations on the Yuba River, the next major drainage basin to the north of the North Fork/Middle Fork American River watershed, for two relatively dry years (October 2001 to September 2003). They found that bedload was only about 1 percent of the total load during that period. The availability of coarse sediment (bedload) for transport can also be influenced by the influx of sediment from landslides (see above) and the introduction of hydraulic mining debris or other human-induced sediment pulses (see below).

Once suspended load reaches the stream system, it is relatively easy to transport because of its small size. In general, the amount of suspended load increases as stream flow increases, and the amount of suspended sediment transported tends to mirror individual storms and the annual runoff cycle (see Section 3.6). For example, in oak woodland-dominated watersheds in the Sierra Nevada foothills of Yuba County, Lewis and others (2002) found that the suspended sediment load paralleled the seasonal rise and fall of stream discharge. In forested watersheds in the Lake Tahoe basin, the highest amount of suspended sediment transport occurs during summer thunderstorms and rain-on-snow events (Langlois and others 2005). The same patterns likely occur in the North Fork/Middle Fork American River watershed (Mai, personal communication, 2007). When suspended sediment is evaluated on a more detailed storm and season basis, other trends become apparent. One effect commonly seen is that the amount of suspended sediment tends to be higher during the beginning of a storm or the beginning portions of a seasonal runoff period. What occurs is that the available fine-grained sediment is being flushed out of the system and its overall supply is progressively reduced. Thus, specific flows during the earlier parts of a runoff cycle have the higher concentrations while the same flows at the end of the runoff cycle have lower concentrations. These effects have been identified in the Sierra Nevada in foothill oak woodland watersheds (Lewis and others 2002) and forested watersheds in the Yuba River (Curtis and others 2006) and Lake Tahoe basin (Langlois and others 2005; Stubblefield and others 2006).

3.12.4 Sediment Dynamics

A useful conceptual approach to visualizing the influx and movement of sediment in a watershed is that sediment supply depends on large-scale interactions of climate and weather processes with the physical and biotic landscape (Benda and Dunne 1997; McBain and Trush 2004). The long-term climatic and individual weather events drive periods of lesser and greater sediment influx to the stream system from landslides, surface erosion, and stream bed and stream bank erosion. The same climatic and weather cycles produce the stream flow that moves the bedload and suspended load through the stream system. These sediment influxes can be chronic or large sediment pulses (Cui and others 2003), and it may take years, decades, or longer for individual large particles to work their way out of the watershed. Human use of the landscape can also increase sediment influx over natural conditions, both on the chronic level and as large sediment pulses.

On a geologic time scale, the watershed is still eroding and transporting sediment related to stream incision of the landscape, and on a long time scale, it is transporting sediments deposited by glaciers in the upper watershed. However, the most extensive modification to the landscape and sediment influx was hydraulic gold mining that occurred in the mid- to late- 1800s and again in the early 20th century (James 1997, 1999; Laddish 1996). Hydraulic gold mining washed almost incomprehensibly large volumes of sediment into the North Fork and the Middle Fork American rivers. Hydraulic gold mining began in 1853, and by 1881 19.6 to 24.8 million cubic yards of debris had entered the North Fork American River and 10.4 to 14.3 million cubic yards had entered the Middle Fork American River (James 1997). If the largest full-size dump truck holds 25 cubic yards, then the 19.6 million cubic yard value is the equivalent of about 785,000 dump truck loads. There was another period of hydraulic mining in the late 1930s and early 1940s that also introduced sediment into the river system (James 1999). Laddish (1996) estimated that a total of 213 million cubic yards of hydraulic mining debris were introduced into the North Fork American River. Laddish (1996) mapped the hydraulic mining debris in the North Fork American River for about 4.35 miles upstream the North Fork Dam and Lake Clementine. She estimates that there are still 13.7 million cubic yards of hydraulic mining debris in the stream channel and in historical stream terrace deposits next to the channel.

The volume of hydraulic mining debris overwhelmed the stream system causing substantial amounts of deposition and stream bed elevation (aggradation). Prior to the building of dams on the river systems, this sediment was also progressively transported downstream. James (1999) identifies two periods when substantial amounts of sediment reached the lower American River in Sacramento causing deposition and elevation of the stream bed. The first sediment influx reached Sacramento about 1910 to 1915. After this the bed elevation reduced. Another influx of hydraulic mining debris sediment reached Sacramento about the mid-1930s. In 1939, the North Fork Dam (creating Lake Clementine) was constructed on the North Fork American River, specifically to prevent the downstream transport of this hydraulic mining debris and the bed elevation in Sacramento decreased afterward (James 1997). Work by Laddish (1996) and Rutten (1998) on the hydraulic mining debris in the North Fork American River upstream of Lake Clementine showed that the upper part of the 4.35 mile studied reach entrenched about 16 feet while in the lower reach the stream bed aggraded about 26 feet. In addition, about 6.5 million cubic yards of sediment (mostly bedload) has been deposited in Lake Clementine in the 54 years between 1936 and 1993 (James 1997). This amounts to about 121,000 cubic yards per year of bedload sediment transport into the reservoir, although—as discussed above—the amount of bedload moved varies substantially from year to year.

Other information on sediment transport in the area comes from the investigation of Ralston Dam on the Middle Fork American River (Jones and Stokes 2002). A 1990 report indicated that 56,000 cubic yards per year had accumulated in the Ralston Afterbay between 1966 and 1990. A subsequent investigation found that about 36,250 cubic yards per year had accumulated between 1987 and 1995. The difference in these two values was attributed to the sediment influx associated with the collapse of the Hell Hole Dam on the Rubicon River in 1964 (Scott and Gravlee 1968). The earlier and higher values reflect the initial and continued influx of that sediment, while the later and lower values reflect that substantial portions of that sediment have already made their way down river. Kattleman (1996) compiled available reservoir sedimentation studies from the Sierra Nevada and the values reported above are within the range he identified. Snyder and others (2004) provide recent data on the deposition of sediment, including hydraulic mining debris, in Englebright Lake on the Yuba River. Like Lake Clementine, Englebright Dam was constructed to capture hydraulic mining debris.

As suggested by the above discussion, reservoirs trap sediment and prevent it from being transported downstream. In general, most bedload is trapped in a reservoir while a substantial portion of the suspended load may be transported out of the reservoir. A common effect of this sediment trapping is that there may be entrenchment of the stream and coarsening of the stream bed sediment size downstream of the reservoir (Furniss and Guntle 2004). Because the larger rivers in the North Fork/Middle Fork American River watershed are relatively bedrock-dominated, stream entrenchment is uncommon. Coarsening of the stream bed material, however, has been reported (Jones and Stokes 2002).

CHAPTER 4: WATERSHED INDICATORS, MODELING, AND PRIORITIZATION

4.1 Introduction

The purpose of Chapter 4 is to describe the two approaches used to identify the potential sediment delivery risk to streams in the North Fork/Middle Fork American River watershed. First, specific indicators were used to assess the watershed condition and vulnerability. Second, watershed modeling was used to characterize the relative risk to erosion and sedimentation, and to develop a priority ranking to target potential problem areas and optimize the implementation of management practices. Results and discussions of both approaches are presented here. The data analysis and synthesis used the best available spatial data for the North Fork/Middle Fork American River watershed. In Chapter 4, the data summaries and related discussions emphasize 6th-level and 7th-level HUC subwatersheds. Refer to Section 1.3 for a description of these subwatershed levels.

The subwatershed prioritization described in the final section of this chapter can be used to compare the potential risk of sedimentation of a subwatershed relative to another subwatershed in the North Fork/Middle Fork American River watershed. In other words, potential risk may be rated higher or lower in one subwatershed compared to another evaluated in this study, but the ratings should not be used to evaluate the absolute sedimentation potential of an area. As described throughout Chapter 3, major sediment sources identified in the North Fork/Middle Fork American River watershed relate to historical mining activities and not to watershed-scale accelerated erosion problems. Sediment-related water quality does not appear to be a major concern, except in localized areas. Nonetheless, knowledge of the relative potential risk of sedimentation from one subwatershed to another is useful in prioritizing and targeting future site-specific projects to optimize limited funding to enhance or maintain watershed health by minimizing potential sediment-related impacts to key resources.

When interpreting the subwatershed prioritization results, it is important to note that a high-priority ranking suggests a higher potential risk of erosion (under bare soil conditions) and a higher potential risk of sediment delivery relative to a lower-priority ranking. However, localized surface erosion and sedimentation occurs even in subwatersheds with low-priority rankings, just as subwatersheds with high-priority rankings may have effective vegetative cover, drainage conditions, or watershed management practices that minimize surface erosion and sedimentation.

4.2 Erosion Hazard and Precipitation Sensitivity Ratings

4.2.1 Erosion Hazard Rating

One of the intermediate and unique products developed in this North Fork/Middle Fork American River Sediment Study was an evaluation of the relative susceptibility of watersheds to surface erosion processes under bare soil conditions, independent of existing vegetation. Models of surface erosion hazards are commonly part of coarse-filter watershed assessment and land management planning (e.g., Curtis and others 2006; USDA Forest Service 1998, 2000). Surface erosion processes (e.g., rainsplash, sheetwash, rilling) are described in Section 3.12. In general, hillslopes with higher potential for surface erosion are more likely to contribute sediment to streams. As a result, the erosion hazard rating was one of several variables assessed in the spatially-explicit watershed sedimentation risk model.

The individual components of the erosion hazard rating (surface soil texture, hydrologic soil group, and slope steepness) developed for this study are presented in Sections 3.4 and 3.5. These soil and terrain components were selected after literature research, review of the available spatial data, and extensive discussion with the ARWG TAC. The selected components best represent the relative susceptibility of bare soil to surface erosion processes in the North Fork/Middle Fork American River watershed. A subcommittee including members of the NRCS, USDA Forest Service, PCWA, and Tetra Tech EC provided specific input that was incorporated into the final erosion hazard ratings. Detailed information related to the evaluation of each component and their combination into a single erosion hazard rating is presented in Appendix D. In general, the approach balanced systematic logic with the best professional judgment of ARWG TAC members, based on years of field observations of the soil map units in the North Fork/Middle Fork American River and adjacent Sierra Nevada watersheds.

Given the soil properties in the watershed, the professional judgment of the ARWG TAC was to consider a combination of surface soil texture, hydrologic soil group, and slope steepness to assess the potential for surface erosion under bare soil conditions in the North Fork/Middle Fork American River watershed, as opposed to the more widely used combination of soil erodibility index (K factor) and slope steepness. The K factor was developed using simulated plot data and represents inherent soil erodibility in the original Universal Soil Loss Equation (USLE), an equation designed to predict soil loss from sheet and rill erosion by water (Wischmeier and Smith 1958). Although the NRCS and USDA Forest Service have identified K factors for the soil mapping units that occur in the North Fork/Middle Fork American River watershed, the original range in K factors was established based on clean-tilled continuous fallow agricultural plots. According to Wischmeier (1976), estimates of soil loss based on K factor can be applied to woodland and other areas. However, the accuracy of these estimates would be limited by the availability of site-specific data. Due to limited site-specific information in the North Fork/Middle Fork American River watershed, the combination of the alternate soil properties listed above (surface soil texture and hydrologic soil group) and slope steepness was used to characterize soil erodibility instead of the combination of K factor and slope steepness. In addition, the relative importance of precipitation types and patterns found in this area made it justifiable to regroup the soils based on textures and develop a more refined risk for erosion hazard. Others have used similar approaches to evaluate potential surface erosion and identify highly erodible lands. For example, the Eldorado National Forest considers erosion hazard ratings and hydrologic soil groups in the natural sensitivity index used to assess risk of cumulative watershed effects (USDA Forest Service 1998).

Soils data were obtained from the NRCS (as described in Section 3.5) and aggregated by dominant condition—an NRCS-recommended method that was determined to be most appropriate for the available soils data. The overall erosion hazard rating was computed for each 10-square meter grid cell based on the mathematical product of individual ratings for each of the three components (surface soil texture, soil hydrologic group, and slope steepness). Erosion hazard ratings for each cell were aggregated by subwatershed. A review of this map-based approach was conducted by visiting a subset of subwatersheds throughout the North Fork/Middle Fork American River watershed and comparing the GIS analysis outputs with the on-the-ground conditions. Selected photos taken during field trips and a brief report of field activities and observations are included in Appendix C.

Based on field observations, the erosion hazard ratings were adjusted to better represent the surface erosion hazards on areas with slopes between 50 and 70 percent (i.e., slope angles of 27 to 35 degrees). Steep hillslopes just below the angle of repose appeared to be more potentially susceptible to surface erosion processes than the original GIS analysis results showed. For areas with slopes between 50 and 70 percent, the erosion hazard rating was modified and mapped as high, regardless of soil type. After a wildfire or vegetation-removing activity, these hillslopes would be expected to be highly susceptible to surface erosion processes. The final erosion hazard map includes five relative ratings—high through low—as shown on Map 4-1.

4.2.2 Precipitation Sensitivity Rating

Another intermediate and unique product developed in this watershed assessment was the precipitation sensitivity rating—the relative susceptibility of land surfaces to rain-on-snow and high-intensity precipitation events. Like the erosion hazard rating, the precipitation sensitivity rating provides a derived data layer that, when combined with other relevant data layers, forms part of the spatially explicit watershed sedimentation risk model. As described in Sections 3.6 and 3.12, rain-on-snow events have been correlated with greater surface erosion and mass wasting hazards in the North Fork/Middle Fork American River watershed and in other areas throughout the western United States. Similarly, the potential for soil erosion, mass movements, and sediment delivery to streams increases with increasing precipitation intensity. These two factors were combined to create an overall precipitation sensitivity rating.

The precipitation sensitivity rating was computed for each 10-square-meter grid cell based on the mathematical product of individual ratings for each of the two components (precipitation zones and precipitation intensities). For the watershed prioritization model, precipitation sensitivity ratings for each cell were aggregated by subwatershed. Areas with erodible soils (i.e., high erosion hazard ratings) or mass wasting-prone geologic formations (i.e., Mehrten or Valley Springs) would be expected to be more susceptible to erosion during high-intensity rainstorms on saturated snowpacks. The final precipitation sensitivity map includes five relative ratings—high through low—as shown on Map 4-2.

Detailed information related to the evaluation of each component and their combination into a single precipitation sensitivity rating is presented in Appendix D. The non-aggregated data for this and the other elements of the watershed prioritization model (presented below in Section 4.4) are provided to the ARWG as part of the data transfer for this project. These intermediate products may prove useful to guide watershed resource specialists in further investigations. In addition, the watershed indicators presented below in Section 4.3 include percentages for each subwatershed by precipitation sensitivity rating.

4.2.3 Assumptions and Limitations

Both the erosion hazard and the precipitation sensitivity ratings provide useful multi-thematic information that can be used to compare the potential sediment contribution of a subwatershed relative to another subwatershed in the North Fork/Middle Fork American River watershed. The ratings are based on publicly available data layers that cover the entire North Fork/Middle Fork American River watershed. As mentioned previously, a subwatershed with a high erosion hazard rating suggests a higher potential risk of surface erosion under bare soil conditions relative to a subwatershed with a low erosion hazard rating. However, localized surface erosion occurs even in subwatersheds rated as low, just as subwatersheds rated as high may have dense vegetative cover or effective best management practices (BMPs) that minimize surface erosion problems. Similarly, a high precipitation sensitivity rating in a subwatershed does not mean that a damaging storm will occur, but rather it provides an indication of where such a storm may be more likely to occur based on past precipitation events.

As described throughout Chapter 3, major sediment sources identified in the North Fork/Middle Fork American River watershed relate to historical mining activities and not to watershed-scale accelerated erosion problems. Sediment-related water quality does not appear to be a major concern, except in localized areas. Nonetheless, knowledge of the relative potential risk of sedimentation from one subwatershed to another is useful in prioritizing and targeting the appropriate management strategies to optimize limited funding. The relative ratings were developed for this study based on the best available information. This study does not address the effects of land use or management activities on the risk of sediment-based cumulative watershed effects.

4.3 Watershed Indicators and Vulnerability Assessment

Watershed vulnerability reflects the inherent risk that conditions could be degraded if certain sensitive land types in a watershed were disturbed (Heller and others 2002). Several watershed indicators were developed to quantify the relative potential vulnerability of different subwatersheds throughout the North Fork/Middle Fork American River watershed. These indicators focus on quantifiable parameters (assessed in GIS) that reflect erosion and sedimentation potential, a landscape approach commonly applied in similar watershed assessments (e.g., Georgetown Divide Resource Conservation District 2004; USDA Forest Service 2000, 2003a). Like the erosion hazard and precipitation sensitivity ratings, the watershed indicators were developed based on literature research, review of the available spatial data, and extensive discussion with the ARWG TAC.

The watershed indicators fall into one of three categories: (A) surface erosion and mass wasting hazards, (B) road-stream interaction hazards, and (C) stream network and hydrologic hazards, as shown in Table 4-1. The indicators were computed in GIS using a single data layer, intersecting more than one data layer, or, for erosion hazard and precipitation sensitivity ratings, combining derived data layers based on a model. In each case, the watershed indicators are presented by subwatershed; in other words, the landscape metric of interest is averaged across the entire subwatershed. A finer-scale approach was used in the watershed modeling to prioritize subwatersheds across the North Fork/Middle Fork American River watershed. As in all the tables in this section, the GIS analysis outputs are sorted by both 5th-level and 6th-level HUC subwatersheds.

Refer to Sections 1.3 and 1.4 for an explanation of these units and for a guide to the report organization relative to these units.

Table 4-1. GIS Data Layers and Selected Watershed Indicators at a Glance. [1]

[A] Surface Erosion and Mass Wasting Hazards	[B] Road-Stream Interaction Hazards	[C] Stream Network and Hydrologic Hazards
GIS Data Layers Used to Derive Watershed Indicators:		
(1) Surface soil texture; (2) Hydrologic soil group; (3) Slope steepness; (4) Roads (by surface types) and trails; (5) Mehrten and Valley Springs formations; and (6) Mass wasting risk categories (National Forest System lands only).	(1) Roads (by surface types) and trails; (2) Streams (with contour-crenulated ephemeral streams on National Forest System lands only); (3) Known fish-bearing streams; (4) Surface soil texture; (5) Hydrologic soil group; and (6) Slope steepness.	(1) Streams (with contour-crenulated ephemeral streams on National Forest System lands only); (2) Roads (by surface types) and trails; (3) Precipitation zones (rain-dominated, rain-on-snow, and snow-dominated); (4) Precipitation intensity (based on 100-year, 6-hour storm); (5) Surface soil texture; (6) Hydrologic soil group; and (7) Slope steepness.
Selected Watershed Indicators:		
(1) Area by erosion hazard rating (combination of surface soil texture, hydrologic soil group, and slope steepness); (2) Unpaved roads (gravel and native surface) on areas of high erosion hazard rating; (3) Area of Mehrten and Valley Springs formations; (4) Area of Mehrten and Valley Springs formations on steep slopes (>50%); (5) Roads and trails on Mehrten and Valley Springs formations on steep slopes (>50%); (6) Area by mass wasting risk categories (National Forest System lands only); and (7) Roads and trails on areas of high mass wasting risk rating (National Forest System lands only).	(1) Roads (by surface type) and trails; (2) Roads and trails within 100 meters of streams; (3) Roads and trails within 100 meters of known fish-bearing streams; (4) Unpaved roads on highly erodible soils (high erosion hazard rating) within 100 meters of streams; (5) Unpaved roads on highly erodible soils within 100 meters of known fish-bearing streams; (6) Road (by surface type) intersections with streams; and (7) Road intersections with known fish-bearing streams.	(1) Drainage density (with and without contour-crenulated ephemeral streams); (2) Roads and trails on rain-on-snow zones; (3) Areas of highly erodible soils in rain-on-snow zones; (4) Areas of highly erodible soils by precipitation intensity; (5) Area by precipitation sensitivity rating (combination of precipitation zone and precipitation intensity); and (6) Roads in high precipitation sensitivity rating areas.

[1] This chapter presents both watershed indicators (listed here) and watershed submodels (listed in Table 4-23). Although they involve many of the same watershed characteristics, the methods used to calculate each differ. Watershed indicators, presented in this table, are summaries by subwatershed of the amount and extent of different watershed characteristics (e.g., length of road and road density, acres of steep slopes and percentages of steep slopes). Refer to Section 4.4 for descriptions of watershed submodels and for a synthesis of the results of both methods.

4.3.1 Surface Erosion and Mass Wasting Hazards

The results of the erosion hazard rating (described in Section 4.2) are summarized in Table 4-2 and graphically presented in Map 4-1. The 6th-level HUC subwatershed with the largest extent of high erosion hazard rating (51.1 percent) is the North Fork American River-Mumford Bar, followed by the Upper and Lower North Fork Middle Fork Americans with 38.5 and 44.2 percent, respectively, and the Middle Fork American River-Duncan Canyon with 37.4 percent. The 6th-level HUC subwatershed with the lowest extent of high erosion hazard rating (5.2 percent) is the South Fork Rubicon River.

The 6th-level HUC subwatershed with the greatest density of unpaved roads on areas with high erosion hazard ratings is the Upper North Fork Middle Fork American River, with 0.84 mile of unpaved roads on high erosion hazard ratings per square mile of watershed (Table 4-3). Other subwatersheds with densities greater than 0.50 mile per square mile include the adjacent Lower North Fork Middle Fork American (0.58 mile per square mile), the Middle Fork American River-Duncan Canyon (0.56 mile per square mile), and the Middle Fork American River-Bottle Hill (0.52 mile per square mile). The lowest density of unpaved roads on areas with high erosion hazard ratings occurs in the Upper Rubicon River with less than 0.01 mile per square mile.

As one watershed indicator, the percentage of Mehrten Formation and underlying Valley Springs Formation on steep slopes (greater than 50 percent)—common locations of mass wasting events—was characterized. This approach was developed based on knowledge of the landscape and with input from the ARWG TAC, and confirmed by Tom Koler, the Forest Geologist for the Eldorado National Forest. For National Forest System lands, we also evaluated mass wasting risk included in the USDA Forest Service geomorphology GIS data layer. Mass wasting and hillslope erosion processes are described in Section 3.12. The watershed prioritization presented below in Section 4.4 incorporated a different assessment of mass wasting risk on National Forest System lands.

The 6th-level HUC subwatershed with the greatest extent underlain by Mehrten and Valley Springs formations is the Long Canyon Creek with 65.8 percent (Table 4-4). The Headwaters Long Canyon Creek 7th-level HUC subwatershed is one of three smaller 7th-level HUC subwatersheds within the Long Canyon Creek 6th-level HUC subwatershed. During a field review of Headwaters Long Canyon Creek, substantial localized erosion and sedimentation was noted along an approximately 1-mile reach of Long Canyon Creek (Cornwell, personal communication, 2007). This site-specific sediment problem may be related to the extent of the geologic contact between the Mehrten and Valley Springs formations in this area, or it may be related to other site-specific conditions. As described below in Section 4.4, the extent of Mehrten and Valley Springs formations was not evaluated as part of the watershed prioritization. Instead, more detailed mapping of mass wasting risk compiled by the USDA Forest Service was evaluated on National Forest System lands, including Headwaters Long Canyon Creek. The emphasis of that mapping is described in Section 3.5. The watershed indicators presented here are offered to supplement the watershed prioritization presented in Section 4.4.

Several additional subwatersheds have over 40 percent in these geologic units, including Headwaters Middle Fork American River (49.4 percent), Shirttail Canyon (46.3 percent), Pilot Creek (43.7 percent), and Middle Fork American River-Duncan Canyon (42.1 percent). At the other end of the spectrum, the North Folsom Reservoir subwatershed at the very bottom of the North Fork/Middle Fork American River watershed contains no Mehrten or Valley Springs formation.

Table 4-2. Erosion Hazard Ratings by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Map 4-1).

6th-level HUC Nested Under 5th-level HUC	Low		Moderately Low		Moderate		Moderately High		High		Total	
	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)
Upper Middle Fork American River												
Headwaters Middle Fork American River	10,508	28.1	12,839	34.3	4,129	11.0	5,205	13.9	4,778	12.8	37,459	100.0
Middle Fork American River-Duncan Canyon	7,677	23.0	4,985	14.9	4,239	12.7	4,038	12.1	12,491	37.4	33,430	100.0
Rubicon River												
Five Lakes Creek	9,118	21.5	14,350	33.9	5,375	12.7	6,347	15.0	7,122	16.8	42,312	100.0
Long Canyon Creek	13,661	43.6	8,956	28.6	1,091	3.5	1,628	5.2	6,029	19.2	31,366	100.0
Lower Rubicon River	13,143	31.3	8,676	20.7	3,658	8.7	3,425	8.2	13,070	31.1	41,972	100.0
Pilot Creek	8,832	45.6	5,697	29.4	3,121	16.1	419	2.2	1,287	6.7	19,356	100.0
South Fork Rubicon River	20,143	55.2	10,178	27.9	3,023	8.3	1,223	3.4	1,912	5.2	36,480	100.0
Upper Rubicon River	18,426	60.7	8,809	29.0	561	1.9	244	0.8	2,292	7.6	30,332	100.0
North Fork Middle Fork American												
Lower North Fork Middle Fork American	7,165	20.6	2,654	7.6	5,015	14.4	4,542	13.1	15,377	44.2	34,754	100.0
Upper North Fork Middle Fork American	3,626	14.8	3,664	15.0	3,560	14.6	4,174	17.1	9,411	38.5	24,436	100.0
Lower Middle Fork American River												
Middle Fork American River-Bottle Hill	6,674	22.8	6,154	21.1	4,088	14.0	2,503	8.6	9,807	33.6	29,226	100.0
Middle Fork American River-Todd Creek	9,882	30.1	7,690	23.4	5,936	18.1	2,180	6.6	7,153	21.8	32,841	100.0
Upper North Fork American River												
Headwaters North Fork American River	7,904	22.8	12,137	35.1	4,360	12.6	4,669	13.5	5,547	16.0	34,618	100.0
North Fork American River-Granite Creek	5,710	17.5	10,598	32.5	2,964	9.1	4,018	12.3	9,363	28.7	32,653	100.0
North Fork American River-Indian Creek	8,591	23.4	7,605	20.7	5,978	16.3	3,535	9.6	10,983	29.9	36,692	100.0
North Fork American River-Mumford Bar	3,342	14.3	1,281	5.5	3,311	14.2	3,481	14.9	11,915	51.1	23,330	100.0
North Fork of North Fork American River	9,868	28.2	8,985	25.7	3,726	10.6	3,705	10.6	8,702	24.9	34,987	100.0
Lower North Fork American River												
North Folsom Reservoir	4,606	65.2	1,344	19.0	260	3.7	106	1.5	748	10.6	7,065	100.0
North Fork American River-Clipper Creek	5,927	22.1	4,467	16.6	7,119	26.5	2,996	11.2	6,323	23.6	26,831	100.0
Shirttail Canyon	12,981	37.1	7,375	21.1	7,983	22.8	2,468	7.1	4,196	12.0	35,003	100.0

Table 4-3. Unpaved Roads on Areas with High Erosion Hazard Ratings by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Length (miles)	Density (mi/mi^2)
Upper Middle Fork American River		
Headwaters Middle Fork American River	10.1	0.17
Middle Fork American River-Duncan Canyon	29.3	0.56
Rubicon River		
Five Lakes Creek	4.0	0.06
Long Canyon Creek	9.4	0.19
Lower Rubicon River	16.3	0.25
Pilot Creek	3.4	0.11
South Fork Rubicon River	1.1	0.02
Upper Rubicon River	0.2	<0.01
North Fork Middle Fork American		
Lower North Fork Middle Fork American	31.3	0.58
Upper North Fork Middle Fork American	32.1	0.84
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	23.7	0.52
Middle Fork American River-Todd Creek	17.1	0.33
Upper North Fork American River		
Headwaters North Fork American River	1.8	0.03
North Fork American River-Granite Creek	1.8	0.04
North Fork American River-Indian Creek	14.5	0.25
North Fork American River-Mumford Bar	6.5	0.18
North Fork of North Fork American River	15.4	0.28
Lower North Fork American River		
North Folsom Reservoir	2.2	0.20
North Fork American River-Clipper Creek	14.7	0.35
Shirttail Canyon	8.3	0.15

Table 4-4. Areas with Mehrten/Valley Springs Formations by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Area (acres)	Extent (%)
Upper Middle Fork American River		
Headwaters Middle Fork American River	18,517	49.4
Middle Fork American River-Duncan Canyon	14,065	42.1
Rubicon River		
Five Lakes Creek	12,197	28.8
Long Canyon Creek	20,627	65.8
Lower Rubicon River	12,787	30.5
Pilot Creek	8,453	43.7
South Fork Rubicon River	1,014	2.8
Upper Rubicon River	317	1.0
North Fork Middle Fork American		
Lower North Fork Middle Fork American	10,594	30.5
Upper North Fork Middle Fork American	4,225	17.3
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	7,262	24.8
Middle Fork American River-Todd Creek	2,681	8.2
Upper North Fork American River		
Headwaters North Fork American River	12,729	36.8
North Fork American River-Granite Creek	5,941	18.2
North Fork American River-Indian Creek	9,802	26.7
North Fork American River-Mumford Bar	5,604	24.0
North Fork of North Fork American River	5,605	16.0
Lower North Fork American River		
North Folsom Reservoir	<1	<0.1
North Fork American River-Clipper Creek	1,478	5.5
Shirttail Canyon	16,221	46.3

A small proportion of the 6th-level HUC subwatersheds (less than 0.5 percent) contain Mehrten or Valley Springs formations on slopes greater than 50 percent. The Five Lakes and Long Canyon Creeks have the largest portion with 0.4 percent each (Table 4-5). Road densities on these steep, mass wasting-prone formations are also relatively low throughout the North Fork/Middle Fork American River watershed. The highest density is 0.15 mile of road or trail on Mehrten or Valley Springs formation with greater than 50 percent slope per square mile of watershed, which occurs in the Lower North Fork Middle Fork American subwatershed (Table 4-6). Five subwatersheds have road densities less than 0.01 mile per square mile on these steep, mass wasting-prone areas; these include the South Fork Rubicon River, Upper Rubicon River, Middle Fork American River-Todd Creek, North Folsom Reservoir, and North Fork American River-Clipper Creek subwatersheds.

Table 4-5. Areas of Mehrten/Valley Springs Formations on Steep Slopes (>50 percent) by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Area (acres)	Extent (%)
Upper Middle Fork American River		
Headwaters Middle Fork American River	1,937	0.3
Middle Fork American River-Duncan Canyon	1,178	0.2
Rubicon River		
Five Lakes Creek	2,431	0.4
Long Canyon Creek	2,574	0.4
Lower Rubicon River	1,265	0.2
Pilot Creek	112	<0.1
South Fork Rubicon River	41	<0.1
Upper Rubicon River	17	<0.1
North Fork Middle Fork American		
Lower North Fork Middle Fork American	1,149	0.2
Upper North Fork Middle Fork American	115	<0.1
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	415	0.1
Middle Fork American River-Todd Creek	16	<0.1
Upper North Fork American River		
Headwaters North Fork American River	2,025	0.3
North Fork American River-Granite Creek	1,053	0.2
North Fork American River-Indian Creek	803	0.1
North Fork American River-Mumford Bar	678	0.1
North Fork of North Fork American River	393	0.1
Lower North Fork American River		
North Folsom Reservoir	<1	<0.1
North Fork American River-Clipper Creek	7	<0.1
Shirttail Canyon	338	0.1

Table 4-6. Roads and Trails on Areas of Mehrten/Valley Springs Formations with Steep Slopes (>50 percent) by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Length (miles)	Density (mi/mi^2)
Upper Middle Fork American River		
Headwaters Middle Fork American River	3.5	0.06
Middle Fork American River-Duncan Canyon	4.7	0.09
Rubicon River		
Five Lakes Creek	2.5	0.04
Long Canyon Creek	6.6	0.13
Lower Rubicon River	5.2	0.08
Pilot Creek	0.7	0.02
South Fork Rubicon River	0.2	<0.01
Upper Rubicon River	<0.1	<0.01
North Fork Middle Fork American		
Lower North Fork Middle Fork American	8.3	0.15
Upper North Fork Middle Fork American	1.0	0.03
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	3.0	0.07
Middle Fork American River-Todd Creek	0.1	<0.01
Upper North Fork American River		
Headwaters North Fork American River	3.1	0.06
North Fork American River-Granite Creek	1.2	0.02
North Fork American River-Indian Creek	5.2	0.09
North Fork American River-Mumford Bar	3.1	0.08
North Fork of North Fork American River	2.3	0.04
Lower North Fork American River		
North Folsom Reservoir	<0.1	<0.01
North Fork American River-Clipper Creek	0.1	<0.01
Shirttail Canyon	2.1	0.04

Based on the USDA Forest Service geomorphology GIS data layer, mass wasting risk categories were evaluated by 6th-level HUC subwatersheds on National Forest System lands in the North Fork/Middle Fork American River watershed. The distribution of all mass wasting risk categories is shown in Table 4-7. The Lower North Fork Middle Fork American subwatershed contains the greatest extent (22.9 percent) under active mass wasting. The next-highest extents of active mass wasting are found in the Headwaters North Fork American River (19.2 percent), the Lower Rubicon River (17.2 percent), and the Upper Rubicon River (17.1 percent). Subwatersheds that contain portions outside National Forest System lands are indicated by total percentages less than 100 in Table 4-7. For example, at the lowest end, the North Folsom Reservoir subwatershed has no acres in any mass wasting risk category because none of the subwatershed occurs on National Forest System lands.

Table 4-7. Mass Wasting Risk by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Active Mass Wasting [1]		Moderate Mass Wasting		Low Mass Wasting		Meadows and Colluvial Apron		Other		Total [2]	
	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)
Upper Middle Fork American River												
Headwaters Middle Fork American River	5,048	13.5	8,556	22.8	7,297	19.5	7,748	20.7	8,811	23.5	37,459	100.0
Middle Fork American River-Duncan Canyon	4,500	13.5	9,389	28.1	8,924	26.7	849	2.5	9,769	29.2	33,430	100.0
Rubicon River												
Five Lakes Creek	6,050	14.3	12,476	29.5	8,936	21.1	7,305	17.3	7,541	17.8	42,307	100.0
Long Canyon Creek	3,238	10.3	5,093	16.2	8,218	26.2	2,354	7.5	12,462	39.7	31,366	100.0
Lower Rubicon River	7,203	17.2	9,923	23.6	12,061	28.7	270	0.6	12,515	29.8	41,972	100.0
Pilot Creek	961	5.0	1,154	6.0	2,657	13.7	1,326	6.9	13,258	68.5	19,356	100.0
South Fork Rubicon River	2,330	6.4	2,892	7.9	3,525	9.7	11,472	31.4	16,261	44.6	36,480	100.0
Upper Rubicon River	5,197	17.1	3,473	11.4	3,080	10.2	4,876	16.1	13,630	44.9	30,255	99.7
North Fork Middle Fork American												
Lower North Fork Middle Fork American	7,961	22.9	1,762	5.1	9,978	28.7	<1	<0.1	15,054	43.3	34,754	100.0
Upper North Fork Middle Fork American	3,906	16.0	468	1.9	3,795	15.5	106	0.4	16,161	66.1	24,436	100.0
Lower Middle Fork American River												
Middle Fork American River-Bottle Hill	3,597	12.3	2,164	7.4	6,609	22.6	87	0.3	11,880	40.6	24,337	83.3
Middle Fork American River-Todd Creek	112	0.3	<1	<0.1	715	2.2	644	2.0	1,793	5.5	3,264	9.9
Upper North Fork American River												
Headwaters North Fork American River	6,644	19.2	2,446	7.1	9,479	27.4	5,882	17.0	10,168	29.4	34,618	100.0
North Fork American River-Granite Creek	5,441	16.7	4,212	12.9	9,243	28.3	2,615	8.0	11,141	34.1	32,653	100.0
North Fork American River-Indian Creek	3,211	8.7	<1	<0.1	1,564	4.3	424	1.2	4,833	13.2	10,031	27.3
North Fork American River-Mumford Bar	3,917	16.8	8,149	34.9	7,108	30.5	636	2.7	3,521	15.1	23,330	100.0
North Fork of North Fork American River	2,919	8.3	1,354	3.9	5,190	14.8	4,569	13.1	20,955	59.9	34,987	100.0
Lower North Fork American River												
North Folsom Reservoir	<1	<0.1	<1	<0.1	<1	<0.1	<1	<0.1	<1	<0.1	<1	<0.1
North Fork American River-Clipper Creek	<1	<0.1	<1	<0.1	<1	<0.1	<1	<0.1	132	0.5	132	0.5
Shirttail Canyon	461	1.3	62	0.2	368	1.1	2,388	6.8	15,028	42.9	18,307	52.3

[1] Mass wasting risk was mapped (along with geomorphology) only on National Forest System lands. Mapping focused on landforms and not on the absence or presence of Mehrten and Valley Springs formations. (For more information, refer to Section 3.5.) As a result, some areas (e.g., the Headwaters Long Canyon Creek 7th-level HUC subwatershed, part of the Long Canyon Creek 6th-level HUC subwatershed) with localized mass wasting related to the Mehrten and Valley Springs formations are not rated with high mass wasting risk values in this table.

[2] Mass wasting risk was mapped only on National Forest System lands. Totals less than 100 percent represent 6th-level HUC subwatersheds with part or all of their areas outside of USDA Forest Service administration.

The density of roads and trails on areas mapped as active mass wasting risk peak at 0.40 mile per square mile in the Lower Rubicon River subwatershed (Table 4-8). Other densities that exceeded 0.20 mile per square mile occurred in the Headwaters Middle Fork American River (0.34 mile per square mile), the Lower North Fork American River (0.33 mile per square mile), the Middle Fork American River-Duncan Canyon (0.22 mile per square mile), and the Middle Fork American River-Todd Creek (0.21 mile per square mile) subwatersheds.

Table 4-8. Roads and Trails on Areas with Active Mass Wasting Risk by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Length (miles)	Density (mi/mi^2)
Upper Middle Fork American River		
Headwaters Middle Fork American River	19.9	0.34
Middle Fork American River-Duncan Canyon	11.4	0.22
Rubicon River		
Five Lakes Creek	9.2	0.14
Long Canyon Creek	5.5	0.11
Lower Rubicon River	26.4	0.40
Pilot Creek	3.4	0.11
South Fork Rubicon River	3.9	0.07
Upper Rubicon River	5.3	0.11
North Fork Middle Fork American		
Lower North Fork Middle Fork American	17.7	0.33
Upper North Fork Middle Fork American	4.4	0.12
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	9.5	0.21
Middle Fork American River-Todd Creek	0.2	<0.01
Upper North Fork American River		
Headwaters North Fork American River	7.2	0.13
North Fork American River-Granite Creek	6.2	0.12
North Fork American River-Indian Creek	6.1	0.11
North Fork American River-Mumford Bar	6.3	0.17
North Fork of North Fork American River	6.8	0.12
Lower North Fork American River		
North Folsom Reservoir	<0.1	<0.01
North Fork American River-Clipper Creek	<0.1	<0.01
Shirttail Canyon	<0.1	<0.01

4.3.2 Road-Stream Interaction Hazards

Several road-stream interactions were evaluated using the available GIS data layers. These address the importance of roads as contributors and conveyors of sediment to streams. The first watershed indicator presents overall road density by 6th-level HUC subwatersheds (Table 4-9). The highest total combined road and trail densities occur in the North Folsom Reservoir (5.64 miles per square mile), Shirttail Canyon (5.37 miles per square mile), and North Fork American River-Indian Creek subwatersheds (5.19 miles per square mile). The lowest overall density, 1.36 miles per square mile, occurs in the North Fork American River-Granite Creek subwatershed.

Table 4-9. Roads (by Surface Types) and Trails by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Paved		Gravel		Native		Trail		Total	
	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)	Length (miles)	Density (mi/mi²)
Upper Middle Fork American River										
Headwaters Middle Fork American River	15.0	0.26	11.0	0.19	138.3	2.36	30.2	0.52	194.5	3.32
Middle Fork American River-Duncan Canyon	22.2	0.42	10.5	0.20	116.8	2.24	19.1	0.36	168.6	3.23
Rubicon River										
Five Lakes Creek	2.5	0.04	<0.1	<0.01	52.1	0.79	58.3	0.88	113.0	1.71
Long Canyon Creek	40.3	0.82	<0.1	<0.01	134.1	2.74	21.6	0.44	196.1	4.00
Lower Rubicon River	26.1	0.40	<0.1	<0.01	177.4	2.70	39.0	0.60	242.6	3.70
Pilot Creek	13.6	0.45	<0.1	<0.01	101.1	3.34	2.6	0.08	117.3	3.88
South Fork Rubicon River	34.4	0.60	1.0	0.02	154.6	2.71	32.4	0.57	222.4	3.90
Upper Rubicon River	<0.1	<0.01	<0.1	<0.01	22.7	0.48	55.7	1.18	78.4	1.65
North Fork Middle Fork American										
Lower North Fork Middle Fork American	26.2	0.48	26.1	0.48	133.5	2.46	41.3	0.76	227.1	4.18
Upper North Fork Middle Fork American	14.9	0.39	10.0	0.26	145.7	3.82	4.7	0.12	175.2	4.59
Lower Middle Fork American River										
Middle Fork American River-Bottle Hill	36.6	0.80	0.6	0.01	150.6	3.30	34.9	0.76	222.7	4.88
Middle Fork American River-Todd Creek	101.5	1.98	7.1	0.14	122.0	2.38	8.3	0.16	238.9	4.66
Upper North Fork American River										
Headwaters North Fork American River	22.5	0.42	<0.1	<0.01	52.4	0.97	21.8	0.40	96.7	1.79
North Fork American River-Granite Creek	1.0	0.02	<0.1	<0.01	36.4	0.71	32.2	0.63	69.6	1.36
North Fork American River-Indian Creek	95.5	1.67	3.1	0.05	167.4	2.92	31.6	0.55	297.6	5.19
North Fork American River-Mumford Bar	1.8	0.05	0	0	47.5	1.30	25.9	0.71	75.2	2.06
North Fork of North Fork American River	38.4	0.70	<0.1	<0.01	159.6	2.92	24.2	0.44	222.1	4.06
Lower North Fork American River										
North Folsom Reservoir	34.5	3.13	<0.1	<0.01	27.7	2.51	<0.1	<0.01	62.2	5.64
North Fork American River-Clipper Creek	90.5	2.16	10.6	0.25	93.6	2.23	<0.1	<0.01	194.7	4.64
Shirttail Canyon	39.1	0.71	11.7	0.21	195.6	3.58	47.5	0.87	293.8	5.37

Many studies link overall road density with sediment levels, but Schiess and others (2000) suggest that road density alone is a poor measure of road-related sediment production and delivery to the stream network. They find that a program of road density reduction tends to eliminate road sections with the least sediment impact and can even inhibit road realignments that would actually reduce sediment delivery. Increasing the distance between roads and streams can be a more effective means of reducing sediment delivery, even though it may require increasing road density (Schiess and others 2000). To address the proximity of roads to streams in the North Fork/Middle Fork American River watershed, several other watershed indicators were developed.

Stream buffers are a commonly used BMP designed to reduce the potential impacts of roads on sedimentation. For example, on National Forest System lands riparian conservation areas (RCAs) are delineated as 300 feet on either side of perennial streams and specific aquatic features and 150 feet on either side of seasonally flowing streams in the Sierra Nevada (USDA Forest Service 2004a). While some amount of sediment is produced on most forest roads, the sediment delivery to a stream is a function of the distance to the stream (Schiess and others 2000). To address the potential impacts of roads and trails near streams, the density of roads and trails within 100 meters of streams in the North Fork/Middle Fork American River watershed was considered (Table 4-10). Densities for the 6th-level HUC subwatersheds range from 0.82 mile per square mile in the Five Lakes Creek to 3.25 miles per square mile in the Middle Fork American River-Bottle Hill. Road and trail densities within 100 meters of streams also exceed 3 miles per square mile in two other 6th-level HUC subwatersheds: the Upper and Lower North Fork Middle Fork American with 3.03 and 3.02 miles per square mile, respectively. It should be noted that these data include contour-crenulated ephemeral streams, which were only mapped on National Forest System lands. As a result, stream densities and subsequently road-stream interactions are generally greater in subwatersheds managed by the USDA Forest Service than in subwatersheds outside these areas, where ephemeral streams were not mapped.

Known fish-bearing streams are described in Section 3.9. The proximity of roads and trails to these potential aquatic resources at risk is another watershed indicator evaluated in this study. The highest density of roads and trails within 100 meters of known fish-bearing streams is 0.55 mile per square mile in the North Folsom Reservoir subwatershed (Table 4-11). The lowest is 0.05 mile per square mile just upstream in the Shirttail Canyon subwatershed. Other 6th-level HUC subwatersheds with relatively high densities include the Long Canyon Creek (0.53 mile per square mile), North Fork American River-Indian Creek (0.36 mile per square mile), South Fork Rubicon River (0.32 mile per square mile), and the Middle Fork American River-Todd Creek (0.31 mile per square mile). In many of these subwatersheds, the existing roads parallel known fish-bearing streams. The overall road density, however, may not be high, as in the Long Canyon Creek subwatershed.

Unpaved roads (i.e., gravel and native surface) have an even greater potential for contributing sediment to streams than paved roads or trails. Considering the density of these roads on areas with high erosion hazard ratings within 100 meters of streams narrows the focus even more for potential erosion sources and potential sediment

Table 4-10. Roads and Trails within 100 Meters of Streams [1] by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Length (miles)	Density (mi/mi^2)
Upper Middle Fork American River		
Headwaters Middle Fork American River	104.7	1.79
Middle Fork American River-Duncan Canyon	104.8	2.01
Rubicon River		
Five Lakes Creek	54.4	0.82
Long Canyon Creek	106.8	2.18
Lower Rubicon River	129.2	1.97
Pilot Creek	72.4	2.39
South Fork Rubicon River	119.6	2.10
Upper Rubicon River	45.5	0.96
North Fork Middle Fork American		
Lower North Fork Middle Fork American	164.0	3.02
Upper North Fork Middle Fork American	115.7	3.03
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	148.5	3.25
Middle Fork American River-Todd Creek	107.9	2.10
Upper North Fork American River		
Headwaters North Fork American River	51.7	0.96
North Fork American River-Granite Creek	43.9	0.86
North Fork American River-Indian Creek	95.6	1.67
North Fork American River-Mumford Bar	52.2	1.43
North Fork of North Fork American River	130.2	2.38
Lower North Fork American River		
North Folsom Reservoir	9.3	0.84
North Fork American River-Clipper Creek	53.4	1.27
Shirttail Canyon	123.4	2.26

[1] Streams include contour-crenulated ephemeral streams mapped for National Forest System lands.

Table 4-11. Roads and Trails within 100 Meters of Known Fish-Bearing Streams by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Length (miles)	Density (mi/mi^2)
Upper Middle Fork American River		
Headwaters Middle Fork American River	14.0	0.24
Middle Fork American River-Duncan Canyon	7.8	0.15
Rubicon River		
Five Lakes Creek	11.0	0.17
Long Canyon Creek	25.7	0.53
Lower Rubicon River	9.7	0.15
Pilot Creek	2.8	0.09
South Fork Rubicon River	18.3	0.32
Upper Rubicon River	7.3	0.15
North Fork Middle Fork American		
Lower North Fork Middle Fork American	5.6	0.10
Upper North Fork Middle Fork American	4.8	0.13
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	12.5	0.27
Middle Fork American River-Todd Creek	15.8	0.31
Upper North Fork American River		
Headwaters North Fork American River	7.8	0.14
North Fork American River-Granite Creek	8.7	0.17
North Fork American River-Indian Creek	20.9	0.36
North Fork American River-Mumford Bar	6.9	0.19
North Fork of North Fork American River	15.5	0.28
Lower North Fork American River		
North Folsom Reservoir	6.1	0.55
North Fork American River-Clipper Creek	4.6	0.11
Shirttail Canyon	2.5	0.05

delivery locations. The density of unpaved roads in these areas ranges from less than 0.01 (Upper Rubicon River subwatershed) to 0.66 (Upper North Fork Middle Fork American subwatershed) mile per square mile in the North Fork/Middle Fork American River watershed (Table 4-12). Other 6th-level HUC subwatersheds with relatively high densities include the Lower North Fork Middle Fork American (0.48 mile per square mile), the Middle Fork American River-Bottle Hill (0.42 mile per square mile), and the Middle Fork American River-Duncan Canyon (0.39 mile per square mile). Again, the densities of these potentially high-risk roads on subwatersheds within National Forest System lands are generally greater than densities on other subwatersheds because they include contour-crenulated ephemeral streams.

Table 4-12. Unpaved Roads within 100 Meters of Streams on Areas with High Erosion Hazard Ratings by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC [1]	Extent of Subwatershed on NFS Lands (%)	Length (miles)	Density (mi/mi²)
Upper Middle Fork American River	100		
Headwaters Middle Fork American River	100	5.4	0.09
Middle Fork American River-Duncan Canyon	100	20.5	0.39
Rubicon River	100		
Five Lakes Creek	100	1	0.01
Long Canyon Creek	100	7.1	0.14
Lower Rubicon River	100	11.7	0.18
Pilot Creek	100	3	0.1
South Fork Rubicon River	100	0.7	0.01
Upper Rubicon River	100	0.2	<0.01
North Fork Middle Fork American	98		
Lower North Fork Middle Fork American	97	25.8	0.48
Upper North Fork Middle Fork American	100	25.4	0.66
Lower Middle Fork American River	40		
Middle Fork American River-Bottle Hill	74	19.4	0.42
Middle Fork American River-Todd Creek	10	11.7	0.23
Upper North Fork American River	77		
Headwaters North Fork American River	100	0.9	0.02
North Fork American River-Granite Creek	100	1.1	0.02
North Fork American River-Indian Creek	12	6.5	0.11
North Fork American River-Mumford Bar	100	4.7	0.13
North Fork of North Fork American River	86	9.8	0.18
Lower North Fork American River	23		
North Folsom Reservoir	0	0.5	0.04
North Fork American River-Clipper Creek	0	6.3	0.15
Shirttail Canyon	45	4.9	0.09

[1] Streams include contour-crenulated ephemeral streams mapped for National Forest System lands. The extent of each 5th-level and 6th-level HUC subwatershed on National Forest System lands (with contour-crenulated ephemeral stream mapping) is shown in the above table. Comparing subwatersheds with less than 100 percent coverage of contour-crenulated ephemeral streams could result in misinterpretations. For example, lower densities may indicate lack of contour-crenulated ephemeral streams. Refer to Section 3.7 for the average and range in the ratio of drainage densities with and without contour-crenulated ephemeral streams.

Similarly, focusing on unpaved roads on areas with high erosion hazard ratings within 100 meters of known fish-bearing streams provides an assessment of the relative risk of sedimentation to aquatic resources. The highest density occurs in both the Middle Fork American River-Todd Creek and North Folsom Reservoir (0.09 mile per square mile) subwatersheds, followed by the Middle Fork American River-Duncan Canyon (0.07 mile per square mile) (Table 4-13).

Table 4-13. Unpaved Roads within 100 Meters of Known Fish-Bearing Streams on Areas with High Erosion Hazard Ratings by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Length (miles)	Density (mi/mi^2)
Upper Middle Fork American River		
Headwaters Middle Fork American River	0.7	0.01
Middle Fork American River-Duncan Canyon	3.6	0.07
Rubicon River		
Five Lakes Creek	0.1	<0.01
Long Canyon Creek	1.8	0.04
Lower Rubicon River	1.2	0.02
Pilot Creek	0.4	0.01
South Fork Rubicon River	0.1	<0.01
North Fork Middle Fork American		
Lower North Fork Middle Fork American	0.4	0.01
Upper North Fork Middle Fork American	0.9	0.02
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	2.5	0.05
Middle Fork American River-Todd Creek	4.4	0.09
Upper North Fork American River		
Headwaters North Fork American River	<0.1	<0.01
North Fork American River-Granite Creek	0.1	<0.01
North Fork American River-Indian Creek	0.9	0.01
North Fork American River-Mumford Bar	0.2	<0.01
North Fork of North Fork American River	1.0	0.02
Lower North Fork American River		
North Folsom Reservoir	0.9	0.09
North Fork American River-Clipper Creek	2.2	0.05
Shirttail Canyon	<0.1	<0.01

Road-stream crossings provide a particularly high potential for sediment delivery. MacDonald and Coe (2005) found that road-stream crossings accounted for about 60 percent of road segments that were connected to the stream network in the Eldorado National Forest. Table 4-14 presents intersections mapped in GIS by overlaying the roads and streams layers. As noted in other watershed indicators, the stream data include contour-crenulated ephemeral streams mapped only on National Forest System lands. As a result, more road-stream intersections are mapped on lands managed by the USDA Forest Service than on other lands. The 6th-level HUC subwatersheds with over 10 road-stream intersections per square mile include the Middle Fork American River-Bottle Hill (14.39 intersections per square mile), Upper and Lower North Fork Middle Fork American (11.60 and 12.82 intersections per square mile, respectively), Pilot Creek (10.51 intersections per square mile), and South Fork Rubicon River (10.26 intersections per square mile). The fewest intersections per square mile (1.36) are mapped in the North Folsom Reservoir subwatershed, where contour-crenulated ephemeral streams were not mapped.

Table 4-14. Intersections of Roads (by Surface Types) or Trails with Streams [1] by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Paved Road-Stream Intersections		Gravel Road-Stream Intersections		Native Road-Stream Intersections		Trail-Stream Intersections		Total	
	Number	Density (#/mi²)	Number	Density (#/mi²)	Number	Density (#/mi²)	Number	Density (#/mi²)	Number	Density (#/mi²)
Upper Middle Fork American River										
Headwaters Middle Fork American River	43	0.73	23	0.39	411	7.02	85	1.45	562	9.60
Middle Fork American River-Duncan Canyon	61	1.17	36	0.69	337	6.45	47	0.90	481	9.21
Rubicon River										
Five Lakes Creek	6	0.09	0	0	104	1.57	136	2.06	246	3.72
Long Canyon Creek	132	2.69	0	0	281	5.73	40	0.82	453	9.24
Lower Rubicon River	60	0.91	0	0	385	5.87	125	1.91	570	8.69
Pilot Creek	19	0.63	0	0	291	9.62	8	0.26	318	10.51
South Fork Rubicon River	75	1.32	4	0.07	406	7.12	100	1.75	585	10.26
Upper Rubicon River	0	0	0	0	59	1.24	183	3.86	242	5.11
North Fork Middle Fork American										
Lower North Fork Middle Fork American	67	1.23	105	1.93	377	6.94	147	2.71	696	12.82
Upper North Fork Middle Fork American	34	0.89	39	1.02	348	9.11	22	0.58	443	11.60
Lower Middle Fork American River										
Middle Fork American River-Bottle Hill	73	1.60	2	0.04	473	10.36	109	2.39	657	14.39
Middle Fork American River-Todd Creek	105	2.05	18	0.35	280	5.46	25	0.49	428	8.34
Upper North Fork American River										
Headwaters North Fork American River	44	0.81	0	0	143	2.64	81	1.50	268	4.95
North Fork American River-Granite Creek	0	0	0	0	97	1.90	100	1.96	197	3.86
North Fork American River-Indian Creek	63	1.10	1	0.02	129	2.25	27	0.47	220	3.84
North Fork American River-Mumford Bar	0	0	0	0	130	3.57	93	2.55	223	6.12
North Fork of North Fork American River	66	1.21	0	0	385	7.04	71	1.30	522	9.55
Lower North Fork American River										
North Folsom Reservoir	9	0.82	0	0	6	0.54	0	0	15	1.36
North Fork American River-Clipper Creek	50	1.19	13	0.31	58	1.38	0	0	121	2.89
Shirttail Canyon	72	1.32	45	0.82	288	5.27	53	0.97	458	8.37

[1] Streams include contour-crenulated ephemeral streams mapped for National Forest System lands.

Road crossings on known fish-bearing streams provide potential opportunities for sediment delivery to aquatic resources at risk. The highest densities of intersections between roads and trails and known fish-bearing streams occur in the North Folsom Reservoir subwatershed, with 1.81 intersections per square mile (Table 4-15). The lowest density occurs in the Shirttail Canyon subwatershed, with 0.07 intersections per square mile.

Table 4-15. Intersections of Roads or Trails with Known Fish-Bearing Streams by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Number	Density (#/mi^2)
Upper Middle Fork American River		
Headwaters Middle Fork American River	28	0.48
Middle Fork American River-Duncan Canyon	27	0.52
Rubicon River		
Five Lakes Creek	18	0.27
Long Canyon Creek	34	0.69
Lower Rubicon River	12	0.18
Pilot Creek	9	0.30
South Fork Rubicon River	49	0.86
Upper Rubicon River	9	0.19
North Fork Middle Fork American		
Lower North Fork Middle Fork American	6	0.11
Upper North Fork Middle Fork American	8	0.21
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	28	0.61
Middle Fork American River-Todd Creek	28	0.55
Upper North Fork American River		
Headwaters North Fork American River	8	0.15
North Fork American River-Granite Creek	10	0.20
North Fork American River-Indian Creek	9	0.16
North Fork American River-Mumford Bar	4	0.11
North Fork of North Fork American River	26	0.48
Lower North Fork American River		
North Folsom Reservoir	20	1.81
North Fork American River-Clipper Creek	12	0.29
Shirttail Canyon	4	0.07

4.3.3 Stream Network and Hydrologic Hazards

The final series of watershed indicators relates to the potential for erosion based on runoff potential and precipitation regime, and the potential for sediment delivery based on stream proximity.

Drainage densities are presented separately using perennial and intermittent streams (Table 4-16) and using perennial and intermittent streams plus contour-crenulated ephemeral streams mapped on National Forest System lands (Table 4-17). Section 3.7 describes the average and range in the ratio of drainage densities with and without contour-crenulated ephemeral streams. We chose not to extrapolate these ratios to areas without contour-crenulated stream mapping because the geomorphology of the mapped areas (mid- to high-elevation and moderate- to high-relief subwatersheds predominantly on forested lands) is different from the unmapped lower areas (relatively low-elevation, low-relief subwatersheds on non-forested lands) within the North Fork/Middle Fork American River watershed. Subwatersheds with higher drainage densities generally have more conduits for delivering eroded sediments downstream than subwatersheds with lower drainage densities. In the latter, eroded soil may be redeposited more frequently on adjacent hillslopes or in swales instead of reaching the stream network.

Table 4-16. Drainage Densities by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (mapped Perennial and Intermittent Streams).

6th-level HUC Nested Under 5th-level HUC	Length (miles)	Density (mi/mi^2)
Upper Middle Fork American River		
Headwaters Middle Fork American River	100.4	1.71
Middle Fork American River-Duncan Canyon	103.0	1.97
Rubicon River		
Five Lakes Creek	98.7	1.49
Long Canyon Creek	72.9	1.49
Lower Rubicon River	97.3	1.48
Pilot Creek	54.1	1.79
South Fork Rubicon River	74.0	1.30
Upper Rubicon River	58.5	1.23
North Fork Middle Fork American		
Lower North Fork Middle Fork American	121.6	2.24
Upper North Fork Middle Fork American	81.4	2.13
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	110.5	2.42
Middle Fork American River-Todd Creek	100.7	1.96
Upper North Fork American River		
Headwaters North Fork American River	82.0	1.52
North Fork American River-Granite Creek	82.4	1.62
North Fork American River-Indian Creek	125.5	2.19
North Fork American River-Mumford Bar	59.1	1.62
North Fork of North Fork American River	107.0	1.96
Lower North Fork American River		
North Folsom Reservoir	15.7	1.42
North Fork American River-Clipper Creek	92.8	2.21
Shirttail Canyon	111.5	2.04

Table 4-17. Drainage Densities by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (mapped Perennial and Intermittent Streams, plus Contour-crenulated Ephemeral Streams on National Forest System lands).

6th-level HUC Nested Under 5th-level HUC	Length (miles)	Density (mi/mi²)
Upper Middle Fork American River		
Headwaters Middle Fork American River	302.3	5.16
Middle Fork American River-Duncan Canyon	331.0	6.34
Rubicon River		
Five Lakes Creek	297.1	4.49
Long Canyon Creek	246.9	5.04
Lower Rubicon River	352.9	5.38
Pilot Creek	178.1	5.89
South Fork Rubicon River	284.0	4.98
Upper Rubicon River	282.0	5.95
North Fork Middle Fork American		
Lower North Fork Middle Fork American	439.2	8.09
Upper North Fork Middle Fork American	274.9	7.20
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	361.7	7.92
Middle Fork American River-Todd Creek	211.3	4.12
Upper North Fork American River		
Headwaters North Fork American River	324.1	5.99
North Fork American River-Granite Creek	343.4	6.73
North Fork American River-Indian Creek	203.9	3.56
North Fork American River-Mumford Bar	285.8	7.84
North Fork of North Fork American River	318.8	5.83
Lower North Fork American River		
North Folsom Reservoir	15.7	1.42
North Fork American River-Clipper Creek	92.8	2.21
Shirttail Canyon	208.6	3.81

Considering only perennial and intermittent streams, the highest drainage density (2.42 miles per square mile) occurs in the Middle Fork American River-Bottle Hill subwatershed. Other 6th-level HUC subwatersheds with drainage densities that exceed 2 miles per square mile include the Upper and Lower North Fork Middle Fork American River (2.13 and 2.24 miles per square mile, respectively), the North Fork American River-Clipper Creek (2.21 miles per square mile), the North Fork American River-Indian Creek (2.19 miles per square mile), and the Shirttail Canyon (2.04 miles per square mile). After adding the contour-crenulated ephemeral streams on National Forest System lands, drainage densities are calculated up to 8.09 and 7.20 miles per square mile (in the Upper and Lower North Fork Middle Fork American, respectively), 7.92 miles per square mile (in the Middle Fork American River-Bottle Creek), and 7.84 miles per square mile (in the North Fork American River-Mumford Bar).

Roads and trails in the rain-on-snow zone may be more susceptible to runoff conditions that result in surface erosion and sediment delivery to streams. The highest density of roads and trails in this zone (3.84 miles per square mile) occurs in the Pilot Creek subwatershed (Table 4-18). Other 6th-level HUC subwatersheds with densities greater than 3.5 miles per square mile include the Upper and Lower North Fork Middle Fork American (3.59 and 3.51 miles per square mile, respectively) and the Long Canyon Creek (3.53 miles per square mile).

Table 4-18. Roads and Trails on Rain-on-Snow Zones by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Length (miles)	Density (mi/mi²)
Upper Middle Fork American River		
Headwaters Middle Fork American River	126.8	2.17
Middle Fork American River-Duncan Canyon	147.4	2.82
Rubicon River		
Five Lakes Creek	27.6	0.42
Long Canyon Creek	173.1	3.53
Lower Rubicon River	210.8	3.21
Pilot Creek	116.2	3.84
South Fork Rubicon River	127.0	2.23
Upper Rubicon River	<0.1	<0.01
North Fork Middle Fork American		
Lower North Fork Middle Fork American	190.6	3.51
Upper North Fork Middle Fork American	137.3	3.59
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	51.1	1.12
Middle Fork American River-Todd Creek	<0.1	<0.01
Upper North Fork American River		
Headwaters North Fork American River	6.3	0.12
North Fork American River-Granite Creek	14.6	0.29
North Fork American River-Indian Creek	117.3	2.05
North Fork American River-Mumford Bar	51.8	1.42
North Fork of North Fork American River	190.1	3.48
Lower North Fork American River		
North Folsom Reservoir	<0.1	<0.01
North Fork American River-Clipper Creek	<0.1	<0.01
Shirttail Canyon	151.6	2.77

The combination of areas with high erosion hazard ratings in rain-on-snow zones also can be used to assess the relative susceptibility of subwatersheds to surface erosion processes. The 6th-level HUC subwatershed with the greatest extent in these areas is the Upper North Fork Middle Fork American, with 34.6 percent (Table 4-19). Other subwatersheds that include over 20 percent of high erosion hazard ratings in rain-on-snow zones include the North Fork American River-Mumford Bar and Granite Creek (31.1 and 21.1 percent, respectively) and the Lower North Fork Middle Fork American River (21.8 percent).

Table 4-19. Areas with High Erosion Hazard Ratings on Rain-on-Snow Zones by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Area (acres)	Extent (%)
Upper Middle Fork American River		
Headwaters Middle Fork American River	2,106	5.6
Middle Fork American River-Duncan Canyon	6,461	19.3
Rubicon River		
Five Lakes Creek	2,109	5.0
Long Canyon Creek	3,683	11.7
Lower Rubicon River	6,346	15.1
Pilot Creek	736	3.8
South Fork Rubicon River	904	2.5
Upper Rubicon River	1	<0.1
North Fork Middle Fork American		
Lower North Fork Middle Fork American	7,590	21.8
Upper North Fork Middle Fork American	8,452	34.6
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	290	1.0
Middle Fork American River-Todd Creek	<1	<0.1
Upper North Fork American River		
Headwaters North Fork American River	1,463	4.2
North Fork American River-Granite Creek	6,902	21.1
North Fork American River-Indian Creek	1,329	3.6
North Fork American River-Mumford Bar	7,266	31.1
North Fork of North Fork American River	5,974	17.1
Lower North Fork American River		
North Folsom Reservoir	<1	<0.1
North Fork American River-Clipper Creek	<1	<0.1
Shirttail Canyon	478	1.4

Similarly, the extent of subwatersheds in areas of high erosion hazard ratings and high precipitation intensity can provide a relative potential for erosion and sediment delivery. Two 6th-level HUC subwatersheds contain more than 15 percent in these areas: the North Fork American River-Granite Creek (18.8 percent) and the Upper North Fork Middle Fork American River (15.2 percent) (Table 4-20). Many subwatersheds are completely outside of these areas (Table 4-20).

Table 4-20. Areas of High Erosion Hazard Ratings [1] by Precipitation Intensity (PI) by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	High Erosion Hazard Rating											
	Low PI		Moderately Low PI		Moderate PI		Moderately High PI		High PI		Total	
	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)
Upper Middle Fork American River												
Headwaters Middle Fork American River	<1	<0.1	<1	<0.1	705	1.9	3,121	8.3	952	2.5	4,778	12.8
Middle Fork American River-Duncan Canyon	<1	<0.1	772	2.3	8,946	26.8	1,715	5.1	1,057	3.2	12,491	37.4
Rubicon River												
Five Lakes Creek	<1	<0.1	0	0	4,541	10.7	2,423	5.7	158	0.4	7,122	16.8
Long Canyon Creek	<1	<0.1	<1	<0.1	4,696	15.0	1,334	4.3	<1	<0.1	6,029	19.2
Lower Rubicon River	<1	<0.1	569	1.4	9,980	23.8	2,521	6.0	<1	<0.1	13,070	31.1
Pilot Creek	<1	<0.1	<1	<0.1	809	4.2	478	2.5	<1	<0.1	1,287	6.7
South Fork Rubicon River	<1	<0.1	<1	<0.1	159	0.4	1,753	4.8	<1	<0.1	1,912	5.2
Upper Rubicon River	<1	<0.1	<1	<0.1	1,302	4.3	990	3.3	<1	<0.1	2,292	7.6
North Fork Middle Fork American												
Lower North Fork Middle Fork American	<1	<0.1	871	2.5	11,980	34.5	2,526	7.3	<1	<0.1	15,377	44.2
Upper North Fork Middle Fork American	<1	<0.1	<1	<0.1	1,584	6.5	4,102	16.8	3,725	15.2	9,411	38.5
Lower Middle Fork American River												
Middle Fork American River-Bottle Hill	<1	<0.1	5,562	19.0	3,419	11.7	826	2.8	<1	<0.1	9,807	33.6
Middle Fork American River-Todd Creek	50	0.2	5,210	15.9	1,039	3.2	854	2.6	<1	<0.1	7,153	21.8
Upper North Fork American River												
Headwaters North Fork American River	<1	<0.1	4	<0.1	1,659	4.8	2,463	7.1	1,420	4.1	5,547	16.0
North Fork American River-Granite Creek	<1	<0.1	<1	<0.1	<1	<0.1	3,213	9.8	6,150	18.8	9,363	28.7
North Fork American River-Indian Creek	<1	<0.1	558	1.5	9,675	26.4	628	1.7	122	0.3	10,983	29.9
North Fork American River-Mumford Bar	<1	<0.1	<1	<0.1	6,146	26.3	5,330	22.8	438	1.9	11,915	51.1
North Fork of North Fork American River	<1	<0.1	<1	<0.1	2,503	7.2	3,414	9.8	2,786	8.0	8,702	24.9
Lower North Fork American River												
North Folsom Reservoir	728	10.3	20	0.3	<1	<0.1	<1	<0.1	<1	<0.1	748	10.6
North Fork American River-Clipper Creek	27	0.1	5,743	21.4	552	2.1	<1	<0.1	<1	<0.1	6,323	23.6
Shirttail Canyon	<1	<0.1	159	0.5	3,940	11.3	97	0.3	<1	<0.1	4,196	12.0

[1] Due to space limitations, only areas with high erosion hazard ratings are included. Areas of moderately high, moderate, moderately low, and low erosion hazard ratings are not shown here.

The precipitation sensitivity rating developed for this study is described in Section 4.2. Table 4-21 and Map 4-2 show the extents of each subwatershed in these relative hazard rating categories. In the Sierra Nevada, watershed sensitivity is generally highest in the rain-on-snow zone during high-intensity storms. The 6th-level HUC subwatersheds with the greatest extent of high precipitation sensitivity ratings are the Pilot Creek (79.1 percent), Upper North Fork Middle Fork American (70.9 percent), and North Fork of North Fork American River (70.7 percent). The Upper Rubicon River, Middle Fork American River-Todd Creek, North Folsom Reservoir, and North Fork American River-Clipper Creek subwatersheds all have less than 0.1 percent in the high precipitation sensitivity rating.

Subwatersheds with roads and trails on areas with high precipitation sensitivity ratings may be at relatively higher risk for surface erosion and mass wasting than other subwatersheds. The 6th-level HUC subwatersheds with the highest density of roads and trails on areas with high precipitation sensitivity ratings include Headwaters North Fork American River (1.48 miles per square mile), South Fork Rubicon River (1.45 miles per square mile), and Headwaters Middle Fork American River (1.12 miles per square mile). Seven subwatersheds have less than 0.1 mile of roads or trails in these areas (Table 4-22).

4.3.4 Assumptions and Limitations

The selected watershed indicators provide a quantitative means to compare the relative potential for erosion and sedimentation between subwatersheds in the North Fork/Middle Fork American River watershed. However, several subwatersheds are composite watersheds; they do not drain to a single point. For example, the Upper and Lower North Fork Middle Fork American subwatersheds form two parts of a single larger composite watershed. To retain a reasonable map unit size, CalWater separated these into two distinct subwatersheds at the 6th-level HUC. To aid in tracking how 6th-level HUC subwatersheds drain in the North Fork/Middle Fork American River watershed, data are presented throughout this section by 6th-level HUC subwatersheds nested together under the larger 5th-level HUC subwatersheds.

Contour-crenulated ephemeral streams (based on the USDA Forest Service streams GIS data layer) and mass wasting risks (based on the USDA Forest Service geomorphology GIS data layer) are mapped only on National Forest System lands. The data presented should be carefully interpreted to avoid introducing errors; only subwatersheds completely within National Forest System lands can be accurately compared using these data.

The watershed indicators present the best available spatial data for all or large portions of the North Fork/Middle Fork American River watershed. Data were carefully reviewed to ensure appropriate scales, extents, and quality (see Appendix B for details). Some caution should be exercised in interpreting data obtained from multiple sources. For example, roads were mapped separately on and off National Forest System lands. More accurate roads mapping in certain areas could lead to comparatively higher road densities. Field verification of digital data, including road-stream intersections or stream crossings, was not included in the scope of this study.

Table 4-21. Precipitation Sensitivity Ratings by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Map 4-2).

6th-level HUC Nested Under 5th-level HUC	High		Moderately High		Moderate		Moderately Low		Low		Total	
	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)	Area (acres)	Extent (%)
Upper Middle Fork American River												
Headwaters Middle Fork American River	15,860	42.3	1,433	3.8	19	0.1	20,147	53.8	<1	<0.1	37,459	100.0
Middle Fork American River-Duncan Canyon	8,055	24.1	12,270	36.7	6,154	18.4	6,952	20.8	<1	<0.1	33,430	100.0
Rubicon River												
Five Lakes Creek	93	0.2	9,582	22.6	<1	<0.1	32,566	77.0	72	0.2	42,312	100.0
Long Canyon Creek	13,337	42.5	12,969	41.3	2,555	8.1	2,505	8.0	<1	<0.1	31,366	100.0
Lower Rubicon River	8,471	20.2	22,090	52.6	8,758	20.9	2,653	6.3	<1	<0.1	41,972	100.0
Pilot Creek	15,301	79.1	2,760	14.3	1,170	6.0	124	0.6	<1	<0.1	19,356	100.0
South Fork Rubicon River	15,211	41.7	1,773	4.9	<1	<0.1	19,496	53.4	<1	<0.1	36,480	100.0
Upper Rubicon River	<1	<0.1	20	0.1	<1	<0.1	30,313	99.9	<1	<0.1	30,332	100.0
North Fork Middle Fork American												
Lower North Fork Middle Fork American	10,005	28.8	13,056	37.6	10,447	30.1	1,246	3.6	<1	<0.1	34,754	100.0
Upper North Fork Middle Fork American	17,328	70.9	2,114	8.7	275	1.1	4,719	19.3	<1	<0.1	24,436	100.0
Lower Middle Fork American River												
Middle Fork American River-Bottle Hill	707	2.4	3,292	11.3	13,083	44.8	12,144	41.6	<1	<0.1	29,226	100.0
Middle Fork American River-Todd Creek	<1	<0.1	<1	<0.1	14,109	43.0	18,181	55.4	551	1.7	32,841	100.0
Upper North Fork American River												
Headwaters North Fork American River	5,840	16.9	52	0.2	<1	<0.1	28,596	82.6	129	0.4	34,618	100.0
North Fork American River-Granite Creek	15,286	46.8	288	0.9	720	2.2	16,359	50.1	<1	<0.1	32,653	100.0
North Fork American River-Indian Creek	4,489	12.2	4,926	13.4	26,162	71.3	1,115	3.0	<1	<0.1	36,692	100.0
North Fork American River-Mumford Bar	10,329	44.3	4,664	20.0	7,125	30.5	1,212	5.2	<1	<0.1	23,330	100.0
North Fork of North Fork American River	24,742	70.7	2,222	6.4	2,750	7.9	5,273	15.1	<1	<0.1	34,987	100.0
Lower North Fork American River												
North Folsom Reservoir	<1	<0.1	<1	<0.1	<1	<0.1	2,888	40.9	4,177	59.1	7,065	100.0
North Fork American River-Clipper Creek	<1	<0.1	<1	<0.1	6,563	24.5	20,126	75.0	142	0.5	26,831	100.0
Shirttail Canyon	5,934	17.0	10,899	31.1	17,840	51.0	330	0.9	<1	<0.1	35,003	100.0

Table 4-22. Roads and Trails on Areas of High Precipitation Sensitivity Rating by 6th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed.

6th-level HUC Nested Under 5th-level HUC	Length (miles)	Density (mi/mi^2)
Upper Middle Fork American River		
Headwaters Middle Fork American River	65.4	1.12
Middle Fork American River-Duncan Canyon	10.2	0.20
Rubicon River		
Five Lakes Creek	52.9	0.80
Long Canyon Creek	17.6	0.36
Lower Rubicon River	7.6	0.12
Pilot Creek	0.9	0.03
South Fork Rubicon River	82.7	1.45
Upper Rubicon River	34.9	0.74
North Fork Middle Fork American		
Lower North Fork Middle Fork American	<0.1	<0.01
Upper North Fork Middle Fork American	38.0	0.99
Lower Middle Fork American River		
Middle Fork American River-Bottle Hill	<0.1	<0.01
Middle Fork American River-Todd Creek	<0.1	<0.01
Upper North Fork American River		
Headwaters North Fork American River	80.3	1.48
North Fork American River-Granite Creek	50.3	0.99
North Fork American River-Indian Creek	<0.1	<0.01
North Fork American River-Mumford Bar	7.7	0.21
North Fork of North Fork American River	29.2	0.53
Lower North Fork American River		
North Folsom Reservoir	<0.1	<0.01
North Fork American River-Clipper Creek	<0.1	<0.01
Shirttail Canyon	<0.1	<0.01

This report presents a coarse-filter analysis of potential erosion hazard and sedimentation risk. The study does not address the effects of land use or management activities. It is not a detailed, fieldwork-based analysis of hillslope erosion and stream channel sedimentation. By design, the coarse-filter analysis presented in this report can be used to prioritize additional, more focused studies. The analysis is not intended and is not sufficiently site-specific to serve as the basis for regulatory compliance.

4.4 Knowledge-based Modeling and Risk-based Prioritization

Watershed relative risk to erosion and sedimentation is characterized based on inherent physical conditions. The GIS-based watershed modeling and relative risk screening can facilitate multi-criteria decision making for strategic priority-setting. The combined approach of prioritization and targeting is emphasized for sediment-related water quality management in the North Fork/Middle Fork American River watershed.

4.4.1 Development of Submodels

Through extensive research, data review, and collaboration with the ARWG TAC, seven submodels were developed to address different potential watershed susceptibilities to erosion and sedimentation. These were integrated into one overall model that assesses the relative risk of sedimentation in subwatersheds across the North Fork/Middle Fork American River watershed. The seven submodels represent several potential hazards, including high-intensity rain-on-snow events, inherent susceptibility to surface erosion, inherent susceptibility to mass wasting, proximity to streams, proximity to source channel reaches, level of anthropogenic disturbance (represented by proximity to roads), and road-stream connectivity (Table 4-23). These submodels were designed to operate independently or be combined to produce an integrated priority ranking for 7th-level HUC subwatersheds. Similar approaches using submodels or "modules" have been applied in similar landscape/watershed assessments (e.g., Heller and others 2002; Burton and others 1999).

Relevant GIS data layers were analyzed and aggregated by individual 10-square-meter cells and eventually by subwatershed, regardless of ownership, across the entire North Fork/Middle Fork American River watershed. However, where finer resolution datasets were available (on National Forest System lands), a second parallel set of submodels was developed (Table 4-23). These finer-scaled data could not have been included for the entire watershed, because they were mapped only on National Forest System lands. To avoid losing the best available information, we developed the two parallel watershed prioritization models: one that included seven submodels based on the best available data that covered the entire North Fork/Middle Fork American River watershed, and one that included seven submodels based on the finer-scaled data, where available, on National Forest System lands. Because these separate prioritization models are based on different datasets, they should not be directly compared. Instead, the overall prioritization of a subwatershed within a model is relative to other subwatersheds within that model.

GIS Methods

Watersheds differ tremendously in their variability; soil types, slope steepness, drainage densities, and other basic characteristics are not homogenous within a watershed boundary. Simplifications or generalizations must be made at some level to reduce real-world situations to model capabilities. A raster-based GIS approach reasonably represents the variations within the watershed variables, and defines a scale at which these variables can be analyzed (Brady and others 2001; Curtis and others 2006). In the raster-based model created for the North Fork/Middle Fork American River watershed, geospatial data were divided along a grid into 10-square-meter cells, allowing for consistent best-resolution analysis within each subwatershed. The submodels were created using these rasterized geospatial datasets. For submodels that involved measures of density (e.g., road density, stream density), the density for each target cell was cumulated in the adjacent 1-kilometer square around that cell. This approach allowed us to evaluate 1 million adjacent square meters (or 10,000 cells) in computing the average density for each target cell. A similar raster-based approach was implemented for density and other calculations in the Tahoe National Forest Roads Analysis (Girvetz and Shilling 2003) and in other similar watershed assessments (e.g., Brady and others 2001).

Table 4-23. Series of Submodels to Prioritize the Relative Risk of Sedimentation by 7th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed. [1]

				Indices for Entire WAA			Indices for NFS Lands		
Indices	Submodels	Entire Watershed Assessment Area (WAA)	National Forest System (NFS) Lands	Hillslope Sensitivity Index (HSI)	Road Impact Index (RII)	Stream Sensitivity Index (SSI)	Hillslope Sensitivity Index (HSI)	Road Impact Index (RII)	Stream Sensitivity Index (SSI)
HSI	Precipitation Sensitivity Rating	√	√	√			√		
	Erosion Hazard Rating	√	√	√			√		
	Mass Wasting Hazard Rating (Mehrten/ Valley Springs and Slope Steepness)	√		√					
	Mass Wasting Risk[2]		√				√		
RII	Unpaved Road Density on Slopes >30%	√	√		√			√	
	Unpaved Roads within 100 meters of Streams	√			√				
	Unpaved Roads within 100 meters of Streams[3]		√					√	
SSI	Stream Density	√				√			
	Stream Density[3]		√						√
	Source Channel Reaches (>20% slope)	√				√			
	Source Channel Reaches (>20% slope)[3]		√						√

[1] This chapter presents both watershed indicators (listed in Table 4-1) and watershed submodels (listed here). Although they involve many of the same watershed characteristics, the methods used to calculate each differ. Watershed submodels, presented in this table, involve rating potential risks on a 10-square-meter, cell-by-cell basis. These fine-scaled results are aggregated through the steps described in this section to create the watershed prioritization model. Refer to Section 4.3 for descriptions of watershed indicators. The Subsection 4.4.4 synthesizes the results of both methods.

[2] Mass wasting risk was mapped as part of the geomorphology GIS data layer on National Forest System lands.

[3] Submodels include contour-crenulated ephemeral streams, which were mapped as part of the streams GIS data layer on National Forest System lands.

For each submodel, conditions were categorized into a scale in which a value of one indicates the lowest potential risk and five indicates the highest potential risk, relative to other subwatersheds in the North Fork/Middle Fork American River watershed. This approach is consistent with similar studies (e.g., Burton and others 1999; USDA Forest Service 2003a). The details of how this system of class breaks was applied to each submodel are presented in Appendix D. In general, class breaks were assigned based on natural breaks in the datasets (Jenks 1967), with limited professional judgment. To avoid introducing bias, we avoided weighting individual variables and relied instead on the statistical distributions of the datasets (e.g., the statistically calculated breaks in stream density values) or well-established thresholds (e.g., areas of Mehrten or Valley Springs have been correlated with mass wasting in the watershed).

We used the ModelBuilder tool developed by ESRI® to allow us flexibility in defining the class breaks for each submodel. The ModelBuilder interface provides a graphical modeling framework for designing and implementing geoprocessing models. Models are data flow diagrams that link together a series of tools and data to create advanced procedures and workflows. Using ModelBuilder, we were able to iteratively attempt several different statistical and professional judgment approaches to define class breaks, and to evaluate the results compared to published literature and our observations in the field, before selecting the final approach. The ModelBuilder interface also shows data histograms with class breaks to aid in visualizing the different approaches. Using ModelBuilder allowed us to present preliminary submodels to the ARWG TAC and to make adjustments based on their input without the need to recreate each step in each submodel. The ModelBuilder interface documents the final submodels, which provides transparency, allowed us to perform extensive quality checks, and permits GIS users to make adjustments and rerun the submodels in the future to incorporate updated information or newly acquired GIS data. Screenshots of the ModelBuilder interfaces are included in Appendix D.

4.4.2 Development of Thematic Indices

Overall, the seven submodels can be grouped into three types: those that relate to hillslope sensitivity, those that involve road impacts, and those that address stream sensitivity. The Eldorado National Forest Cumulative Off-Site Watershed Effects Analysis Process (USDA Forest Service 1998) involves creating a similar indexing (also based on multiplication of individual factors), called the Natural Sensitivity Index, to determine which areas may be more susceptible to erosion and sedimentation.

Hillslope Sensitivity Index

Briefly, the submodels developed for this study that relate to hillslope sensitivity include both the precipitation sensitivity and erosion hazard ratings described in Section 4.2, as well as mass wasting submodels. A mass wasting hazard rating was developed for the entire North Fork/Middle Fork American River watershed, based on the combination of Mehrten or Valley Springs formations and specific slope steepness categories. On National Forest System lands, the mass wasting risks mapped as part of the geomorphology GIS layer were converted into a submodel (Table 4-23). Again, refer to Appendix D for details on how each of the submodel ratings were developed, including, for example, the slope steepness breakdowns applied in the mass wasting hazard rating.

Road Impact Index

Submodels related to road impacts include unpaved road density on hillslopes greater than 30 percent and unpaved roads within 100 meters of streams. Unpaved roads include gravel and native surface, which have the highest risk of erosion and sedimentation. The 30 percent threshold for slope steepness was determined based on professional judgment in consultation with the ARWG TAC, supported by field observations. Two submodels were created to represent roads within 100 meters of streams—one that includes perennial and intermittent streams across the entire North Fork/Middle Fork American River watershed, and one that also includes contour-crenulated ephemeral streams on subwatersheds on National Forest System lands (Table 4-23). These submodels include roads that intersect streams and roads that parallel streams, both of which have greater sedimentation potential.

Stream Sensitivity Index

The submodels that address stream sensitivity include overall stream density and density of source channel reaches (i.e., stream segments with channel gradients greater than 0.2 or 20 percent). For both stream density and source channel reaches, separate submodels were developed for subwatersheds on and off National Forest System lands (Table 4-23). On National Forest System lands, contour-crenulated ephemeral streams were included, while off these lands, only perennial and intermittent streams were included. In subwatersheds with relatively high stream densities, the potential for eroded materials to reach a nearby stream is greater than in subwatersheds with lower stream densities. Source channels (described in Section 3.8) were included because they represent steeper headwater stream reaches with sufficient stream power to erode the channel bed and bank materials. These streams also act as receptor sites for colluvial material and debris flows.

Model Integration

For each overall prioritization model (i.e., for the entire watershed assessment area and for National Forest System lands only), the appropriate seven submodels were combined mathematically into three dimensionless, thematic indices: a hillslope sensitivity index, a road impact index, and a stream sensitivity index (Table 4-23). We multiplied together the individual scores (one through five) assigned for each submodel in each 10-square-meter cell in the North Fork/Middle Fork American River watershed.

Precipitation sensitivity rating, erosion hazard rating, and mass wasting hazard or mass wasting risk were combined for the hillslope sensitivity index. Unpaved road density on hillslopes greater than 30 percent and unpaved roads within 100 meters of streams (contour-crenulated and non-contour-crenulated) were combined for the road impact index. Stream density and source channel reach density (contour-crenulated and non-contour-crenulated) were combined for the stream sensitivity index. For example, to derive the hillslope sensitivity index score for a single cell, the precipitation sensitivity rating (one through five), erosion hazard rating (one through five), and mass wasting number—either the mass wasting hazard rating (one through five, if outside of National Forest System lands) or the mass wasting risk rating (one through five, if on National Forest System lands)—were multiplied together.

The mathematical products for the hillslope sensitivity index were reclassified using statistics into values of one (low potential risk) through three (high potential risk) based on natural breaks in the data (Jenks 1967). The same step also was performed for the road impact index, and for the stream sensitivity index. Each dimensionless, thematic index was evaluated visually using working maps that showed the index value (one through five) mapped to each 10-square-meter cell in the North Fork/Middle Fork American River watershed. Patterns in the relative risks associated with the hillslope sensitivity index, the road impact index, and the stream sensitivity index were evaluated and compared to field observations.

4.4.3 Development of Priority Ranking

The next step in the integrated watershed prioritization was to combine the values for the three separate thematic indices in each 10-square-meter cell in the North Fork/Middle Fork American River watershed. All possible combinations of these indices and the resulting priority categories are shown in Table 4-24. In general, areas with the highest potential risks were identified as the top priority for further analysis. Following this logic, the highest potential risk rating (i.e., index value of 3) leads to the lowest priority ranking (i.e., priority category 1).

Cells that had high values (index values of 3) for the hillslope sensitivity, road impact, and stream sensitivity indices were classified as priority category 1, indicating that these would be the top priority areas for watershed enhancement practices. Likewise, cells with two of the three indices rated high and the remaining index rated moderate (index value of 2) were considered as priority category 1. When a cell had only one index that rated high and the other two were moderate, the cell was classified as priority category 2, indicating that these would be in the second tier of areas for watershed enhancement practices. Similarly, cells with two indices rated as high and the remaining index rated as low (index value of 1) would fall into priority category 2, as would cells with moderate ratings for all three indices. Cells with all remaining combinations of indices were classified as priority category 3, indicating that these would be the lowest priority areas for watershed improvement activities, given limited financial resources.

As described above, up until the final step, the prioritization models retained the highest-resolution data possible. Priority categories were assigned to every 10-square-meter cell in the entire North Fork/Middle Fork American River watershed. However, the ultimate goal of the ranking process was to prioritize subwatersheds and target management or enhancement practices. The final step in the prioritization modeling process therefore involved aggregating the cell results for each 7th-level HUC subwatershed. Several approaches are available to aggregate rasterized data, and each was evaluated before selecting the best approach, a simple mean. Within each 7th-level HUC subwatershed, the priority categories (i.e., 1, 2, or 3) of all the 10-square-meter cells were averaged. Aggregating this way provided results consistent with field observations and input from the ARWG TAC, as well as a reasonable range in the number of subwatersheds that were assigned to each priority category.

Table 4-24. Thematic Index Ratings (1-3), Priority Scores (1-27), and Priority Categories (1, 2, or 3). [1]

Hillslope Sensitivity Index (HSI)	Road Impact Index (RII)	Stream Sensitivity Index (SSI)	Priority Score (HSI)*(RII)*(SSI)	Priority Category
3	3	3	27	1
3	3	2	18	1
2	3	3	18	1
3	2	3	18	1
2	3	2	12	2
3	2	2	12	2
2	2	3	12	2
3	3	1	9	2
1	3	3	9	2
3	1	3	9	2
2	2	2	8	2
2	3	1	6	3
1	3	2	6	3
3	2	1	6	3
1	2	3	6	3
3	1	2	6	3
2	1	3	6	3
2	2	1	4	3
1	2	2	4	3
2	1	2	4	3
1	3	1	3	3
3	1	1	3	3
1	1	3	3	3
1	2	1	2	3
2	1	1	2	3
1	1	2	2	3
1	1	1	1	3

[1] In general, areas with the highest potential risks were identified as the top priority for further analysis. Following this logic, higher potential risk ratings lead to lower priority category ranking.

Note: HIS = hillslope sensitivity index, RII = road impact index, SSI = stream sensitivity index.
Index Ratings for HSI, RII, and SSI: 3 = high potential risk, 2 = moderate potential risk, 1 = low potential risk.
Priority Categories: 1 = top priority, 2 = second-tier priority, 3 = lowest priority.

4.4.4 Results of Watershed Prioritization

The final prioritization model results for 7th-level HUC subwatersheds outside of National Forest System lands (with less than 75 percent on National Forest System lands) are presented in Map 4-3 and Table 4-25. The results for 7th-level HUC subwatersheds within National Forest System lands (with at least 75 percent on National Forest System lands) are presented in Map 4-4 and Table 4-26. The 7th-level HUC subwatersheds are nested under both the 6th-level and 5th-level HUC subwatersheds on the maps and tables. The results are grouped in this manner to facilitate scaled, adaptive decision making for focusing future actions. In other words, if several top-priority 7th-level HUC subwatersheds occur in a 6th-level HUC subwatershed, then a strategic program might consider further investigations of potential erosion and sedimentation throughout the entire 6th-level HUC subwatershed.

As stated throughout, this report presents a coarse-filter analysis of potential erosion hazard and sedimentation risk. By design, the analysis can be used to prioritize additional, more focused studies. It is not intended and is not sufficiently site-specific to serve as the basis for regulatory compliance. This watershed assessment does not address the effects of land use or management activities. It is not a detailed, fieldwork-based analysis of hillslope erosion and stream channel sedimentation. For example, localized erosion and sedimentation has been observed in the Headwaters Long Canyon Creek 7th-level HUC subwatershed. The watershed prioritization presented in this report takes into account broader subwatershed characteristics and does not incorporate site-specific erosion and sedimentation hazards. Based on those broad subwatershed characteristics, the overall priority category for the Headwaters Long Canyon Creek is 3, the lowest priority for future investigations. Based on the coarse-filter analysis, other subwatersheds appear to have greater potential risks of erosion and sedimentation than this subwatershed. If further field investigations of the site of localized erosion and sedimentation reveal that sediment is impacting key resources, the next steps in that area would involve appropriate watershed protection measures. However, further investigation could determine that the localized erosion and sedimentation is naturally occurring, in which case, improved management practices may not be warranted.

Compared to the watershed indicators and vulnerability assessment presented above in Section 4.3, the integrated watershed prioritization results reflect similar patterns. The 6th-level HUC subwatersheds that include at least one top-priority 7th-level HUC subwatershed are listed below.

- For the prioritization model covering non-National Forest System lands (see complete results in Table 4-25):
  - North Fork American River-Indian Creek
- For the prioritization model covering National Forest System lands (see complete results in Table 4-26):
  - Middle Fork American River-Duncan Canyon
  - Lower Rubicon River
  - Lower North Fork Middle Fork American
  - Upper North Fork Middle Fork American
  - North Fork American River-Mumford Bar

Each of these 6th-level HUC subwatersheds appeared more susceptible to the surface erosion and mass wasting, road-stream interaction, and stream network and hydrologic hazards presented in Section 4.3. The selection of the higher-priority 7th-level HUC subwatersheds within each of these 6th-level HUC subwatersheds is based on the inherent susceptibility of these areas to erosion and sedimentation processes, coupled with relatively dense road systems, many of which were likely created during mining, logging, and other historical land use activities.

Table 4-25. Priority Rankings for non-National Forest System Lands by 7th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Map 4-3).

5th-level Hydrologic Unit Name	6th-level Hydrologic Unit Name	7th-level Hydrologic Unit Name	7th-level HUC	HSI	RII	SSI	Priority Score (HSI)*(RII)*(SSI)	Priority Category
Upper Middle Fork American River								
	Headwaters Middle Fork American River							
		Headwaters Middle Fork American River	18020128010101	-	-	-	-	-
		Middle Fork American River-Talbot Creek	18020128010102	-	-	-	-	-
		Middle Fork American River-Rice Creek	18020128010103	-	-	-	-	-
		Middle Fork American River-Dolly Creek	18020128010104	-	-	-	-	-
		Middle Fork American River-French Meadows Reservoir	18020128010105	-	-	-	-	-
		Middle Fork American River-Chipmunk Creek	18020128010106	-	-	-	-	-
	Middle Fork American River-Duncan Canyon							
		Upper Duncan Canyon	18020128010201	-	-	-	-	-
		Lower Duncan Canyon	18020128010202	-	-	-	-	-
		Middle Fork American River-Big Mosquito Creek	18020128010203	-	-	-	-	-
		Middle Fork American River-Brushy Canyon	18020128010204	-	-	-	-	-
Rubicon River								
	Five Lakes Creek							
		Upper Five Lakes Creek	18020128020201	-	-	-	-	-
		Middle Five Lakes Creek	18020128020202	-	-	-	-	-
		Lower Five Lakes Creek	18020128020203	-	-	-	-	-
		Barker Creek	18020128020204	-	-	-	-	-
		Rubicon River-Little McKinstry Meadow	18020128020205	-	-	-	-	-
		Rubicon River-Upper Hell Hole	18020128020206	-	-	-	-	-
		Rubicon River-Hell Hole Reservoir	18020128020207	-	-	-	-	-
	Long Canyon Creek							
		Headwaters Long Canyon	18020128020501	-	-	-	-	-
		Middle Long Canyon	18020128020502	-	-	-	-	-
		Wallace Canyon	18020128020503	-	-	-	-	-
		Lower Long Canyon	18020128020504	-	-	-	-	-
	Lower Rubicon River							
		Lower Rubicon River-Parsley Bar	18020128020601	-	-	-	-	-
		Lower Rubicon River-Ellicott Bridge	18020128020602	-	-	-	-	-
		Lower Rubicon River-Vaughn Cabin	18020128020603	-	-	-	-	-
		Lower Rubicon River-Pigeon Roost Canyon	18020128020604	-	-	-	-	-
		Big Grizzly Canyon	18020128020605	-	-	-	-	-
		Lower Rubicon River	18020128020606	-	-	-	-	-
	Pilot Creek							
		Upper Pilot Creek	18020128020401	-	-	-	-	-
		Lower Pilot Creek	18020128020402	-	-	-	-	-
	South Fork Rubicon River							
		Loon Lake	18020128020301	-	-	-	-	-
		Upper Gerle Creek	18020128020302	-	-	-	-	-
		Lower Gerle Creek	18020128020303	-	-	-	-	-
		Upper South Fork Rubicon River	18020128020304	-	-	-	-	-
		Lower South Fork Rubicon River	18020128020305	-	-	-	-	-
	Upper Rubicon River							
		Upper Rubicon River-China Flat	18020128020101	-	-	-	-	-
		Upper Rubicon River-Phipps Creek	18020128020102	-	-	-	-	-
		Upper Rubicon River-Rubicon Reservoir	18020128020103	-	-	-	-	-
		Upper Rubicon River-Rockbound Lake	18020128020104	-	-	-	-	-
		Upper Rubicon River-Miller Creek	18020128020105	-	-	-	-	-
North Fork Middle Fork American								
	Lower North Fork Middle Fork American							
		North Fork Middle Fork American River-Bear Wallow	18020128030201	-	-	-	-	-
		Grouse Creek	18020128030202	-	-	-	-	-
		Peavine Creek	18020128030203	-	-	-	-	-
		East El Dorado Canyon	18020128030204	-	-	-	-	-
		West El Dorado Canyon	18020128030205	-	-	-	-	-
		North Fork Middle Fork American River-El Dorado Canyon	18020128030206	-	-	-	-	-
	Upper North Fork Middle Fork American							
		Screwauger Canyon	18020128030101	-	-	-	-	-
		Deep Creek	18020128030102	-	-	-	-	-
		Secret Canyon	18020128030103	-	-	-	-	-
		Upper North Fork Middle Fork American River	18020128030104	-	-	-	-	-
Lower Middle Fork American River								
	Middle Fork American River-Bottle Hill							
		Middle Fork American River-Horseshoe Bar	18020128040101	-	-	-	-	-
		Volcano Canyon-Middle Fork American River	18020128040102	2	3	1	6	3
		Otter Creek-Middle Fork American River	18020128040103	-	-	-	-	-
		Middle Fork American River-Snyder Creek	18020128040104	2	2	3	12	2
	Middle Fork American River-Todd Creek							
		Middle Fork American River-Todd Creek	18020128040201	1	2	2	4	3
		Canyon Creek-Middle Fork American River	18020128040202	1	3	1	3	3
		Middle Fork American River-Gas Canyon	18020128040203	1	2	2	4	3
		Middle Fork American River-Mammoth Bar	18020128040204	1	3	2	6	3
Upper North Fork American River								
	Headwaters North Fork American River							
		Headwaters North Fork American River	18020128050101	-	-	-	-	-
		North Fork American River-Cedars	18020128050102	-	-	-	-	-
		North Fork American River-Onion Creek	18020128050103	-	-	-	-	-
		Palisade Creek	18020128050104	-	-	-	-	-
		North Fork American River-Heath Springs	18020128050105	-	-	-	-	-

Table 4-25. Priority Rankings for non-National Forest System Lands by 7th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Map 4-3) (Continued).

5th-level Hydrologic Unit Name	6th-level Hydrologic Unit Name	7th-level Hydrologic Unit Name	7th-level HUC	HSI	RII	SSI	Priority Score (HSI)*(RII)*(SSI)	Priority Category
	North Fork American River-Granite Creek							
		North Fork American River-Wildcat Canyon	18020128050201	-	-	-	-	-
		North Fork American River-Sailor Canyon	18020128050202	-	-	-	-	-
		Upper Big Granite Creek	18020128050203	-	-	-	-	-
		North Fork American River-Big Granite Creek	18020128050204	-	-	-	-	-
		Big Valley Canyon	18020128050205	-	-	-	-	-
	North Fork American River-Indian Creek							
		North Fork American River-Giant Gap	18020128050501	3	1	3	9	2
		Canyon Creek-North Fork American River	18020128050502	2	3	1	6	3
		North Fork American River-Pickering Bar	18020128050503	3	2	3	18	1
		Indian Creek-North Fork American River	18020128050504	2	2	2	8	2
		North Fork American River-Secret Ravine	18020128050505	2	2	2	8	2
	North Fork American River-Mumford Bar							
		North Fork American River-Tadpole Creek	18020128050301	-	-	-	-	-
		North Fork American River-Humbug Creek	18020128050302	-	-	-	-	-
		North Fork American River-Humbug Bar	18020128050303	-	-	-	-	-
	North Fork of North Fork American River							
		Headwaters North Fork of North Fork American River	18020128050401	-	-	-	-	-
		North Fork of North Fork American River-Long Valley Reservoir	18020128050402	-	-	-	-	-
		North Fork of North Fork American River-E Fork of N Fork of N Fork American	18020128050403	-	-	-	-	-
		Fulda Creek	18020128050404	-	-	-	-	-
		Lower North Fork of North Fork American River	18020128050405	3	2	2	12	2
Lower North Fork American River								
	North Folsom Reservoir							
		North Folsom Reservoir	18020128060301	1	2	1	2	3
	North Fork American River-Clipper Creek							
		North Fork American River-Bunch Ravine	18020128060201	1	3	2	6	3
		North Fork American River-Codfish Creek	18020128060202	1	3	2	6	3
		North Fork American River-Lake Clemintine[1]	18020128060203	1	1	1	1	3
	Shirttail Canyon							
		Upper North Shirttail Canyon	18020128060101	-	-	-	-	-
		Lower North Shirttail Canyon	18020128060102	2	2	1	4	3
		Headwaters Shirttail Canyon	18020128060103	-	-	-	-	-
		Shirttail Canyon-Grizzly Canyon	18020128060104	2	3	2	12	2
		Brushy Canyon-Shirttail Canyon	18020128060105	1	3	1	3	3
		Lower Shirttail Canyon	18020128060106	2	3	2	12	2

[1] The 7th-level HUC subwatershed name provided by CalWater spells Lake Clementine as “Clemintine”.

Note: Dash (-) indicates that subwatershed is on National Forest System lands. Indices and priority rankings can be found in Table 4-26.

HSI= hillslope sensitivity index, RII= road impact index, SSI= stream sensitivity index.

Index Ratings for HSI, RII, and SSI: 3= high potential risk, 2= moderate potential risk, 1= low potential risk.

Priority Categories: 1= top priority, 2= second-tier priority, 3= lowest priority.

Table 4-26. Priority Rankings for National Forest System Lands by 7th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Map 4-4).

5th-level Hydrologic Unit Name	6th-level Hydrologic Unit Name	7th-level Hydrologic Unit Name	7th-level HUC	HSI	RII	SSI	Priority Score (HSI)*(RII)*(SSI)	Priority Category
Upper Middle Fork American River								
	Headwaters Middle Fork American River							
		Headwaters Middle Fork American River	18020128010101	2	1	2	4	3
		Middle Fork American River-Talbot Creek	18020128010102	2	2	3	12	2
		Middle Fork American River-Rice Creek	18020128010103	1	2	1	2	3
		Middle Fork American River-Dolly Creek	18020128010104	2	2	1	4	3
		Middle Fork American River-French Meadows Reservoir	18020128010105	2	2	1	4	3
		Middle Fork American River-Chipmunk Creek	18020128010106	3	2	2	12	2
	Middle Fork American River-Duncan Canyon							
		Upper Duncan Canyon	18020128010201	1	1	2	2	3
		Lower Duncan Canyon	18020128010202	3	3	2	18	1
		Middle Fork American River-Big Mosquito Creek	18020128010203	3	3	3	27	1
		Middle Fork American River-Brushy Canyon	18020128010204	3	2	3	18	1
Rubicon River								
	Five Lakes Creek							
		Upper Five Lakes Creek	18020128020201	2	1	1	2	3
		Middle Five Lakes Creek	18020128020202	2	1	1	2	3
		Lower Five Lakes Creek	18020128020203	1	1	1	1	3
		Barker Creek	18020128020204	1	1	2	2	3
		Rubicon River-Little McKinstry Meadow	18020128020205	2	1	2	4	3
		Rubicon River-Upper Hell Hole	18020128020206	2	1	1	2	3
		Rubicon River-Hell Hole Reservoir	18020128020207	2	1	1	2	3
	Long Canyon Creek							
		Headwaters Long Canyon	18020128020501	2	2	1	4	3
		Middle Long Canyon	18020128020502	2	1	2	4	3
		Wallace Canyon	18020128020503	1	2	1	2	3
		Lower Long Canyon	18020128020504	3	1	3	9	2
	Lower Rubicon River							
		Lower Rubicon River-Parsley Bar	18020128020601	2	2	1	4	3
		Lower Rubicon River-Ellicott Bridge	18020128020602	2	3	2	12	2
		Lower Rubicon River-Vaughn Cabin	18020128020603	3	2	3	18	1
		Lower Rubicon River-Pigeon Roost Canyon	18020128020604	3	2	3	18	1
		Big Grizzly Canyon	18020128020605	2	2	2	8	2
		Lower Rubicon River	18020128020606	3	2	3	18	1
	Pilot Creek							
		Upper Pilot Creek	18020128020401	1	2	1	2	3
		Lower Pilot Creek	18020128020402	1	2	2	4	3
	South Fork Rubicon River							
		Loon Lake	18020128020301	1	1	1	1	3
		Upper Gerle Creek	18020128020302	1	2	1	2	3
		Lower Gerle Creek	18020128020303	1	1	1	1	3
		Upper South Fork Rubicon River	18020128020304	1	1	1	1	3
		Lower South Fork Rubicon River	18020128020305	2	2	1	4	3
	Upper Rubicon River							
		Upper Rubicon River-China Flat	18020128020101	2	1	2	4	3
		Upper Rubicon River-Phipps Creek	18020128020102	1	1	2	2	3
		Upper Rubicon River-Rubicon Reservoir	18020128020103	1	1	2	2	3
		Upper Rubicon River-Rockbound Lake	18020128020104	1	1	1	1	3
		Upper Rubicon River-Miller Creek	18020128020105	1	1	1	1	3
North Fork Middle Fork American								
	Lower North Fork Middle Fork American							
		North Fork Middle Fork American River-Bear Wallow	18020128030201	3	2	3	18	1
		Grouse Creek	18020128030202	3	3	3	27	1
		Peavine Creek	18020128030203	2	3	3	18	1
		East El Dorado Canyon	18020128030204	3	2	3	18	1
		West El Dorado Canyon	18020128030205	2	2	3	12	2
		North Fork Middle Fork American River-El Dorado Canyon	18020128030206	3	2	3	18	1
	Upper North Fork Middle Fork American							
		Screwauger Canyon	18020128030101	3	3	2	18	1
		Deep Creek	18020128030102	3	3	2	18	1
		Secret Canyon	18020128030103	3	2	2	12	2
		Upper North Fork Middle Fork American River	18020128030104	3	2	3	18	1
Lower Middle Fork American River								
	Middle Fork American River-Bottle Hill							
		Middle Fork American River-Horseshoe Bar	18020128040101	2	2	3	12	2
		Volcano Canyon-Middle Fork American River	18020128040102	-	-	-	-	-
		Otter Creek-Middle Fork American River	18020128040103	1	3	3	9	2
		Middle Fork American River-Snyder Creek	18020128040104	-	-	-	-	-
	Middle Fork American River-Todd Creek							
		Middle Fork American River-Todd Creek	18020128040201	-	-	-	-	-
		Canyon Creek-Middle Fork American River	18020128040202	-	-	-	-	-
		Middle Fork American River-Gas Canyon	18020128040203	-	-	-	-	-
		Middle Fork American River-Mammoth Bar	18020128040204	-	-	-	-	-
Upper North Fork American River								
	Headwaters North Fork American River							
		Headwaters North Fork American River	18020128050101	2	1	2	4	3
		North Fork American River-Cedars	18020128050102	1	1	2	2	3
		North Fork American River-Onion Creek	18020128050103	1	1	2	2	3
		Palisade Creek	18020128050104	1	1	2	2	3
		North Fork American River-Heath Springs	18020128050105	2	1	2	4	3

Table 4-26. Priority Rankings for National Forest System Lands by 7th-level HUC Subwatersheds in the North Fork/Middle Fork American River Watershed (see Map 4-4) (Continued).

5th-level Hydrologic Unit Name	6th-level Hydrologic Unit Name	7th-level Hydrologic Unit Name	7th-level HUC	HSI	RII	SSI	Priority Score (HSI)*(RII)*(SSI)	Priority Category
	North Fork American River-Granite Creek							
		North Fork American River-Wildcat Canyon	18020128050201	3	1	3	9	2
		North Fork American River-Sailor Canyon	18020128050202	3	1	3	9	2
		Upper Big Granite Creek	18020128050203	1	1	2	2	3
		North Fork American River-Big Granite Creek	18020128050204	3	1	3	9	2
		Big Valley Canyon	18020128050205	2	2	3	12	2
	North Fork American River-Indian Creek							
		North Fork American River-Giant Gap	18020128050501	-	-	-	-	-
		Canyon Creek-North Fork American River	18020128050502	-	-	-	-	-
		North Fork American River-Pickering Bar	18020128050503	-	-	-	-	-
		Indian Creek-North Fork American River	18020128050504	-	-	-	-	-
		North Fork American River-Secret Ravine	18020128050505	-	-	-	-	-
	North Fork American River-Mumford Bar							
		North Fork American River-Tadpole Creek	18020128050301	3	2	3	18	1
		North Fork American River-Humbug Creek	18020128050302	3	2	3	18	1
		North Fork American River-Humbug Bar	18020128050303	3	1	3	9	2
	North Fork of North Fork American River							
		Headwaters North Fork of North Fork American River	18020128050401	1	3	2	6	3
		North Fork of North Fork American River-Long Valley Reservoir	18020128050402	1	2	1	2	3
		North Fork of North Fork American River-E Fork of N Fork of N Fork American	18020128050403	2	2	1	4	3
		Fulda Creek	18020128050404	2	2	1	4	3
		Lower North Fork of North Fork American River	18020128050405	-	-	-	-	-
Lower North Fork American River								
	North Folsom Reservoir							
		North Folsom Reservoir	18020128060301	-	-	-	-	-
	North Fork American River-Clipper Creek							
		North Fork American River-Bunch Ravine	18020128060201	-	-	-	-	-
		North Fork American River-Codfish Creek	18020128060202	-	-	-	-	-
		North Fork American River-Lake Clemintine[1]	18020128060203	-	-	-	-	-
	Shirttail Canyon							
		Upper North Shirttail Canyon	18020128060101	1	1	1	1	3
		Lower North Shirttail Canyon	18020128060102	-	-	-	-	-
		Headwaters Shirttail Canyon	18020128060103	1	2	1	2	3
		Shirttail Canyon-Grizzly Canyon	18020128060104	-	-	-	-	-
		Brushy Canyon-Shirttail Canyon	18020128060105	-	-	-	-	-
		Lower Shirttail Canyon	18020128060106	-	-	-	-	-

[1] The 7th-level HUC subwatershed name provided by CalWater spells Lake Clementine as "Clemintine".

Note: Dash (-) indicates that subwatershed is not on National Forest System lands. Indices and priority rankings can be found in Table 4-25.

HSI= hillslope sensitivity index, RII= road impact index, SSI= stream sensitivity index.

Index Ratings for HSI, RII, and SSI: 3= high potential risk, 2= moderate potential risk, 1= low potential risk.

Priority Categories: 1= top priority, 2= second-tier priority, 3= lowest priority.

The priority category 1 subwatersheds represent areas with higher potentials for contributing sediment to streams, relative to other subwatersheds in the North Fork/Middle Fork American River watershed. Some stream segments are more sensitive to sediment inputs than others. This study considered several resources at risk, including degraded water quality conditions, aquatic species and habitat, and water development. However, as described in Appendix B, little information related to these specific resources at risk is publicly available in the watershed. The limited data that are available are presented in Sections 3.8 (water quality), 3.9 (aquatic species and habitat), and 3.11 (water development).

Most of the priority category 1 and 2 subwatersheds identified in Map 4-3 are grouped on the mainstem North Fork American River, with one priority category 2 subwatershed on the Middle Fork American River. Both of these forks of the American River are identified as known fish-bearing streams (Map 3-14). However, background information about the species present is unavailable, making any predictions about whether the species or habitat in these streams could be impacted by sedimentation difficult to evaluate. Of the mapped water developments (Map 3-16), the priority category 1 and 2 subwatersheds are located upstream of the North Fork Dam (and Lake Clementine) and the American River Pump Station.

Similarly, all of the priority category 1 and 2 subwatersheds identified in Map 4-4 contain at least one segment of known fish-bearing streams (Map 3-14). However, background information about the species present is unavailable. As a result, the potential impacts of sediment delivery on the aquatic species or habitat in these areas are unknown. All of the top-priority (priority category 1) 7th-level HUC subwatersheds eventually drain to the American River Pump Station (Map 3-16). In addition, like the results summarized for Map 4-3, the North Fork American River-Mumford Bar 6th-level HUC subwatershed drains to the North Fork American River upstream of North Fork Dam (and Lake Clementine). The higher-priority 7th-level HUC subwatersheds in the Middle Fork American River-Duncan Canyon drain to the mapped Interbay and Ralston Afterbay features. The higher-priority 7th-level HUC subwatersheds in the Lower Rubicon River also drain into the Ralston Afterbay. The higher-priority 7th-level HUC subwatersheds in the Upper and Lower North Fork Middle Fork American drain only into the American River Pump Station.

The relative positions of priority category 1 and 2 subwatersheds relative to response channel reaches provide a more complete picture of the potential adverse impacts of sediment inputs because low-gradient (less than 0.03 or 3 percent) streams are mapped consistently throughout the North Fork/Middle Fork American River watershed. This approach of considering both the relative vulnerability of the watershed (which influences the priority category) and the likelihood of sediment deliverability (based on the proximity of response channels and other resources at risk) was also referred to in the Washington Administrative Code (222-22-050) and in the Watershed Analysis Manual (Washington Forest Practices Board 1997). Response channel reaches eventually receive most of the material that is eroded upstream and often experience significant morphometric adjustment (e.g., sediment bars, alluvial fans) in response to increased sediment supply. Of the priority category 1 and 2 subwatersheds shown on Map 4-3, those in the North Fork American River-Indian Creek 6th-level HUC subwatershed appear to have the greatest potential for contributing sediment to response channels. Of the priority category 1 and 2 subwatersheds shown on Map 4-4, those in the North Fork American River-Mumford Bar and in the Lower Rubicon River 6th-level HUC subwatersheds appear to have the greatest continuous segments of low-gradient response reaches.

Assumptions and Limitations

The watershed prioritization models are based on the best available information both on and off National Forest System lands. Again, caution should be used before making any direct comparisons between the subwatersheds priority rankings developed using these separate data sources. The final results provide suggestions for strategic priorities to target watershed enhancement practices. A subwatershed with a low priority ranking (priority category 3) should still receive site-specific attention to prevent sedimentation from localized erosion sources. Conversely, a subwatershed with a high priority ranking (priority category 1 or 2) may not have identified erosion or sedimentation concerns, particularly under adequate vegetative cover and drainage conditions.

CHAPTER 5: MANAGEMENT STRATEGIES AND PRIORITIES

5.1 Introduction

The purpose of Chapter 5 is to identify management strategies and priorities for enhancement opportunities for the North Fork/Middle Fork American River watershed. Management strategies and priorities for watershed enhancement will be addressed from two perspectives. The first is management measures and the second is management actions with respect to watershed protection and restoration. Management measures are often referred to as best management practices (BMPs) and are general or specific approaches to control soil erosion or sediment sources. However, as noted in U.S. Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency 2005) the term 'best' can be subjective and may lead to using a particular method in an inappropriate circumstance. This chapter, therefore, will generally use the term management measure. BMP will be used when referencing a particular publication that uses that term.

The approach taken here is similar to the "steps to select management practices" presented in EPA (2005). The intent of that process is to understand current management efforts, identify areas of concern, and then identify possible management practices or measures. Chapter 4 of this watershed assessment report identifies the areas of concern through a combined prioritization and targeting approach. This chapter considers existing management activities as the standards and guidelines applied to the current landscape by various federal, state, and county regulations, as well as cooperative and voluntary efforts for erosion and sediment control. Additionally, this chapter recognizes that there is a history to land-use activities and that, while current management measures are relatively effective, the landscape has "legacy" problem sites where no erosion and sediment control measures were applied (e.g., hydraulic mining sites from the gold rush era), older practices were used that may not be as efficient as current measures, or effective measures have not been maintained. Consequently, there are various opportunities for enhancement at the site-specific level, as well as at the subwatershed and watershed levels.

The management measures and actions for watershed enhancement are keyed to the two highest subwatershed priority rankings identified in Chapter 4, that is, priority category 1 and 2 7th-level HUC subwatersheds (Table 4-25 and Map 4-3; Table 4-26 and Map 4-4). The basic assumption in formulating the management strategies is that landowners intend to be good stewards of their lands and therefore many of the basic enhancement or maintenance approaches described here are suitable for landowners in priority category 3 subwatersheds as well.

There are a wide variety of detailed manuals for evaluating a site and designing specific management measures to minimize soil erosion and sediment delivery to streams (e.g., Fifield 2004; San Francisco Regional Water Quality Control Board 2002; Weaver and Hagans 1994), including the individual county stormwater manuals and other resources described throughout this chapter. The information synthesis presented here, therefore, is designed to serve as a general guide to site evaluation based on the various land uses in the watershed, to identify types of appropriate management measures, and to identify resources that provide the more detailed information on how to reduce erosion and sedimentation.

5.2 Management Measures for Priority Subwatersheds

This section describes management measures and identifies appropriate reference materials based on the land uses in the watershed (see Map 3-3). Management measures seek to control erosion during site construction and can also be applied to address existing conditions at developed or previously disturbed sites. Management measures seek to maintain some form of ground cover to prevent rainsplash and surface erosion, capture eroded sediment before it leaves a site, and promote infiltration as well as other methods to slow water runoff. Such measures reduce soil erosion and the amount of sediment delivered to streams. They also reduce peak discharges in local streams, which minimizes the potential for increased sediment supply from stream bank and stream bed erosion.

Any new development or forestry activity in the North Fork/Middle Fork American River watershed is conducted under a variety of federal, state, county, and local regulatory programs that minimize the potential for soil erosion and peak flow increases. However, much of the watershed has existing development and activities done at earlier times when less was known about management measures and when they were less effective. In addition, conditions change over time so that, unknowingly, a location may be contributing increased sediment and influencing peak stream flows. Consequently, one action that can be taken by smaller landowners in all the land use types discussed below is to conduct a site assessment of their property. This site assessment approach is not suggested for larger land bases because the larger land bases are addressed by various other procedures. Preparing timber harvest plans on private lands requires a cumulative effects analysis of a wider area. Similarly, the USDA Forest Service conducts a cumulative watershed effects analysis for ground-disturbing actions and has a variety of inventory processes, including roads analyses. Lastly, many ranch owners are participants in the California Rangeland Water Quality Management Plan, which includes the development of a ranch inventory and map, and then the identification and implementation of BMPs.

The discussion below addresses management measures in four groupings. The first grouping includes all the developed land uses associated with towns, homes, and commercial development. These land uses include Rural Residential, Low-Density Residential, Medium-Density Residential, and Industrial, as identified in Map 3-3. The second grouping addresses agricultural land uses including ranching, grazing, and cropland, including viticulture (wine grapes). The third grouping addresses forestry operations on private lands and National Forest System lands. The fourth grouping addresses historical mining sites.

5.2.1 Rural Residential and Other Developed Lands

Similar to other areas in the Sierra Nevada, the North Fork/Middle Fork American River watershed is experiencing rapid population growth, particularly in the vicinity of the various communities in the watershed (see Section 3.3). Table 5-1 identifies the land uses near these urban/rural communities and the priority

Table 5-1. Subwatershed Priority Ranking Category and Land Uses (based on Map 3-3) in the Vicinity of Urban/Rural Developed Areas in the North Fork/Middle Fork American River Watershed.

	Urban/Rural Developed Areas										
	East of Auburn	Applegate	Weimar	Colfax	Blue Canyon	Emigrant Gap	Ice Lakes	Foresthill	Cool	Georgetown	Volcanoville
	Subwatershed (7th-level HUC)										
	North Folsom Reservoir	North Fork American River-Lake Clementine	North Fork American River-Bunch Ravine	North Fork American River-Bunch Ravine	Lower North Fork of North Fork American River	Fulda Creek	North Fork American River-Onion Creek	Middle Fork American River-Snyder Creek	North Folsom Reservoir	Canyon Creek-Middle Fork American River	Middle Fork American River-Snyder Creek
	Subwatershed (7th-level HUC) Priority Ranking Category										
	3	3	3	3	2	3	3	2	3	3	2
	Land Use										
Rural Residential	✓	✓	✓	✓	✓						✓
Low Density Residential				✓	✓	✓	✓	✓	✓		
Medium Density Residential	✓								✓	✓	
Community/Neighborhood Commercial/Office	✓	✓				✓	✓	✓	✓	✓	
Industrial								✓		✓	
Public/Quasi-Public										✓	
Agriculture					✓		✓				
Open Space							✓			✓	
Forest					✓	✓	✓	✓			✓

ranking for the subwatershed in which that community occurs (i.e., priority category 1, 2 or 3). Most communities are in 7th-level HUC subwatersheds ranked as priority category 3, although Blue Canyon, Foresthill, and Volcanoville are in subwatersheds ranked as priority category 2. The management measures discussed below can be applied in all subwatersheds; however, they are especially important in those identified as priority category 2, and are highly recommended there.

New construction in these areas is controlled by designs required by the Placer County and El Dorado County stormwater control manuals. These manuals contain information on controlling runoff and erosion from all types of construction and development. Additionally, construction disturbing greater than 1 acre requires developing and implementing surface water management plans, which include specifics on erosion control during construction. However, special attention to stormwater runoff on developed lands is warranted in priority category 2 subwatersheds. In these areas, larger developments can consider the use of low impact development (LID) techniques. Traditional stormwater management collects and moves stormwater through storm drains and pipes. LID, however, uses site design and stormwater management to reduce impermeable surfaces and increase on-site infiltration to maintain pre-development water runoff rates and volumes. These techniques also reduce the long-term erosion from a site.

Property Self-Assessment

As noted in the introduction to this section, owners of already constructed sites can perform property self assessments. Site assessments include producing a sketch drawing of a property identifying the location of bare soil areas, areas where surface water runoff occurs, and sensitive areas such as drainage ways and streams on or adjacent to the property. Land owners can take a fall or winter walk on their property during a heavy rainstorm as a good means of understanding how the site functions with respect to water and soil runoff. With this information, a variety of simple and cost-effective measures can be applied. Cobourn and others (n.d.) as well as Cobourn and others (2003) provide guidance on how to conduct such an assessment and how to identify management measures to apply. Measures to reduce erosion, increase infiltration, and reduce the speed of runoff can include:

- Paving or applying gravel to existing unpaved driveways and parking areas;
- Using permeable pavement for new driveways or replacing older driveways with permeable pavement;
- Ensuring that there is appropriate ground cover (vegetation, mulch) on the property;
- Using dry wells, cisterns, or other measures to slow water from roof downspouts; and
- Ensuring adequate vegetation cover in the riparian areas adjacent to streams.

For home owners, excellent opportunities for such enhancements occur when homes are being remodeled or outdoor landscaping is being upgraded. Although it depends on specific conditions, such improvements can sometimes increase value (see California Coastal Commission LID fact sheet below under Available Resources). At a minimum, when homes are placed on the market these improvements can be identified as "green" components in the same way as items such as solar upgrades.

For owners of small industrial developments or commercial centers, similar opportunities occur. For example, if a site's parking lots and landscaping are being improved, there will also be opportunities to increase ground cover with vegetation, mulch, or rock and to increase sediment filtration with grassy swales or various types of water infiltration methods. New parking lots can use permeable pavements, or these materials can be used when older parking lots require upgrading. These sites can also use dry wells, cisterns, or other measures to slow water from their roof downspouts. Such "low impact development features" do not have to require substantial costs. In addition, several of these LID measures can provide aesthetic enhancements, which increase the quality of the property. Such improvements are worth pointing out to customers. See Low Impact Development in the Available Resources section below.

Defensible Space

An excellent opportunity for upgrading erosion and runoff control exists for owners of structures in wooded areas. California Public Resources Code 4291 now requires that defensible space clearance around buildings and structures be 100 feet rather than the previously required 30 feet. Most importantly, all flammable vegetation and other combustible growth must be cleared within 30 feet of each building or structure (California State Board of Forestry and Fire Protection and California Department of Forestry and Fire Protection 2006). Consequently, owners of homes, commercial buildings, or other structures generally have to perform yearly maintenance, which provides them the opportunity to evaluate their property for erosion control and water infiltration at the same time.

The 30-foot zone requires the clearance of flammable vegetation or other combustible growth. This cleared zone has the potential to be a source of erosion and increased runoff. Two methods to minimize erosion in this zone are maintaining live, low-growing ground cover or a green and mowed lawn, or providing a surface covering. Placing a surface covering of gravel, red lava rock, brick chips, or river rock can provide an attractive, low-maintenance alternative for reducing erosion, increasing infiltration, and reducing runoff speed.

In the outer 70-foot reduced fuel zone, the emphasis is on eliminating ladder fuels and the ability of fire to spread from plant to plant toward the structure. Therefore, dead vegetation on shrubs and the lower dead tree limbs are trimmed. Additionally, spacing between shrubs and trees must be maintained. This zone, therefore, could have substantial amounts of bare soil and could be a source of erosion and increased runoff. Methods to minimize erosion in this zone could be to protect areas where water concentrates (e.g., natural depressions leading to streams) by extending live, low-growing ground covers such as green and mowed grass (where appropriate) to the area or placing gravel or rock coverings. In areas where natural grass occurs, this ground cover can be retained but should be kept at a reduced height to prevent fire spread. If the property contains a stream that directly receives runoff, there may be opportunities to slow the flow of water before it reaches the stream. For example, a pathway of permeable paving stones could be installed 10 or 15 feet from the stream but along the contour. Digging a small trench on the uphill side and filling it with gravel will slow surface runoff from above and capture some sediment before it reaches the stream.

Animal Keeping

Many owners of small acreages in rural areas keep various domestic animals. Commonly, these include horses, llamas, goats, and sometimes sheep. The animals may be kept in various pastures, corrals, or barns. In some cases, particularly corrals, such animals may impact the vegetation cover on the property such that the potential for soil erosion is increased. During a property self-assessment, opportunities for improving these conditions may be identified. Santa Cruz County (California) has prepared a variety of materials to assist horse owners in improving site characteristics. These methods are useful for keeping most animals and are identified in the Available Resources section. The most important measures would be to maintain ground cover in pasture areas and to maintain vegetation cover and exclude animals from areas immediately adjacent to streams (i.e., the riparian zone).

Available Resources

(1) Placer County Flood Control and Water Conservation District Stormwater Management Manual (SWMM)

This document contains regulations for Placer County for construction site runoff management, drainage management, and general stormwater management. It can be found at:
http://www.placer.ca.gov/Home/Works/Resources/Swmm.aspx

Additionally, see Low Impact Development options identified below.

(2) Storm Water Management Plan (SWMP) - Western El Dorado County

This document contains regulations for El Dorado County for construction site runoff management, drainage management, and general stormwater management. It can be found at:
http://www.co.el-dorado.ca.us/emd/solidwaste/storm.html

Additionally, see Low Impact Development options identified below.

(3) Construction Storm Water Program

Construction disturbing sites of 1 or more acres requires the development of a Storm Water Pollution Prevention Plan (SWPPP). This program is found at:
http://www.swrcb.ca/gov/stormwtr/construction.htm

(4) Creating Defensible Space Around Structures

The State Board of Forestry and Fire Protection and California Department of Forestry and Fire Protection *General Guidelines for Creating Defensible Space* are found at:
http://www.fire.ca.gov/cdfbofdb/pdfs/Copyof4291finalguidelines9_29_06.pdf

The California Department of Forestry and Fire Protection's *Homeowners Checklist* for making your home fire safe is found at:
http://www.fire.ca.gov/about_content/downloads/CDFchecklist2006.pdf

(5) Stream Care Guide

This stream care guide for Santa Cruz County was sent to residents to help those living adjacent to critical streams. The guide is full of information on the management measures for protecting aquatic habitat and can be found at:
http://www.fishnet4c.org/pdf/santa_cruz_stream_care_guide.pdf

(6) Animal Keeping

Horse Keeping: A Guide to Land Management for Clean Water can be found at:
http://www.awqa.org/pubs/conservation/Horses/horsekeep.pdf

This reference provides information for horse owners on maintaining water quality on their land. The manual includes information on assessing property, a chapter on conservation measures for erosion reduction, and a section with references for additional information. This information is applicable to keeping a variety of animals on small acreages.

A fact sheet *Water Quality and Horse Keeping Facilities* is available at:
http://www.awqa.org/pubs/conservation/Horses/waterquality.pdf

(7) Low Impact Development (LID)

The Tahoe Regional Planning Agency's (TRPA) Web site contains a variety of information on management measures that can be used for homes and commercial developments to reduce erosion, sediment delivery, and peak flow increases. The main management measures Web site is accessible at:
http://www.tahoebmp.org/documents.aspx

The TRPA BMPs retrofit program has information on how to conduct a site assessment. This information is available in their contractor notes publication at:
http://www.tahoebmp.org/bmp_pdfs/BMP_Contractors_Notes.pdf

Contra Costa County has a variety of materials on stormwater management for new development, including many management measures that could be implemented during site upgrading. These resources are available at:
http://www.cccleanwater.org/construction/nd.php

Specific measures from the Contra Costa County Web site are available at:
http://www.cccleanwater.org/construction/Publications/StartAtTheSource/ch6_site_design_landscape_details.pdf

The California Coastal Commission has an informative fact sheet on LID available at:
http://www.coastal.ca.gov/nps/lid-factsheet.pdf

The Environmental Protection Agency's LID Web page is at:
http://www.epa.gov/owow/nps/lid/

A variety of LID information including bioretention applications, conservation design for stormwater management, field evaluation of permeable pavements, and other items are found at:
http://www.psat.wa.gov/Programs/LID.htm
and
http://www.psat.wa.gov/Programs/LID/lid_cd/pdf_docs.htm

The Seattle Public Utilities Street Edge Alternatives program contains a variety of techniques to provide drainage that mimics the natural landscape. Information is available at:
http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/Street_Edge_Alternatives/index.asp

(8) Roads Manual for the Fishery Network of the Central California Coastal Counties

The following site includes the Roads Manual for the Fishery Network of the Central California Coastal Counties:
http://www.fishnet4c.org/projects_roads_manual.html

Topics include: vegetation, road maintenance, working near streams, and sediment control. Appendix A includes a BMP toolbox.

(9) Five Counties Salmonid Conservation Program

The following documents include information on dealing with urban road problems and principles for treating road sedimentation problems:
http://www.5counties.org/
and
http://www.5counties.org/Projects/FinalGeneralProjectPages/RoadsManual800.htm

(10) Plant and Vegetation Recommendations

The High Sierra Resource Conservation and Development Council's *Vegetation Establishment Guidelines for the Sierra Nevada Foothills and Mountains* provides a wide range of information on the types of plants to use, seedbed preparation, and seeding and fertilization rates. The publication is available at:
http://www.highsierra-rcandd.org/Documents/Vegetation_Guidelines.pdf

and
http://www.co.el-dorado.ca.us/EMD/solidwaste/StormWater/HSRCD%20 Vegetation%20Guidelines%20Final%202005.pdf

The University of California Cooperative Extension also provides a list of *Selected Perennial Grasses Suitable for Foothill Rangeland*. This fact sheet is available at: http://ucce.ucdavis.edu/files/filelibrary/616/3986.pdf

The California Alpine Resort Environmental Cooperative's *The Sediment Source Control Handbook* provides detailed information on soils, vegetation establishment, and erosion control. The document is available at:
http://www.sbcouncil.org/publications.htm
and
http://www.waterboards.ca.gov/lahontan/docs/carec_full.pdf

5.2.2 Agricultural (Ranching, Grazing, and Cropland)

According to the California Environmental Protection Agency (1993) (NPS/CZARA Fact Sheet No. 1), agriculture contributes more than half of the pollution entering the nation's waterbodies. The primary pollutants are nutrients, sediment, animal wastes, pesticides, and salts. Agricultural activities can affect aquatic habitat through disturbance from livestock and equipment or through water management (i.e., hydrologic modifications). In the North Fork/Middle Fork American River watershed, no substantial water quality impacts from agriculture have been specifically identified. However, there is a high potential for increases in sediment from site erosion and increases in peak flows if appropriate management measures are not followed.

Water quality issues on ranch and rangelands in California are addressed by the *California Rangeland Water Quality Management Plan*. This plan was developed by the Range Management Advisory Committee and approved by the State Water Resources Control Board as part of the *California Nonpoint Source Pollution Control Plan*. This voluntary program is supported by training that identifies nonpoint sources of pollution on a property (as part of the ranch map) and implements management measures (i.e., BMPs). The training program is conducted by the University of California's Ranch Water Quality Management Short Course (see California Rangelands in the Available Resources section). That Web site (http://californiarangeland.ucdavis.edu/index.htm) provides a wide range of detailed information on range, water quality, and management measures. Program implementation and response has been successful (Larson and others 2005). The California Cattleman's Association also provides information on watershed management at its Web page (see Available Resources section).

Agricultural/cropland use in the watershed is relatively low but includes some orchards and vineyards. Management measures for ranching, grazing, and cropland are provided below.

Management Measures – Ranching and Grazing

- Establish a nonpoint source management plan if one does not already exist.
- If a nonpoint source management plan already exists for the property, re-examine the site inventory and re-evaluate the management measures in place for applicability under current circumstances. Be alert for conditions that have changed since the last inventory was conducted.
- Identify opportunities for enhancement of existing conditions that contribute sediment to streams. Seek cooperative or funding opportunities with local agencies such as the Resource Conservation District to help fund project. In particular be alert for the following:
  - — Road ditches that deliver water and sediment directly to streams – provide a rock surface to minimize erosion;
  - — Steep stretches of roads that are undergoing erosion – install water bar/water breaks as recommended in the Handbook for Forest and Ranch Roads, Table 3;
  - — Lack of appropriate vegetative cover and residual dry matter on grazed hillsides – reseed as appropriate to prevent soil loss and delivery to streams; and
  - — Unvegetated riparian zones where sediment is delivered to streams from adjacent hillsides – re-establish vegetation cover by seeding, planting, or livestock exclusion.
- Institute measures to minimize cattle access to riparian zones such as water troughs, salt licks, and fences where feasible.

Management Measures – Agriculture/Cropland

- Maintain cover crops in fields, orchards, and vineyards to the extent possible.
- Maintain vegetation cover in riparian buffers.
- Apply mulch before the onset of the rainy season to bare slopes that are over 5 percent slope.
- Prior to the rainy season, inspect all existing erosion control measures and drainage features to ensure functionality.
- Inspect erosion control measures after rain storms and upgrade or repair as appropriate.
- Identify areas where surface erosion (overland flow, rills, gullies) occurs and delivers sediment to streams, and correct those situations with cover crops, mulch, contour plowing, energy dissipaters, or other measures.

- Evaluate roads and access avenues for erosion and sediment delivery and establish a covering of rock or a cover crop as appropriate. These measures are particularly important near stream crossings or drainage ways.

Available Resources

(1) California Cattleman's Association

The California Cattleman's Association *Watershed Resource Guide* is available at: http://www.calcattlemen.org/1%20Industry%20Issues/1%20Producer%20Information/Watershed%20Resource%20Guide/Watershed%20Resource%20Guide%20Home.htm

The Web site contains a variety of resources including a link to the State Department of Water Resources *California Rangeland Water Quality Management Plan* at: http://www.calcattlemen.org/1%20Industry%20Issues/1%20Producer%20Information/Watershed%20Resource%20Guide/Case%20Studies/Watershed%20Mgmt%20Plan.pdf.

(2) California Rangelands – University of California

The California Rangelands Program Web site is available through the University of California at: http://californiarangeland.ucdavis.edu/index.htm

This site provides access to a wide variety of resources related to range and ranch management. It includes a link to the *Ranch Water Quality Management Short Course*, which is a component of the State Water Resources Control Board *California Rangeland Water Quality Management Plan* available at: http://californiarangeland.ucdavis.edu/rwqp_files/rwqpsc.htm

(3) University of California, Water Quality Programs

The following Web site contains many useful fact sheets for both rangeland and agriculture: http://waterquality.ucanr.org/

There is a link to the Farm Water Quality Planning Web site and the Ranch Water Quality Planning Web site. Specific management practices are identified for different land uses.

(4) University of California Cooperative Extension—Placer-Nevada Counties and El Dorado County

The following Web sites provide access to a variety of local resources, including locally-based specialists: http://ceplacernevada.ucdavis.edu/

and
http://ceeldorado.ucdavis.edu/

(5) Resource Conservation Districts

Resource Conservation Districts (RCDs) provide access to a variety of local resources including locally-based specialists. Reduction of erosion on farmland, residential land, and rangeland is a priority for these organizations. For example, the Placer County RCD conducted four erosion control and stormwater management workshops in 2005 with over 170 participants. Information could be used to develop erosion control plans, to implement on-site practices, and to guide site monitoring observations pertaining to storm water runoff. They are available at:

El Dorado County Resource Conservation District and Georgetown Divide Resource Conservation District
100 Forni Road, Suite A
Placerville, CA 95667
Phone: (530) 295-5630
Fax: (530) 295-5635

Placer County Resource Conservation District
251 Auburn Ravine, Suite 201
Auburn, CA 95603-3719
Phone: (530) 885-3046
Fax: (530) 823-5504
http://www.placercountyrcd.org/

(6) El Dorado County Agriculture Department

The following Web site provides detailed information on agricultural grading permits and general BMPs for agriculture:
http://www.co.el-dorado.ca.us/ag/bmps.html

It has specific information on El Dorado County requirements, as well as descriptions and designs for a wide variety of measures such as access roads, cover crops, channel stabilization, critical area planting, filter strips, grassed waterways, mulching, residue management, riparian forest and herbaceous buffers, and water and sediment control basins.

(7) Placer County Agricultural Commissioner

This Web site is available at:
http://www.placer.ca.gov/Agriculture.aspx.

(8) Sierra Grape Growers Association

The following Web site contains information on sustainable agricultural practices, which include using cover crops, controlling erosion, and conserving water

resources:
http://www.sierragrapegrowers.org/good_neighbors.htm.

(9) Placer County Wine and Grape Association

The following Web site contains information on vineyard development and management, including the need for drainage systems, seed cover, and erosion control:
http://www.placerwineandgrape.org/resources.htm

(10) Vineyard Site Assessment Guide (for Sonoma County)

This booklet is designed to help land owners develop a vineyard with protection of water quality. Topics include: site assessments, slope, soils, driveways and roads, water access and rights, erosion, vegetation, streams and riparian areas, and other wet areas. Information on costs for permitting is included for each section. The guide is available at:
http://cesonoma.ucdavis.edu/vitic/pdf/vineyard_assess.pdf

(11) University of California Sustainable Agriculture Research and Education Program Cover Crop Resource Page

The following Web site provides extensive information on cover crops to control surface erosion:
http://www.sarep.ucdavis.edu/ccrop/

Specific information is provided for vineyards and orchards. The following publication can be purchased currently through this Web site for $20.00:

Ingels, C., R. Bugg, G. McGourty, and P. Christensen, technical editors. 1998. Cover Cropping in Vineyards – A Grower's Handbook. University of California, Division of Agriculture and Natural Resources, Publication 3338, 162 pp.

(12) Horse Keeping: A Guide to Land Management for Clean Water

This reference provides information for horse owners on maintaining water quality on their land:
http://www.awqa.org/pubs/conservation/Horses/horsekeep.pdf

The manual includes information on assessing your property, a chapter on conservation measures for erosion reduction, and a section with references for additional information. A fact sheet (*Water Quality and Horse Keeping Facilities*) is provided at:
http://www.awqa.org/pubs/conservation/Horses/waterquality.pdf

(13) Private Road Maintenance Guide for Santa Cruz County

Although this booklet was developed for Santa Cruz County, it is extremely useful outside of the county. Many road drainage improvement guidelines are

included, along with erosion and sediment control measures. It is available at:
http://www.awqa.org/pubs/conservation/PrivateRoadGuide.pdf

(14) Forest and Ranch Roads

The *Handbook for Forest and Ranch Roads* is a standard guide used throughout northern California for planning, designing, constructing, maintaining, and closing wildland roads. It is available for purchase from the Mendocino County RCD at:
http://mcrcd.org/

Click on the Publications for Sale link. The present cost is $22.00. Additionally, both a DVD and video tape on Forest and Ranch Roads are available for $17.00, as well as a Road Building Guide for Small Private Roads for $6.00.

5.2.3 Forestry

Forest management measures are generally those recommended by the USDA Forest Service or by the California Board of Forestry and the Department of Forestry and Fire Protection. Forest management practices relevant to this section include timber harvest, road engineering, and silviculture or vegetation management that help reduce the levels of nonpoint source pollution such as sediment (Tetra Tech 2006). Sediment is the pollutant of greatest concern with respect to forestry (Tetra Tech 2006).

The EPA recommendations for forest management to protect water quality can be found at http://www.epa.gov/watertrain/forestry/forestry5.htm. These recommendations include management direction areas that can be the focus of active restoration efforts. The directions include Pre-harvest Planning, Streamside Management Zones, Forest Wetland Protection, Road Construction, Timber Harvesting, Revegetation, and Fire Management.

Pre-harvest Planning focuses on protecting water quality and controlling erosion and sedimentation by performing advance planning for efficient forest harvesting, site preparation, and road systems. Streamside Management Zones are established to protect against detrimental changes in the temperature regime of the water body, to provide bank stability, to provide a filter to keep sediment and pollutants out of the stream, and to withstand wind damage. Under the California Forest Practice Rules, riparian buffers are called Watercourse and Lake Protection Zones (WLPZs). Width of WLPZs varies between 25 and 150 feet, depending on the steepness of the streamside terrain and the class of the watercourse being protected. Forest Wetland Protection includes protecting the function of forest wetlands by tailoring forestry practices to reduce or minimize impacts to these environments.

Road Construction focuses on minimizing delivery of sediment from road construction or reconstruction by following pre-harvest plan layouts and designs for the road system, incorporating adequate drainage structures, and properly installing stream crossings. Logging roads and landings have the potential to be one of the major sources of sediment from managed forestlands (Tetra Tech 2006). Existing roads should be used whenever possible and new roads should be laid out to reduce overall road mileage.

Roads should be tailored to the natural topography and should not be placed in unstable areas that are subject to erosion or deterioration, such as stream canyons or wetlands. Roads should be located on natural benches, flat slopes, and areas of stable soils to minimize effects on watercourses (Tetra Tech 2006).

Revegetation efforts can reduce erosion and sedimentation risk by rapidly revegetating areas with ground disturbance. Fire Management actions include efforts to reduce sediment delivery to streams and to keep chemicals from damaging aquatic resources.

Forestry activities on private lands are addressed in the California Forest Practice Rules, which are periodically updated and contain detail management measures for timber harvesting operations, roads, stream buffers, and other activities. The 2007 version is available at http://www.fire.ca.gov/rsrc-mgt_content/downloads/2007FPRulebook_wDiagrams.pdf#page2. The California Board of Forestry has an ongoing monitoring program evaluating the implementation and effectiveness of management measures for forestry operations on private lands (Cafferata and Munn 2002; Monitoring Study Group 2006). The monitoring has shown that implementation of measures is high and that implemented measures are generally effective, although roads and associated stream crossings have the greatest potential for sediment delivery to streams (Cafferata and Munn 2002; Ice and others 2004; Monitoring Study Group 2006). Timber harvest plan inspections show that the highest concern is with activities adjacent to streams (Ice and others 2004). The modern California Forest Practices Act was enacted in 1973, with implementation complete by 1975 (Ice and others 2004). Numerous areas were harvested prior to those rules, and much older legacy conditions exist related to timber harvest during the gold rush era.

The USDA Forest Service (2004b) Pacific Southwest Region evaluated region-wide implementation and effectiveness of water quality BMPs. Based on the ongoing monitoring and evaluation program, the Forest Service also updated its water quality BMPs in 2000 (USDA Forest Service 2000). In general, the measures were implemented at high rates. Sufficient data were available to statistically evaluate 16 of 29 protocols, and the analysis found that adequate implementation is more likely to meet onsite water quality objectives (USDA Forest Service 2004b). Evaluation of management measures on the Eldorado National Forest from 1992 to 2003 found that BMPs were implemented 89 percent of the time and were effective 92 percent of the time (Mai 2004). Implementation and effectiveness were higher for road-related BMPs, which are a common issue. Other work on forestry practices in the Sierra Nevada is being carried out by Dr. Lee MacDonald at Colorado State University (e.g., see Coe 2006; MacDonald and others 2004). Additionally, the USDA Forest Service has initiated the Sierra Nevada Adaptive Management Project (http://snamp.cnr.berkeley.edu/) with the University of California to evaluate the effects of implementing fuel treatments, including strategically placed area treatments (SPLATs). One of the two proposed sites for this study is in the Deep Creek subwatershed of the Middle Fork American River. Currently, Bear Trap Creek is proposed for the Deep Creek site. This creek flows to Deep Canyon and eventually to Screwauger Canyon. Other local fire studies are being conducted at the Blodgett Forest Research Station (http://forestry.berkeley.edu/research.html), which is predominantly in the South Fork American River watershed but extends slightly into the Middle Fork American River watershed along Wentworth Springs Road east of Georgetown. A completed study included the effects of prescribed fire on riparian zone vegetation, instream large woody debris, and instream fine-grained sediment (Beche and others 2005). It did not find a significant difference in large woody debris or fine-grained sediment in pools between the affected areas and a control. An extensive body of work, not reviewed here, also exists for the Lake Tahoe Basin.

In addition, the USDA Forest Service has initiated a roads analysis process and conducted a variety of road analyses. The Tahoe National Forest has completed an extensive roads analysis (available at http://www.fs.fed.us/r5/tahoe/documents/road_analysis_web/), as well as contributing analyses described in Girvetz and Shilling (2003). The Eldorado National Forest has completed a forest-scale roads analysis (USDA Forest Service 2003b), as well as several roads analyses at more detailed levels (see http://www.fs.fed.us/r5/eldorado/projects/landscape/), including one that extends slightly into the lower Middle Fork American River (USDA Forest Service 2003c).

Management Measures – Private Forestlands

Management measures for forestry operations on private lands for priority category 1 and 2 subwatersheds in the North Fork/Middle Fork American River watershed are focused on roads, road-stream crossings, and streamside zones (i.e., WLPZs) where management measure evaluations have identified the most issues.

The following management measures are recommended for private forestlands:

- When new timber harvests are initiated in planning watersheds (as defined by CDF) with a priority category 1 ranking (as defined in this watershed assessment), upgrade the watercourse crossings in the timber harvest plan area, where necessary. Assess the existing road system, old roads, and old ditches in the timber harvest plan area to identify existing or potential problems and prescribe amelioration where feasible. Stream crossing upgrades may be a corrugated metal pipe, bridge, or ford, as appropriate. Minimize ditch lengths that contribute water and sediment directly to streams by installing ditch relief culverts using the suggested spacing in Weaver and Hagans (1994) (Table 20). Install ditch relief culverts in positions that minimize the potential for runoff to the stream. Rock the exits of the ditch relief culverts to minimize potential for incision. Modify the road surface to minimize road-derived sediment entering the stream. Methods to minimize this sediment influx could include regrading the surface so that surface water does not drain off the road in locations that provide direct access to the stream, rocking the road surface to minimize road erosion and the contribution of fine sediment in the vicinity of the stream crossing, and increased monitoring and road erosion control maintenance at sites identified as having potential sediment contribution.

- When new timber harvests are initiated in planning watersheds with a priority category 1 or 2 ranking, identify harvest units on soils with a high erosion hazard rating and ensure that harvest unit design and road conditions minimize the potential for sediment delivery to streams. Potential sediment delivery could be from a road that drains to a stream or directly to a stream through a riparian area.

- In planning watersheds with a priority category 1 or 2 ranking, identify areas within timber harvest units where flow concentration could potentially occur due to topography. Install drain features that route flow from concentration areas off of harvest units and onto vegetated areas for filtration. Berm inlet assemblies and flumes can be installed adjacent to Class I or II watercourses where natural energy dissipaters are not present. Design variable retention of trees in clumps in flow concentration areas to act as filters, where appropriate.

- When new timber harvests are initiated in planning watersheds with a priority category 1 ranking, evaluate adjacent stream channels for stream bank stability. If areas of potential stream bank instability are identified, avoid streamside tree harvests, especially those trees whose root systems contribute to bank stability along Class I and II watercourses.

- In planning watersheds with a priority category 1 ranking, avoid or minimize harvest units that span across or include both sides of a Class I or II watercourse.

- In planning watersheds with a priority category 1 or 2 ranking, no tractor operations should occur on slopes greater than 50 percent that lead, without flattening, to a Class I or II watercourse. If exceptions are proposed, provide site-specific measures to minimize effects of operations.

- To the greatest extent feasible, minimize the number of roads constructed in riparian zones adjacent to Class I and II watercourses except for stream crossings. When roads must be located adjacent to Class I and II watercourses, stabilize all fills and minimize side casting. Use equipment exclusion zones for existing roads in the riparian areas, especially adjacent to Class I and II watercourses. Exposed soils in riparian zones will be treated according to California Forest Practice Rules.

- Roads should be constructed with outsloping road surfaces. When necessary to inslope, provide inside ditches with cross drains.

Management Measures – National Forest System Lands

The management measures described below are summarized from existing USDA Forest Service documents. This approach is taken because the Forest Service has conducted a variety of evaluations and inventories addressing erosion and sediment delivery issues and appropriate management measures. Based on the evaluation in this document, these management measures are considered appropriate to address existing legacy conditions and, in combination with the Forest Service BMP monitoring program, are appropriate to address sediment issues within the North Fork/Middle Fork American River watershed. Additionally, the risk-based subwatershed prioritization approach used in this analysis can be incorporated into overall program development on these national forests. As noted in the Forest Service reports (USDA Forest Service 2003b, 2004a), however, it must be recognized that the Forest Service does not receive adequate funding to conduct the road maintenance they recognize as necessary. In particular, the National Forest System roads are increasingly used for recreational access by rapidly increasing local and regional populations. Many of these forest roads were originally designed for short-term timber management access and transportation and do not meet the needs of other uses.

The following management measures are recommended for National Forest System lands:

- Reduce road densities by focusing on non-system road closures.
- Reduce the number of stream crossings.
- Improve the design and condition of existing stream crossings.
- Focus road maintenance funding in watersheds or subwatersheds with the highest levels of near-stream roads.
- Hydrologically disconnect roads from streams. Inside and lead-off ditches should not drain to streams but rather should dissipate flow onto relatively flat areas away from streams.
- Perform more field reconnaissance and channel condition evaluation in watersheds or subwatersheds with higher levels of disturbance before completion of project planning.
- Complete road work in highly roaded and highly sensitive watersheds or subwatersheds prior to conducting other forest management activities.
- Rehabilitate off-road vehicle routes identified in roads analyses.
- Rehabilitate user-created roads and trails.
- Eliminate raw stream crossings (i.e., roads crossing physically through streams without any designed road bed, culvert, or bridge), particularly when the road is used daily.
- Coordinate with state, county, and local public road agencies to foster and administer a seamless road system with consistent road standards, maintenance, and improvements, and interface with residential development.
- Conduct periodic training of all staff to ensure that management measures (i.e., BMPs) are implemented and effective.
- Continue to review implementation of riparian conservation areas (i.e., streamside management zones), particularly with respect to width, management prescriptions, and mechanical equipment exclusion.

- Continue to emphasize road maintenance, particularly with respect to road surface drainage and hillslope protection.
- Continue to evaluate and meet riparian conservation objectives during project planning.
- Continue to evaluate and reduce cumulative watershed effects during project planning.

Available Resources

Many of the resources identified in Sections 5.2.1 and 5.2.2 are appropriate for forestry-related land use. In addition, there is an extensive body of professional literature on inventory, evaluation, and techniques for roads, streams, riparian zones, and hillsides that is not reviewed here. Some additional resources, however, are listed below.

(1) California Nonpoint Source Encyclopedia

Section 4.2 Forestry of the *California Nonpoint Source Encyclopedia* contains a review of California Forest Practice Rules and other management measures that can applied to road maintenance, revegetation, and other forestry-related operations. It is available at:
http://www.swrcb.ca.gov/nps/encyclopedia.html

(2) Fire Restoration

The USDA Forest Service provides a detailed manual of treatments, including the *Burned Area Emergency Treatments Catalog*, that can be used to stabilize hillside soils, stream channels, and roads after wildland fires. The manual is available at:
http://www.fs.fed.us/eng/pubs/pdf/BEARCAT/hi_res/06251801.pdf

(3) Roadside Management

The USDA Forest Service provides a useful manual on bioengineering techniques for addressing roadside erosion in *Soil Bioengineering – An Alternative for Roadside Management,* available at:
http://www.fs.fed.us/eng/pubs/pdf/00771801.pdf

(4) Channel and Bank Protection Measures

In 2005, the Transportation Research Board published a document addressing *Environmentally Sensitive Channel- and Bank-protection Measures*. This document and its accompanying interactive software (via CD or download) provide information on how to select, design, and implement stream protection measures. It is available at:
http://www.trb.org/news/blurb_detail.asp?id=5617

(5) California Forest Stewardship Program

This program is designed to encourage good stewardship of forests managed by private parties. This organization provides both technical and financial assistance to promote positive changes in forest management, and assists communities in solving watershed problems cooperatively. Program information is available at:
http://ceres.ca.gov/foreststeward/index.html

(6) U.S. Environmental Protection Agency Watershed Academy Web: Forestry Best Management

The following site provides a training program for forestry BMPs designed to improve water quality:
http://www.epa.gov/watertrain/forestry/forestry5.htm

(7) California Salmonid Stream Habitat Restoration Manual

This document includes detailed information on revegetation practices useful for erosion control efforts to protect instream resources. It is available at:
http://www.dfg.ca.gov/nafwb/manual.html

The “Upslope Erosion Inventory and Sediment Control Guidance” is part of the *California Salmonid Stream Habitat Restoration Manual*. This section is tailored to the identification of erosion problems and provides case studies for details on implementation and costs of upslope erosion control.

5.2.4 Mining

An additional land use that occurs in the watershed that is not included in the above discussions is mining. Historical mines are the primary concern in the North Fork/Middle Fork American River watershed. The condition of historical mines is a data gap that has been identified during this study. An inventory of historical mine sites with respect to the potential for sediment delivery is recommended. Management actions would then be developed at the site-level for those mines with high sediment delivery potential or other pollution concerns associated with surface runoff. Aggregate mining operations are currently guided by existing mining regulations and inspections, and are not part of the identified data gap. Similarly, existing small mining operations are managed through small operations plans that are submitted to the forest managers (if they are on National Forest System lands) and other regulators, so these are not part of the identified data gap.

Available Resources

Severely disturbed mining sites are similar to construction sites in terms of bare soils and hydrologic responses. Consequently, many of the resources identified under Sections 5.2.1 and 5.2.2 are applicable to mining. In particular, see the county stormwater control manuals and construction site management measures, such as San Francisco Regional Water Quality Control Board (2002) and Fifield (2004), and the available resources identified under Fire Restoration, Channel and Streambank Protection Measures, and the California Salmonid Stream Habitat Restoration Manual.

(1) *Rehabilitation of Disturbed Lands in California*

The California Geological Survey Special Publication 123 *Rehabilitation of Disturbed Lands in California: A Manual for Decision Making* assembles a variety of information pertinent to the restoration of severely disturbed lands. This publication is currently available from the California Geological Survey for $25.00. See the following Web site for more information: http://www.consrv.ca.gov/CGS/information/publications/pub_index/issue_papers.htm

(2) *California Surface Mining and Reclamation Policies and Procedures*

Also currently available from the California Geological Survey for $25.00 is Special Publication 51, *California Surface Mining and Reclamation Policies and Procedures*. Although this document relates primarily to new and existing mines, it contains information pertinent to rehabilitating historical mines.

5.3 Risk-based Prioritization and Watershed Enhancement Opportunities

In this section the risk-based prioritization of 7th-level subwatersheds and related priority categories rankings (1, 2, and 3) are addressed with respect to enhancement opportunities. To maintain key resources, these watershed enhancement opportunities are addressed by two strategies. The first strategy is the protection (through disturbance minimization) of potential adverse effects from new activities (e.g., infrastructures, development, agriculture, forestry, roads). The second strategy is active restoration.

As in all applications of this assessment, the reader should note that the assignment of potential risk and priority categories is based on broad subwatershed characteristics. Consequently, only specific portions of a priority category 1 or 2 subwatershed (7th - level HUC subwatershed) may actually be high-risk sites. Similarly, priority category 3 subwatersheds, although generally low risk, may have localized high-risk sites. This approach is useful for comparing and distinguishing between subwatersheds, but this watershed assessment should not be used for site-specific or project-level interpretations. Rather it should be used as one guide to the types of risk factors to assess when conducting a site-specific evaluation.

5.3.1 Relationships between Priority Ranking and Watershed Protection and Restoration

Priority category 1 subwatersheds generally have a combination of all high, or high and moderate potential risk ratings for Hillslope Sensitivity Index (HSI), Road Impact Index (RII), and Stream Sensitivity Index (SSI) (see Table 4-24). These subwatersheds have the highest inherent risk for sediment production and delivery to downstream key resources, as well as high or moderate risk from human land-use impacts (such as roads). Consequently, these subwatersheds are a high priority in which to manage new impacts by disturbance minimization measures. They are also a high priority for seeking active restoration opportunities because they are the most likely to have soil erosion and sediment delivery issues associated with their intrinsic physical characteristics and their level of development. Consequently, active restoration activities would have the greatest potential to minimize possible ongoing impacts.

Priority category 2 subwatersheds generally have moderate potential risk ratings for HSI, RII, and SSI, indicating an intermediate level of inherent risk for sediment production and delivery to downstream key resources (see Table 4-24). Because there is a moderate risk of sediment delivery from natural conditions and a moderate risk from development, degradation of downstream key resources is a potential issue. All the priority category 2 subwatersheds have a high priority for disturbance minimization and a second-tier priority for active restoration activities compared to priority category 1 subwatersheds. However, the priority category 2 group includes two subwatersheds that have high rating for RII combined with a moderate rating for both HSI and SSI. These two subwatersheds are (see Table 4-25) Shirttail Canyon – Grizzly Canyon and Lower Shirttail Canon.

Because of their level of development, both of these subwatersheds would have a high priority for active restoration among the priority category 2 subwatersheds, and a more-detailed inventory might elevate them to priority category 1. The priority category 2 group also includes six subwatersheds that have high ratings for HSI and SSI but a low rating for RII, which places them into priority category 2 rather than priority category 1. Increased development in these subwatersheds, however, would have the potential to increase their management-related risk so that they would be elevated to priority category 1. These six subwatersheds are (see Table 4-25 and Table 4-26):

- Lower Long Canyon,
- North Fork American River – Wildcat Canyon,
- North Fork American River – Sailor Canyon,
- North Fork American River – Big Granite Creek,
- North Fork American River – Humbug Bar, and
- North Fork American River – Giant Gap.

For these priority category 2 subwatersheds, the disturbance minimization strategy could be especially important to prevent potential future effects. However, several of these subwatersheds are generally dominated by the deep inner canyon of the North Fork American River (i.e., Giant Gap, Humbug Bar) or occur in portions of the upper part of the watershed (i.e., Wildcat Canyon, Sailor Canyon), which have minimal potential for future development. Big Granite Creek and Lower Long Canyon subwatersheds, however, have some potential for development or human land-use impacts because of the presence of private lands.

Priority category 3 subwatersheds generally have a low potential risk rating for HSI, RII, and SSI (see Table 4-24), indicating the lowest potential for a high level of sediment production and downstream delivery to key resources. These subwatersheds are considered as lowest priority in terms of active restoration, implementation of disturbance minimization measures, and funding for these watershed enhancement activities. Degraded site-specific conditions may warrant the application of measures suggested for priority category 1 or 2 subwatersheds. These could be applied at a specific site to provide more aggressive treatment of soil erosion and sediment delivery problems.

5.3.2 Targeting and Optimization for Watershed Enhancement

As noted above, the two strategies for watershed enhancement are disturbance minimization and active restoration. The basis for the disturbance minimization and active restoration recommendation is derived from accumulating experience as reflected in the literature and agency prioritization activities for cost-effectiveness. Conservation literature encourages protecting high-quality habitat and key watershed processes as a first priority before active restoration takes place. Protection of functional habitats and watershed processes should take priority over active restoration actions because maintaining functional habitats is easier, less expensive, and more successful than restoring degraded habitats (Beechie and others 2003; Bilby and others 2003; Roni and others 2002). As noted in Section 3.8, water quality in the North Fork/Middle Fork American River watershed is generally good. Consequently, maintaining the existing level of water quality and minimizing the potential for delivery of excess sediment to key resources should be a high priority in the entire watershed.

Because active restoration activities can be expensive, there is a particular need to ensure that such activities achieve maximum benefits. For example, Bernhardt and others (2005) evaluated river restoration efforts across the United States. They found that river restoration commonly: lacks a solid conceptual model of river ecosystems, lacks recognition of multiple interacting temporal and spatial scales, focuses on a single isolated river reach, and focuses on creating a desired channel type that is artificially constrained (Bernhardt and others 2005; Wohl and others 2006). Consequently, in-channel restoration activities are generally more difficult to design and successfully implement (e.g., Kondolf 1998; Kondolf and others 2001). One such inchannel enhancement project in the North Fork/Middle Fork American River watershed is the Ralston Afterbay sediment management project (Jones and Stokes 2002). This project evaluated opportunities for the downstream transfer of coarse sediment past the afterbay. Projects such as these require substantial investments (both time and financial) by participants and years to design, implement, and evaluate. Consequently, actions related to active restoration strategies discussed below concentrate on upland restoration rather than inchannel restoration.

Disturbance Minimization

Minimization of further disturbance is a high priority for priority category 1 and 2 subwatersheds in the North Fork/Middle Fork American River watershed. Ground-disturbing activities can be designed to minimize impacts in sensitive portions of these subwatersheds, which have a higher potential to deliver sediment and impact downstream key resources. In areas where human activity-related mass wasting events are prevalent or high levels of surface erosion are occurring, efforts to revegetate bare ground are recommended. At sites where natural mass wasting events are prevalent or high levels of surface erosion are occurring, more detailed site-specific information would be required to ensure that natural instability could be effective, both physically and in terms of cost. More disturbance minimization measures are identified below.

- When road development is necessary, minimize the impacts by careful location and good design to avoid sediment delivery to the maximum extent feasible and to minimize hydrologic modification.
- When activities occur in an isolated area, perform other road maintenance or enhancement activities (such as installing water bars, ditch relief culverts, rocking road crossings) along other road segments in the area to the extent feasible to minimize overall roads-related impacts.
- When conducting ground-disturbing activities, implement management measures appropriate to the type of activities to avoid sediment delivery to the maximum extent feasible and to minimize hydrologic modification.
- When designing housing, commercial, or industrial developments, consider incorporating LID measures to maintain hydrologic function.
- Avoid the soil erosion and hydrologic impacts from uncontrolled forest fires by implementing vegetation thinning projects and defensible space for wildfire control.
- When designing fire prevention-related vegetation thinning projects in the urban-wildland interface, incorporate opportunities to minimize future soil erosion and hydrologic impacts while giving first consideration to protecting life, homes, and infrastructure.
- When designing wildfire prevention-related vegetation thinning projects in the forest away from the urban-wildland interface, incorporate opportunities to minimize future soil erosion and hydrologic impacts with other resource needs. For example, in identified high erosion hazard or high landslide-prone areas with high sediment delivery potential, thin the vegetation to minimize the potential impacts from catastrophic wildfires.
- Promote and implement ongoing conservation practices for agriculture, grazing, and homes.
- Identify and address any site-specific erosion problems or sediment sources.

Active Restoration

The subwatersheds for active restoration represent the highest risk for sediment delivery, with high natural potential exacerbated by human activities and road construction, and a high potential for sediment transport. Watershed enhancement actions should focus in these areas to reduce the risk of sediment contributions from road conditions and associated land uses.

As mentioned throughout this report, the watershed prioritization provides suggestions for strategic priorities to target watershed enhancement practices. A subwatershed with a low priority ranking should still receive site-specific attention to prevent sedimentation from localized soil erosion sources. Conversely, a subwatershed with a high priority ranking may not have identified erosion or sedimentation concerns, particularly under adequate vegetative cover and drainage conditions.

In the long term, it is important to address the causes of excess sediment delivery to key resources as a higher priority than restoring symptoms of disturbance. Restoring watershed processes that form, connect, and sustain habitats and water quality supports improving the long-term health of a watershed. Key watershed processes include the delivery and movement of sediment, wood, water, and nutrients to the aquatic system. Restoring watershed processes often has a delayed response time. Costs of these projects can vary; however, they have a high probability of success and low variability between projects (Oregon Watershed Enhancement Board 2003).

For restoration action prioritization, the current literature focuses on those actions that have a high probability of success, low variability among projects, and relatively quick response time for improvements (e.g., Palmer and others 2005). Maintaining or modifying vegetation to improve soil stability and the interception and infiltration of precipitation also has the potential to affect water storage in the soil and the delivery to streams (Oregon Watershed Enhancement Board 2003; Palmer and others 2005). Soil stability is a key factor in the function of upland ecosystems.

Encouraging management practices that focus on protecting and maintaining soil integrity through minimizing disturbance and erosion will help restore upland plant systems. These practices include, but are not limited to, using rotational grazing systems, maintaining recommended residual dry matter on grazing lands, using conservation tillage and conservation irrigation techniques, maintaining continuous plant cover, and implementing timber harvesting practices that minimize the potential for sediment delivery to stream channels and hydrologic alterations. Such practices may have a relatively high probability of success but may also have long response times with respect to instream conditions (Oregon Watershed Enhancement Board 2003; Palmer and others 2005).

The scale for restoration efforts affects the prioritization efforts. At the project site scale, the decisions are about design and other tactical issues such as access. At a watershed scale, the focus is on the processes (i.e., sediment transport and deposition, organic material transport, precipitation interception) that are affected by current land uses and historical resource conditions.

In this watershed assessment, roads were used as a surrogate for the range of human land uses that can cause increased soil erosion and sediment delivery, and cause hydrological alteration. Roads, however, are also a substantial contributor of sediment and hydrologic modification (Coe 2006; Ice and others 2004; Monitoring Study Group 2006). Consequently, addressing roads is an important component of active restoration. As noted in Section 5.2.3, however, adequate funding for road maintenance does not exist and substantial budgets for road enhancement or decommissioning are not likely in the near future. Therefore, determining ways to maximize sediment reduction with available budgets is important. Madej and others (2006) present one approach to developing optimization strategies for sediment reduction in steep, forested terrain. Their analysis demonstrates that optimization strategies perform better than the application of a uniform erosion control strategy. The existing roads analyses conducted by the Tahoe National Forest and Eldorado National Forest present opportunities to implement such optimization strategies. Also note that in all the priority category 1 subwatersheds, the dominant land use is forestry—either private or National Forest System lands. Consequently, the restoration activities presented relate to forest roads, timber harvest, wildland fire prevention, and related circumstances. A list of actions for these roads and other hillslope restoration are presented below.

- Take any opportunity to decommission roads. At road-stream crossings, at least excavate the drainage structure (commonly culverts) and excavate road material down to the original stream bed.

- Take any opportunity to improve roads. When activities occur in an isolated area, perform other road maintenance or enhancement activities (such as installing water bars, ditch relief culverts, or rocking road crossings) to the extent feasible to cost-effectively maximize impact avoidance.

- Use existing road inventories or conduct new inventories to identify sediment delivery issues, either quantitatively or qualitatively. Develop a restoration priority sequence. Incorporate any new information that indicates impacts on key resources into the restoration prioritization decision.

- Determine road treatment optimization strategies to maximize the reduction of sediment and hydrologic impacts. Use available scientific literature, research projects, monitoring reports, and professional judgment to:

  — Upgrade road-stream crossings,
  — Control gully erosion, and
  — Stabilize road-related landslides.

- Identify and address human-caused upland site erosion problems, including surface erosion and landslides. Use existing inventories or new inventories (quantitative or qualitative) to place the sites in context and to prioritize restoration activities. Incorporate any new information that indicates impacts on key resources into the restoration prioritization decision.

- Revegetate areas where vegetation has been removed when these sites are delivering sediment to streams. Sites may be past forest fires, timber harvest units that do not meet revegetation requirements, or recreational sites.

- Establish or enhance riparian vegetation in areas where upslope erosion is delivering sediment to stream channels. In timber harvest units or tree thinning projects, place ground cover (mulching, rip-rapping, grass seeding, soil stabilizers) as appropriate to meet cover requirements.

- Inventory nonpoint source erosion issues from legacy mines, establish a restoration prioritization sequence, and design site-specific erosion control measures.

- When designing wildfire prevention-related vegetation thinning projects, incorporate opportunities to minimize future soil erosion and hydrologic impacts with other resource needs, e.g., identify high erosion hazard or high landslide-prone areas with high sediment delivery potential, and thin the vegetation in these areas to minimize the potential impacts from catastrophic wildfires.

5.4 Coordinated Implementation and Collaborative Process

For successful implementation of the management strategies, a coordinated and collaborative process is needed to facilitate a systematic approach and to build the necessary partnerships. The implementation priorities are determined by potential risk of soil erosion and sediment delivery, and are based on a prioritization-targeting-optimization strategy for cost-effectiveness. Efforts to encourage collaboration on watershed enhancement opportunities would utilize the resources available in the American River Watershed Group and the ARWG TAC.

Collaboration actually involves stakeholders in the decision-making process, where education and outreach involve sharing of information with stakeholders and interested parties, but do not, by definition, involve them in the decision-making process.

Yaffee and Wondolleck (2000) identify the following realizations of successful collaboration processes in natural resource management:

- Participants are focused on shared goals and common problems with a sense of urgency and/or a strong sense of place.
- Participants identify with a geographic location or a community.
- A process is established to articulate shared goals to help participants realize interdependence in the group.
- Joint mission or vision statements lead to solutions to shared problems.
- Participants focus on shared places through field trips or restoration activities.
- Fragmentation of the landscape across geographic, political, and land ownership boundaries requires collaboration.
- Collaboration is part of life in a diverse society, and results are more successful and less intrusive than a "command and control" approach.
- Collaboration can produce better decisions through the exploration of shared and individual concerns, information sharing, and creative solutions, as compared to regulatory approaches which generally promote a single approach.
- Collaboration can improve the chances of program implementation because involvement in crafting the program breaks down resistance to implementing management practices.

- Technical advisory committees are used in successful collaboration efforts as an adjunct to stakeholder groups to provide a source of credible scientific review.
- Human relationships in collaborative processes are supported by shared activities outside of the immediate work process.
- Successful outcomes should clearly connect people's efforts to substantive changes in decisions.
- Leaders of the process who focus on objectives, not procedures, and who evaluate performance based on progress toward objectives foster more creative and solution-oriented participation.
- Part of effective collaboration is incorporating independent science and measurable performance measures.

Encouraging stakeholder involvement early in the process will help to ensure successful implementation of the management strategy. Group decision making involves several phases that follow a logical progression. These phases (as outlined below) can be applied to the "steps to select management practices" presented in EPA (2005, Chapter 10, page 10-10) for the development of a watershed enhancement plan.

1. Early consultation is used to determine key interests and concerns as well as the level of interest of the various parties in the process.
2. Initial planning includes a determination of the decision-making process to be used, the key parties affected by the decision (due to proximity, economic situation, responsibilities, or personal values), a determination of the information needs, and clarification of the objectives for the public involvement.
3. Action plan development includes determining the activities that will involve the public and the stakeholders, and committing resources to support those activities.
4. Implementing the program will be an ongoing effort as funding is secured from stakeholders and outside funding groups.
5. Monitoring and evaluating the program will begin before implementation, with the collection of baseline data for the sites of greatest concern. Additionally, watershed-level status and trend information is helpful in determining the larger-scale effectiveness of project activities.
6. Post-implementation feedback includes reporting back to the planning group and the sponsoring agency on the effectiveness or success of the program.

Funding for implementation can be secured from a variety of sources. Funding sources include: CalFed Watershed Programs (through Proposition 13 and Proposition 50), California Department of Conservation, California Forest Stewardship Program, California Department of Fish and Game (Fisheries Restoration Grant Program), Department of Parks and Recreation (through Proposition 40), Proposition 84, and many other sources listed at the California Department of Water Resources Web site (http://www.watershedrestoration.water.ca.gov/urbanstreams/money4cks/).

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CHAPTER 6: MONITORING FRAMEWORK FOR ADAPTIVE MANAGEMENT

6.1 Introduction

The purpose of Chapter 6 is to describe a framework for a watershed-scale erosion and sedimentation monitoring program in an adaptive management context and in a collaborative, non-regulatory setting. The framework provides essential background information for the development of a monitoring plan. The monitoring plan should provide details on the objectives and critical questions, environmental indicators, design and implementation components, performance targets, and evaluation components.

An adaptive management approach is a key element of any ecosystem-based strategy. This approach is also referred to as “learning by doing” because management actions are treated as scientific experiments. In adaptive management, monitoring is integrated with management (linking science with management) for a continuous feedback and adjustment loop to improve management actions. Monitoring is the collection of data relevant to management objectives. If monitoring is integrated with management, adequately designed, and effectively implemented (with clear goals and specific objectives), it will allow us to evaluate how well the management actions meet their objectives and what actions to take to modify management practices to achieve desired outcomes. Adaptive management is essential when there are gaps in critical data and knowledge.

For a successful monitoring program in the North Fork/Middle Fork American River watershed, the following four-steps should be considered:

1. Identify information needs and develop specific monitoring objectives and critical questions;

2. Survey and evaluate existing monitoring efforts relevant to the objectives and critical questions;

3. Develop a monitoring plan integrated with the management actions, with the monitoring plan including objectives and critical questions, specific indicators, sampling design (both spatial and temporal scales) and statistical methods, quality management (quality assurance/quality control), implementation of monitoring activities, and evaluation of performance targets; and

4. Promote a coordinated and collaborative process to facilitate a systematic approach and build public and private partnerships for watershed monitoring and knowledge-based decision making.

Foreseeable challenges in implementation of the adaptive management approach are as follows: (1) deciding on the specific indicators to measure and how to measure them to detect changes; (2) choosing criteria to determine when an indicator is within the desired condition range and a response when it is outside that range; and (3) developing integrative procedures for the feedback and adjustment loop for continuous improvement in management practices.

6.2 Types of Monitoring

Three basic types of monitoring are applied by resources agencies and other organizations to meet specific management objectives in a regulator or non-regulatory setting and to evaluate the efficacy of management actions.

6.2.1 Implementation Monitoring

Implementation monitoring is usually defined as an evaluation of whether or not a specific action has occurred as planned. In other words, determining whether we did what we said we would do, and did it correctly. A variant called compliance monitoring is used to evaluate if an action meets regulatory standards and agency guidelines. Implementation monitoring provides baseline information before and immediately after a project occurs. Examples of implementation monitoring that is currently occurring in the North Fork/Middle Fork American River watershed are the BMP implementation monitoring programs conducted by the Tahoe and Eldorado National Forests. The monitoring itself occurs at the project level to evaluate specific practices, but it can be expanded to include similar types of projects to make comparisons between actions. In a review of timber harvest plan on private forestlands, Brandow and others (2006) found that 64 percent of watercourse crossings monitored had acceptable implementation of all applicable California Forest Practice Rules-related standards and guidelines.

6.2.2 Effectiveness Monitoring

Effectiveness monitoring is defined as an evaluation of whether or not the properly installed or implemented action is having the desired effects to achieve the management objectives. If the action is having undesirable effects, this should be revealed through effectiveness monitoring. Effectiveness monitoring can be conducted at a variety of scales and levels and is often the most used type of monitoring for watershed restoration evaluation. Effectiveness monitoring and evaluation of BMPs for watershed protection are important. Brandow and others (2006) found that California Forest Practice Rules were highly effective in preventing erosion, sedimentation, and sediment transport to channels.

Table 6-1 provides relevant information on the resources and outcomes from different levels of effectiveness monitoring. Using the background information, watershed groups can decide what level of understanding is desired and what commitment of resources would be required for each level of understanding. Effectiveness monitoring can be used at the project scale or at the watershed scale. Project-level effectiveness monitoring should target specific indicators likely to be affected by the project actions, and should include a reference area to capture environmental variability. For quantified measurements, baseline conditions at the site should be measured prior to the action at both control and treatment sites, which will allow for a Before and After Control Impact (BACI) sample design (Stewart-Oaten and others 1986).

Table 6-1. Effectiveness Monitoring Process Matrix (adapted from Dissmeyer 1994).

Level	Questions or Issues	Quality of Data for Decision Making	Skill Levels	Amount of Data Collected	Streams Evaluated	Time to Decision on Effectiveness
1	Screen projects for an obvious yes or no on effectiveness.	Qualitative data and observation; Obvious good or bad recognized; Large uncertainty	One or two trained professionals with knowledge and experience and a technician	Small to moderate amount	Many	A few hours to 1 or 2 days to a week
2	Determine effectiveness of projects on high-value streams.	Quantitative and qualitative data; Moderate amount of precision; Moderate uncertainty	Two professionals trained in hydrology, fisheries, habitat, invertebrates, plus technicians	Moderate to large amount	Many	2 weeks to a month
3	When high-value resources are at stake, produce information to modify practices.	Quantitative data, limited qualitative data; Good precision to detect significant impacts; Minor uncertainty	Professionals in statistics, hydrology, fisheries, invertebrates, channel geomorphology, plus technicians	Large to very large amount–extensive data management system needed	Limited number	2 to 3 months for individual projects; Watershed studies require 1 to 3 years
4	Understand cause-and-effect relationships, and modify practices.	Quantitative data, very little qualitative data; Good precision to detect small changes; Very minor uncertainty	Same as level 3, but many are likely to be researchers	Very large amount–extensive data management system	Very limited number	2, 3, or more years

6.2.3 Status and Trends Monitoring

Status monitoring is the determination of the current conditions of a parameter of interest, also referred to as establishing a baseline. This type of monitoring is often called baseline conditions monitoring and is best conducted before other types of monitoring, as it provides the starting point for any management actions. In addition, this baseline should be placed in the context of the natural variability of a given parameter in a given system. Systems with large infrequent disturbances (like those caused by landslides) are likely to have higher natural variability than those with more chronic issues (such as surface erosion) (MacDonald 2000). Detecting a trend or a signal is more difficult in areas with high natural variability.

There are multiple controls on stream channels and a wide variety of potential historical channel conditions based on location and geomorphic setting. Efforts to assess channel condition must specifically examine the location within the channel network, channel type, the timing of sediment inputs to the channel, historical landscape conditions, and the expected persistence of inputs over space and time.

Trend monitoring is the evaluation of ecological or environmental changes over time, usually over a rather broad geographic area, such as a river basin or watershed. Over an extended time period, trend monitoring should detect whether or not the status of watersheds and/or associated organisms is improving or degenerating (California

Department of Fish and Game 2006). Establishing baseline conditions can be difficult in watersheds that are already heavily impacted by humans (Marin County 2004).

Each of the monitoring types identified above provide relevant information to answer the basic evaluation questions of most watershed monitoring programs.

6.3 Quality Management and Information Sharing

For a science-based monitoring strategy that could be used to make informed decisions, data should be collected using a systematic approach with focused objectives, indicators and design components, a quality management plan, coordinated and collaborative processes, and support for sharing information.

6.3.1 Quality Assurance and Quality Control

Quality assurance involves requiring proper training of personnel, using standardized written protocols, and making sure that survey staff has adequate equipment and resources to conduct the monitoring effort. Quality control includes actions to ensure that data collection is complete and accurate. These measures include checking field forms to ensure data fields are filled out appropriately and completely, making sure that measurements in the field are collected accurately, and carrying out procedures to ensure that data are not lost or entered incorrectly between collection and analysis. A sound quality assurance/quality control program and timely training programs must be in place when using volunteers to ensure that the data collected are usable and reliable. Several state programs provide information on preparing Quality Assurance Project Plans (QAPPs). For example, the SWAMP has an expert advisor for compiling QAPPs (see http://www.swrcb.ca.gov/swamp/qapp.html). QAPP guidance and templates for citizen's monitoring are located at http://www.waterboards.ca.gov/nps/funding.html.

Citizen monitoring can be a useful component of a monitoring program. Citizen monitoring should be integrated into the monitoring framework and must incorporate a quality assurance and quality control procedure. Additionally, the results of citizen monitoring should be evaluated and interpreted by specialists with the appropriate technical backgrounds.

6.3.2 Data Management and Sharing

The California Data Exchange Center (CDEC) installs, maintains, and operates an extensive hydrologic data collection network. The existing data are available at CDEC (2006). The CDEC provides a centralized location to store and process real-time data gathered by various cooperators throughout the state. Currently, numerous federal, state, and local agencies, and private-sector groups collect data from rain, snow, temperature, wind, atmospheric pressure, humidity, and stream stage sensors. The CDEC could serve as a repository for the storage and dissemination of sediment monitoring data from the North Fork/Middle Fork American River watershed. Building public and partnerships can improve the support for sharing information.

6.4 Monitoring Scales and Design Concepts

Establishing the scale of the monitoring effort depends on the management decisions to be made from the information collected through monitoring. Both temporal and spatial scales should be considered when designing a monitoring program for the effects of actions to reduce erosion and sediment delivery to aquatic system. Short-term fluctuations in sediment transport rates at the site or project scale cannot be compared to annual changes in sedimentation rate at the watershed scale, but both provide important information for land management decisions. However, different levels of resources are required to determine the levels of change in those parameters. For example, localized sediment transport can be measured during one storm event, while the establishment of annual sediment yield at the watershed scale can take over a decade of sampling (Bunte and MacDonald 1999).

Additionally, the response time for a management action must be taken into account when planning a monitoring program. If sediment may take years to decades to move from the source to the area where key resources are located (as in the case of loss of root strength following timber harvest), then the monitoring program to measure this response needs to be maintained over that same time period (Bunte and MacDonald 1999). Other effects such as surface erosion from road construction can be seen in days to a year after the action, so a shorter-term monitoring approach is recommended (Bunte and MacDonald 1999). For some responses, a 5- to 10-year interval for change assessment may be appropriate, but for others no significant changes are expected to occur in 5 to 10 years. For other responses, more frequent data collection is appropriate. This timeframe issue for monitoring may be resolved with careful consideration of sampling design to detect measurable changes.

From a spatial perspective, the watershed modeling and prioritization for the North Fork/Middle Fork American River was conducted at the 7th-level HUC or larger subwatershed scale. However, projects are implemented at the site scale, and the effectiveness of specific projects is integral in evaluating the success of the program. Monitoring can be conducted at both the project and the watershed scales to evaluate specific management practices. As mentioned above, monitoring at the project level should include baseline and post implementation monitoring, and also monitoring at a reference area whenever possible. The use of a BACI sample design for project-level monitoring allows for a high level of statistical power from a smaller number of samples because the environmental variation (e.g., noise) is accounted for by the control area. More information on this sampling design concept can be found in Stewart-Oaten and others (1986). Additionally, these data can be compared using a paired sample approach for statistical analysis. Using a reference area to account for natural environmental variability allows for the differences observed in specific indicators to be attributed to the watershed improvement actions instead of background environmental change.

Watershed-scale monitoring is best conducted using a spatially balanced probability design such that conclusions can be made about the watershed with confidence that the monitoring results are actually representative of the watershed conditions. The monitoring results can be extrapolated to a target population with known confidence. A spatially balanced probability design, or Generalized Random-Tessellation Stratified Design (GRTS) (Stevens and Olsen 2004), allows for spatial relationships among sites, accurate and relevant site representation, the ability to focus on multiple sample populations, and the ability to evolve with changing goals and objectives. For example, GRTS can be used to select sample sites covering stream networks in the North Fork/Middle Fork American River watershed. The sites are selected using an algorithm that maintains the spatial balance using the order in which the sites are selected. A target sample size for a stream-based study can be selected by proceeding down the ordered list of sample locations for a specific class of sample types until the desired number of sample sites is reached. Within a 7th-level HUC subwatershed or within the entire watershed assessment area, if data are collected the same way, they can be combined at multiple spatial scales. More information on this design concept is presented in Stevens and others (in press).

The level of precision required to detect the desired change can be traced back to the original level of change stated in the objectives of the monitoring program. This desired level of precision can be used with a pilot study to conduct a power analysis to determine the number of samples that will be required to assess whether the change in the specific indicators measured in the program was significant. Zar (1996) contains more information on conducting a power analysis. A qualified statistician should be consulted on sampling design and statistical analysis components before implementation of a comprehensive monitoring strategy. Determination of the critical questions and objectives, specific environmental indicators, sampling protocols (including stratification), and statistical analysis methods needs to be completed before data are collected. Otherwise, it is likely that insufficient data will be collected, the monitoring objectives will not be met, and the critical questions will remain unanswered.

Overall, time, space, and rates of change are essential criteria for monitoring the existing hillslope and channel processes. Characteristics of good indicators (or diagnostic features) for monitoring environmental changes within a watershed, in addition to those described by MacDonald and others (1991), include those that (Regional Interagency Executive Committee 1995):

- Are sensitive and responsive to management actions,
- Have low spatial and temporal variability,
- Are easy to measure (accurate and precise),
- Relate directly to beneficial uses of the watershed,
- Are early warning indicators, and
- Represent broader or more complex ecological processes or subsystems.

Although primarily used for bioassessment applications, the California Surface Water Ambient Monitoring Program (SWAMP) addresses many aspects of stream site selection methodologies, including the use of a probabilistic monitoring approach (see http://www.swrcb.ca.gov/swamp/reports.html). It utilizes the EPA wadeable streams methodologies (Peck and others 2003), and specific reports that would be useful for consideration in the North Fork/Middle Fork American River watershed include Ode (2002) and Ode and Rehn (2005).

6.5 Approaches to Monitoring Sediment Regime

A comprehensive monitoring strategy to evaluate the rates of soil erosion and sediment delivery in the North Fork/Middle Fork American River watershed needs to be tied to the erosion processes, sediment sources, and transport processes discussed in Section 3.12.

The watershed erosion and sedimentation hazard includes hillslope, stream channel, and hydrologic processes that affect water quality and aquatic habitats (through fine and coarse sediment). In addition, roads and other land-use activities impact the sediment and hydrologic regimes in the watershed.

6.5.1 Hillslope Processes

Hillslope erosion processes include mass wasting and surface erosion. These processes generally involve the movement of sediment downhill and are often exacerbated by high precipitation and by roads along steep or unstable hillslopes. In the North Fork/Middle Fork American River watershed, the areas with the highest risk for mass wasting are steeper hillslopes where a contact plane exists between the Mehrten and Valley Springs formations that are intersected by a road. Monitoring of hillslope processes can be accomplished in a variety of simple ways (e.g., Lewis and others n.d.). However, more detailed measurements may be warranted and monitoring can use erosion pins, silt fences, hillside troughs, or overland flow traps (Gerlach troughs), or sediment traps or settling basins (Robichaud and Brown 2002, 2003; Weaver and others 2005). These monitoring approaches generally are used to meet objectives of effectiveness monitoring at the project site for hillslope stabilization measures or for general status and trend monitoring at the watershed scale as part of a spatially balanced sampling design.

Erosion pins are steel rods of various lengths (e.g., rebar or narrower steel rods); the selection of pins depends on the amount of erosion expected. Longer pins are usually used for measuring stream bank erosion. For hillslope monitoring, the pins are driven into the ground until the head of the pin is flush with the ground. Some practitioners drive the pin through a washer, but others find that this interferes with the natural surface runoff. The pins can be arranged in a transect, from the top of the hill or sampling plot to the base (or through the evaluated area), or they can be arranged in a grid pattern, if appropriate. The amount of erosion is measured at subsequent sampling dates by measuring the distance from the head of the pin to the ground surface.

Evaluation of short-term mass wasting sediment contributions can be accomplished by identifying the landslide site and then by void measurement (i.e., surveying or measuring the hole left by evacuation of a landslide on a hillside, road, or stream bank). Movement over time can be documented by inserting stakes or longer pins into the moving mass and then documenting their original location and movement by surveying with respect to a local monument (Weaver and others 2005). More-detailed evaluation may require consultation with an engineering geologist or specialist. Longer-term evaluation of mass wasting events and their sediment contributions requires evaluating the available long-term series of aerial photographs for an area supplemented with void measurement of the identified landslides.

New innovations in technology currently allow remote sensing of both hillslope erosion and changes in inchannel sediments. The Photo-Electronic Erosion Pin has been developed by the Rickly Hydrological Company and can be set to detect changes in land surfaces continuously. The unit will download to a data logger. It detects the amount of light to which the electronic pin is exposed. More background information on this tool can be found at Rickly Hydrological Company (2004a).

Silt fences can be placed downslope of unstable areas to capture loose sediment. These fences are generally geotextile fabric that allows water to pass through but traps sediment particles. These fences have to be installed properly and maintained in order to function. Silt fences have often been used as a mitigation measure rather than a monitoring device, but the amount of sediment collected in the fence can be removed and measured to determine the volume and rate of surface erosion. Trap efficiency of properly used silt fences has been estimated at 90 percent. Sediment monitoring using silt fences is detailed in Robichaud and Brown (2002).

Hillside (Gerlach) troughs (Hudson 1993; Tricart 1967; Weaver and others 2005) consist of either dug trenches or installed trenches in the ground. These dirt or metal trenches trap coarser sediment and can be designed to discharge water to a separate container so that the amount of water and sediment can be measured to determine rates of sediment delivery. Measuring the duration of the runoff event and volume of water in the container gives the discharge rate. The suspended sediment in the container can be separated from the liquid through settling and measured for volume. Information on these monitoring devices can also be found at Rickly Hydrological Company (2004b). Various types of larger sediment traps and settling basins can be constructed similarly at a site to capture and measure sediment (Weaver and others 2005).

Additionally, survey measurements can be made of rilling and gullies in hillslopes where surface erosion is occurring to measure the volume of soil being eroded. Weaver and others (2005) provide a useful guide to conducting these types of surveys.

Photo documentation has also been used to assess visually large changes in hillslope erosion. This process involves taking repeated photographs from the same vantage point to detect visual change through time. Information on techniques used in photo documentation can be found online at RISC (Resources Information Standards Committee 1998). This document identifies recommended photo subjects, techniques for documenting changes in aquatic conditions, and information on the capture and storage of images, especially with respect to digital photography. Gerstein and Kocher (2005) provide information on photo documentation of salmonid habitat restoration projects.

6.5.2 Channel Processes

Channel processes include stream bank erosion, bedload and suspended sediment transport, and elements of instream habitat affected by sediment, such as the level of fine sediment in substrate, substrate embeddedness, and pool filling. These processes are generally monitored to meet objectives of evaluating rates of erosion and sediment transport or improving aquatic habitat for fish or other species of concern using stream bank stabilization techniques or upslope restoration or sediment control actions. If these methods are used to determine the effectiveness of management practices, hillslope monitoring methods should also be used to determine the onsite effectiveness of the projects. The instream monitoring strategy often is targeted in areas such as response channel reaches, where the effects of fine sediment in stream systems are expected to be detectable. Understanding the context in which stream channels function is important to interpreting channel processes. There are numerous guides to documenting stream channel conditions, but one useful regionally based technical guide is Frazier and others (2005). Additionally, Kondolf and Piegay (2003) provide a thorough review of many fluvial geomorphology techniques.

Bunte and MacDonald (1999) identify the large number of difficulties involved in measuring sediment transport in river systems. They conclude that the "net result of all sediment samples [is] really an index of sediment transport and we can only crudely estimate the likely errors" (Bunte and MacDonald 1999, p. 294). Physically based sediment transport models cannot accurately predict transport rates without site-specific information on sediment size, mode of transport, available energy (which combines discharge, slope, depth, and velocity), the amount of available sediment, and the stream type. This information is more than most agencies have the time or the resources to collect. Consequently, we will not deal with the myriad of uncertainties involved in estimating sediment transport. For more information on this topic, see Bunte and MacDonald (1999).

Inchannel strategies to monitor for accelerated sediment supply and related channel responses often involve stream geomorphic predictors such as channel dimensions, bed material size, pool characteristics, and reach morphology. Montgomery and MacDonald (2002) discuss the responsiveness of a range of parameters to chronic increases of both fine and coarse sediment. They found that responses differed with channel type. Tables 6-2a (for coarse sediment) and 6-2b (for fine sediment) provide a summary of the levels of responses.

Bed material size often is characterized using Wolman pebble counts (i.e., measuring the intermediate axis of 100 randomly selected particles), grid counts, or similar surface substrate evaluation procedures. Wolman pebble counts have been applied to forested watersheds to detect measurable changes due to land-use activities (Bevenger and King 1995). Information on bed material particle size distribution can be used to determine the bedload sediment transport rates, to evaluate the success of watershed improvement projects, and to advance the understanding of stream channel processes (Bundt and Abt 2001). Information on developing a monitoring program that is focused on measuring the effects of land use or management practices such as logging, road construction, livestock grazing, or mining is available in Williams and others (1983). This manual focuses on stream habitat evaluation specifically with respect to percent substrate composition methods that detect changes due to land-use activities. This approach can be applied at the basin, sub-basin, stream reach, or project scale. The cumulative watershed effects approach is another available method that is used to monitor the effects of sediment and other nonpoint source water quality impairments (Bunte and MacDonald 1999; MacDonald 2000).

Table 6-2a. Response of Monitoring Variables by Channel Type to Chronic Increase in Supply of Coarse Sediment (>2 mm).

Response Variables	Cascade	Step Pool	Plane Bed	Pool Riffle	Dune Ripple
Channel Dimensions					
Bankfull Width	Med	Med	High	High	Med
Bankfull Depth	Med	Med	High	High	Med
Bed Material (particle size)					
D_{84}	Low	Med	High	High	High
D_{50}	Med	Med	High	High	High
D_{50} in Pools	Med	High	N/A	High	Low
Percent Fines (< 2 mm)	Low	Low	Low	Low	Low
Embeddedness	Low	Low	Low	Low	Low
Pool Characteristics					
Number	N/A	Low	N/A	High	Med
Area	N/A	Low	N/A	High	Med
Volume	Med	High	N/A	High	Med
Residual Depth	Med	High	N/A	High	Med
V*	N/A	Low	N/A	Low	Med
Reach Morphology					
Thalweg Profiles	Low	High	Low	High	Low
Bank Erosion	Med	Med	Med	High	Med
Habitat Units	Low	Low	Low	High	Low
Channel Scour	Med	Med	High	High	Med

Note: High= Very responsive; Med= Secondary or small response; Low= Little to no response; N/A= Non-applicable
Source: Adapted from Montgomery and MacDonald 2002.

Table 6-2b. Response of Monitoring Variables by Channel Type to Chronic Increase in Supply of Fine Sediment (<2 mm).

Response Variables	Cascade	Step Pool	Plane Bed	Pool Riffle	Dune Ripple
Channel Dimensions					
Bankfull Width	Low	Low	Low	Med	Med
Bankfull Depth	Low	Low	Low	Med	Med
Bed Material (particle size)					
D_{84}	Low	Low	Med	Med	Low
D_{50}	Low	Low	High	High	High
D_{16}	Med	Med	High	High	Med
D_{50} in Pools	Med	Med	N/A	High	High
Percent Fines (< 2 mm)	Med	Med	High	High	N/A
Embeddedness	Med	Med	High	High	N/A
Pool Characteristics					
Number	N/A	Low	N/A	Low	Low
Area	N/A	Med	N/A	Med	Low
Volume	Low	Med	N/A	High	High
Residual Depth	Med	Med	N/A	High	High
V*	N/A	Med	N/A	High	N/A
Reach Morphology					
Thalweg Profiles	Low	Med	Low	High	Med
Bank Erosion	Low	Low	Low	Low	Med
Habitat Units	Low	Low	Low	Med	Low
Channel Scour	Low	Low	Low	Med	Med

Note: High= Very responsive; Med= Secondary or small response; Low= Little to no response; N/A= Non-applicable
Source: Adapted from Montgomery and MacDonald 2002.

A variety of protocols provide information on how to assess channel dimensions, pool characteristics, and reach morphology. Hankin and Reeves (1988) and Peck and others (2003) provide commonly used approaches and descriptions of the parameters listed in Tables 6-2a and 6-2b.

In some settings, to determine spawning gravel quality or the potential for fry survival, subsurface sampling of the substrate is needed (Kondolf and others 2003). For subsurface substrate sampling, McNeil core samplers, shovels, and freeze core samplers can be used. McNiel core samplers are metal containers with a slender cylinder at the bottom that is driven into the stream bed. The subsurface gravel is removed from within the cylinder and placed in a sample container. The core sample is generally passed through a series of sieves for a quantitative analysis of particle size distribution. More information on these samplers can be found at RISC (Resources Information Standards Committee 2006). Information on how to use the samples and sieve the sediment can be found in Shuett-Hames and others (1999). This document contains information on estimating the percentage of fine sediment and comparing spawning gravel composition among stream segments, watersheds, and ecoregions. It also addresses monitoring trends in spawning gravel composition over time. Shovels may also be used in place of McNiel core samplers in certain settings. In low velocity settings, shovels were found to be comparable to the McNiel samplers at a much lower expense (Bundt and Abt 2001).

The number of samples needed for statistical accuracy is usually large, and investigators are frequently surprised by the large sample sizes or volumes needed for the desired statistical accuracy. Bundt and Abt (2001) discuss the proper scope, application, and limitations of various aspects of bed-material sampling methods. Included are an explanation of bed-material strata, the procedures and equipment used in sampling, a discussion of the spatial scheme to be employed, the relation between sample size and accuracy, and methods of particle size analysis. These guidelines provide the user with information for selecting methods and approaches suitable for a particular study in the selected fluvial setting (Bundt and Abt 2001). Shirazi and Seim (1979) found that the mean geometric particle diameter is more useful than percent fines in reporting the status of substrate with respect to use by salmonids for spawning. Chapter 13 (Bed Sediment Measurement) in Kondolf and Piegay (2003) also provides a thorough review of the issues discussed above.

Large changes in physical conditions in stream channels can be monitored using photo point documentation. A good reference for this approach is Ward and others (2003). This document gives some specific examples of conditions that can be evaluated effectively using photo documentation, along with data sheets and field protocols. Additional useful information is in Gerstein and Kocher (2005).

Details on instream and riparian restoration approaches are not addressed here. However, the University of California Center for Forestry has prepared a series of monitoring effectiveness reports related to fisheries habitat, riparian, and culvert fish passage restoration. This information is applicable to the North Fork/Middle Fork American River watershed. These reports are: Gerstein (2005), Gerstein and Harris (2005), Gerstein and Kocher (2005), Gerstein and others (2005a, b), Harris and others

(2005b, c), Kocher and Harris (2005), Stockard and Harris (2005), and Weaver and others (2005). Additionally, there are reports on monitoring the effectiveness of upland restoration (Weaver and others 2005) and on road system upgrading and decommissioning at the watershed scale (Harris and others 2005a). In addition, Roni (2005) provides a variety of background and specific information on monitoring stream and watershed restoration.

6.5.3 Water Quality

Monitoring nonpoint source water quality problems in the North Fork/Middle Fork American River watershed involves determining the sampling scale and frequency desired for the sediment-related indicators. These indicators would include turbidity and total suspended solids (TSS). Deployment of sensors to monitor turbidity is the most cost-effective approach with respect to detecting changes and significant trends in water quality parameters (Eads and Lewis 2002). Sensors record turbidity and those data are combined with a discharge measurement. To determine TSS levels cost effectively, turbidity data can be used to establish a site-specific turbidity-to-TSS relationship that would allow turbidity to be used as a surrogate for TSS. Eads and Lewis (2002) recommend collecting water samples at predetermined turbidity thresholds to establish the relationship with TSS. TSS samples must be analyzed in a laboratory. Single-point in time measurements provide limited information that is difficult to tie to sediment transport processes and high levels of turbidity and suspended sediment. Seasonal cycles in water quality make data analysis more complex; non-parametric statistical approaches such as the seasonal Kendall test (Zar 1996) or other tests should be used to analyze these data.

Specific placement of continuous monitoring devices depends upon the objectives of the monitoring program, but these stations could be used at the project scale if placed upstream and downstream of a watershed improvement project designed to reduce the rates of surface erosion during high runoff periods. They could also be placed at the outflows of true watersheds where a large number of these types of projects have been implemented to try to detect measurable changes at the watershed level.

Additional monitoring techniques have been employed using volunteers. Programs in Oregon have successfully used volunteers to monitor water quality. Information from these programs is available at OPSW (Oregon Plan for Salmon and Watersheds 1999). This manual provides guidance for standard and consistent collection of field-based data, including turbidity, road sediment delivery, and sediment depositional areas. Additional information and protocols for volunteer water quality monitoring for many parameters including turbidity and TSS can be found in Dohner and others (1997). This guide focuses on developing a stream monitoring program using volunteers. It includes water quality monitoring as well as methods for watershed resource survey, macroinvertebrate survey, substrate survey, and physical channel measurement. As noted in Section 6.3, the results of citizen monitoring should be evaluated and interpreted by specialists with the appropriate technical backgrounds.

6.6 Collaborative Partnerships and Community Outreach

> "Collaboration is a process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their own limited vision of what is possible. At its most basic level, collaboration is the sharing of responsibility among people for something they care about. It is a process in which interdependent groups work together to affect the future of an issue of shared interests" (Yaffee and Wondolleck 2000).

Collaboration involves feedback, consultation, and shared decision making. Activities that involve collaborative partnerships include dialogue groups, planning commissions, advisory councils, watershed councils, and co-management opportunities. The American River Watershed Group and ARWG TAC is an example of a collaborative process at work. Development of a successful monitoring program to determine the effectiveness of watershed enhancement efforts would involve further collaboration and coordination on the part of all parties involved.

Research has shown that collaborative processes are typically very time consuming and outcomes are unpredictable. On the positive side, collaboration commonly results in more effective outcomes, increased trust, reduced conflict, mutual learning, and new networks and institutions for sharing information and undertaking projects. Often, collaboratively planned projects are said to have involved better science, addressed more issues, or have been more innovative than traditional planning processes. In some cases collaboration has allowed jurisdictional boundaries to be crossed that were previously thought impermeable. The most commonly reported benefit of collaboration is that it builds social capital, thereby improving participants' capacity for future collaboration. Additionally, collaboration allows for limited resources to be leveraged across groups to allow monitoring funding to be spent most effectively. This approach requires agreement in terms of monitoring goals, objectives, indicators and design concepts (both spatial and temporal aspects), and protocols to be selected for monitoring. The use of volunteers for monitoring reduces the cost for field data collection but requires more effort in terms of training and coordination.

Characteristics of successful collaboration include the following:

- Adequate resources – adequate consistent funding to support operations, usually including paid staff;
- Salient shared need – participants share a common purpose and need, and there is some urgency to that purpose or need (e.g., a mandate, crisis, or other incentive for people to collaborate);
- Credibility – involves those with the authority or power to implement or undermine the group's effort, utilizes the best available information, demonstrates results;

- Capacity – the existence of networks or forums where multiple interests can work together and participate with good leadership and communication skills, an open and respectful attitude, honesty, and a willingness to adapt; and
- Fair process – open to and inclusive of all interested parties; provides equal opportunities for meaningful input; is rational and transparent (people want to know how decisions were made, even if they do not contribute to making them); and contains accountability mechanisms (incentives for cooperative behavior and consequences for uncooperative behavior).

Examples of collaboration in monitoring programs include partnerships between agency personnel and volunteer groups to plan and implement monitoring programs for water quality and aquatic habitat improvement projects. Volunteer coordinators work with local groups to provide training, equipment, technical consultation, and quality control. Data collected by volunteers are checked and verified by agency staff. Quality data are added to agency databases to expand the capacity of agency monitoring programs at a low cost. The California State Water Resources Control Board Citizen Monitoring Program Web site (http://www.swrcb.ca.gov/nps/volunteer.html) provides a variety of resources related to collaborative monitoring.

The collaboration of the multiple stakeholders involved in the management of the North Fork/Middle Fork American River watershed is essential for the implementation of watershed enhancement projects as well as for a monitoring program for those projects. However, with successful collaboration, more projects can be implemented and maintained, and over the long term, costs for a large-scale integrated monitoring program will be reduced. Resources for coordinating monitoring with other regional approaches are available. The Pacific Northwest Aquatic Monitoring Partnership is working at bringing a coordinated approach to monitoring aquatic ecosystems across the western states. Efforts include Washington, Oregon, California, Alaska, and Idaho. More information about these efforts can be found at PNAMP (Pacific Northwest Aquatic Monitoring Partnership 2006).

6.7 Next Steps in Coordinated Monitoring and Collaborative Process

In summary, the efforts thusfar of the participants in the American River Watershed Group and ARWG TAC are to be recognized as a significant step forward in improving the understanding of the level of function of the North Fork/Middle Fork American River watershed. The next steps in the strategy for continuous improvement in knowledge-based decision support system for watershed management include the following:

- Establish a spatially representative network of sampling points to establish baseline conditions with respect to current levels of soil erosion and sediment delivery, and channel habitat conditions in the watershed. Sample these points to determine the baseline conditions and their spatial variability.
- Determine the context of the current conditions with respect to historical conditions relative to changes in human land use and management practices.

- Evaluate the trend in the conditions, using specific indicators, by re-sampling a rotating subset of sample sites through time (at appropriate intervals).

- Establish BACI sample design for effectiveness monitoring at the project scale on a subset of representative projects. Partner with existing monitoring programs currently in place.

- Utilize adaptive management (where monitoring is integrated with management) with the input of both short- and long-term responses to change management practices, as needed, and improve the application of watershed enhancement efforts through feedback and adjustment.

- Promote coordinated and collaborative processes to design, implement, and monitor watershed enhancement practices.

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CHAPTER 7: OPPORTUNITIES AND NEXT STEPS

7.1 Introduction

The purpose of Chapter 7 is to summarize the management opportunities and possible next steps that can be considered and potentially implemented in the North Fork/Middle Fork American River watershed. It addresses opportunities for watershed enhancement (i.e., best management practices, disturbance minimization, and active restoration), monitoring and evaluation for adaptive management, and information needs based on the key findings of this watershed assessment. This chapter recaps the key conclusions and next steps presented in Chapters 4 through 6. The existing watershed conditions are characterized in Chapters 3 and 4. The systematic information synthesis in Chapters 3 through 6 provides the basis for identifying management opportunities in a landscape context and facilitates multi-criteria decision making. This watershed assessment used a series of GIS-based, quantitative spatial analyses and models to characterize and prioritize subwatersheds. This prioritization permits the targeting, with limited financial resources, of the highest potential risk areas where management practices (also referred to as best management practices or BMPs) could be implemented to optimally reduce potential adverse impacts on key resources (aquatic organisms and habitats, water and power infrastructure, and water quality).

This report presents a coarse-filter analysis of potential erosion hazard and sedimentation risks based on the best available spatial data for all or large portions of the North Fork/Middle Fork American River watershed. Data were carefully reviewed to ensure appropriate scales, extents, and quality (see Appendix B for details). This watershed assessment does not address the effects of land use or management activities. It is not an intensive fieldwork-based analysis of hillslope erosion and stream channel sedimentation. By design, the coarse-filter analysis presented in this report can be used to prioritize additional, more focused studies. The current analysis is not intended and is not sufficiently site-specific to serve as the basis for regulatory compliance.

As noted throughout this watershed assessment, the assignment of risk categories is based on broad subwatershed characteristics. When interpreting the prioritization results, it is important to note that a priority category 1 or 2 ranking suggests a higher potential risk of erosion (under bare soil conditions) and a higher potential risk of sediment delivery relative to a priority category 3 ranking. However, localized surface erosion and sedimentation occurs even in priority category 3 subwatersheds, just as priority category 1 and 2 subwatersheds may have effective vegetative cover, drainage conditions, or watershed management practices that minimize surface erosion and sedimentation. This approach is useful for comparing and distinguishing between subwatersheds, but this assessment should not be used for site-specific or project-level interpretations. Rather it should be used as a guide to the types of potential hazard or risk factors to assess when conducting a site-specific evaluation.

The goal of the recommendations is to identify watershed enhancement opportunities and management practices that could contribute towards maintaining watershed functions and minimizing the accelerated delivery of sediment to key resources. In addition, these recommendations can serve as the starting point of a phased action plan (4 to 12 years) for watershed management and strategically guide efforts to obtain the necessary multi-source funding to implement programs based on priorities.

Based on the results of this watershed assessment, the following recommendations are considered reasonable next steps for an integrated and collaborative approach to adaptive decision making and resource management. As critical knowledge and data gaps are filled, this information can be used to evaluate the management strategies for the watershed.

7.2 Priority Watersheds and Targeted Management

1. *Seek voluntary implementation of management measures in priority category 1 and 2 subwatersheds for reduced soil erosion and sediment delivery.*

The subwatersheds identified as priority category 1 and 2 have the highest potential risk of effects to key resources from increased erosion and sedimentation; thus, the management measures (also referred to as BMPs) are targeted for these subwatersheds (Chapter 4– Table 4-25 and Map 4-3; Table 4-26 and Map 4-4). To make a direct link to public and stakeholder activities in the watershed, the management measures are grouped and listed by the land uses that occur in the watershed (Chapter 5, Section 5.2). These management measures are general or specific approaches that individuals or groups can implement to minimize the potential for soil erosion on hillslopes, sediment delivery to streams, or increases in peak flows in local streams.

2. *Promote an integrated and collaborative process for voluntary implementation of management measures to protect beneficial uses and values.*

The ARWG can promote a coordinated and collaborative process to engage watershed residents and stakeholders in the voluntary implementation of the management measures identified in this watershed assessment (Chapter 5, Section 5.4). In addition, the ARWG can conduct systematic and progressive education and outreach campaigns to engage residents and stakeholders in understanding the watershed's generally high water and aquatic habitat quality. It is important to remind residents and stakeholders that maintaining water quality is essential to protecting beneficial uses and values (i.e., drinking water supplies, aquatic organisms and habitat) in the watershed, and that allowing deterioration of water quality by inattention invites regulatory scrutiny and intervention (i.e., Clean Water Act Section 303[d] listing and total maximum daily load [TMDL]).

The integrated and collaborative process can be readily and effectively implemented by existing entities such as the ARWG, Resource Conservation Districts, environmental and conservation organizations, stakeholder organizations, water utilities, local governments, and the Central Valley Regional Water Quality Control Board. The Available Resources listed in Chapter 5, Section 5.2 can be used to prepare straightforward and detailed management measure guidelines targeted to the different land uses in the watershed. The guidelines also can emphasize the effectiveness and relatively low cost of the management measures.

7.3 Watershed Protection and Restoration

1. *Adopt and implement voluntary management actions for watershed protection and restoration.*

The watershed enhancement opportunities are addressed by two strategies: protection by disturbance minimization and active restoration. As described in Chapter 5 (Section 5.3), the watershed protection and restoration strategies also are targeted for the priority category 1 and 2 subwatersheds identified in Chapter 4 (Table 4-25 and Map 4-3; Table 4-26 and Map 4-4).

Disturbance minimization strategies are most appropriate to apply in priority category 1 and 2 subwatersheds because these are most likely to include more sensitive areas and have a higher potential for affecting downstream key resources. The minimization actions would have the greatest potential to prevent sediment-related cumulative watershed effects from further land use disturbance.

Because priority category 1 and 2 subwatersheds are most likely to include more potentially sensitive areas, they most likely merit more detailed on-the-ground analysis and are the most likely candidates for active restoration. To increase the probability of success in protecting key resources, active restoration should focus primarily on upland areas, including forest roads and other hillslope disturbances (see the discussion under the next bullet). Active instream restoration may be appropriate when resources are available.

2. *Promote a coordinated and collaborative process for implementation of the proposed management actions for watershed protection and restoration.*

The voluntary implementation of management actions identified to maintain natural watershed functions (disturbance minimization) and to enhance watershed functions (active restoration) would be most effective through a coordinated and collaborative process by watershed residents and stakeholders (Chapter 5, Section 5.4) guided by the ARWG. Successful implementation of the management strategies, including collaboration, education, and outreach, are briefly described above in Section 7.2 and described more fully in Section 6.6.

Active restoration is different than the other strategies because it generally requires a more substantial commitment of resources. Restoration also requires an understanding of the environmental setting on which the actions will be specifically taken (i.e., some form of baseline condition inventory) so that a sequence of restoration actions can be prioritized and their effectiveness can be evaluated. Consequently, implementing an active restoration program would require an inventory of potential restoration projects. The Tahoe and Eldorado National Forests road inventories already exist and can be a primary target for implementation of active restoration. The ARWG can work with all levels of governments to seek appropriate funding for implementation of the USDA Forest Service's identified roads-related restoration projects.

Wildfire minimization projects provide another potential opportunity for active restoration. These landscape-wide vegetation or fuel management projects are generally based on some form of inventory and prioritization for community or resource protection. The ARWG can work collaboratively with local governments, local Fire Safe Councils, Resource Conservation Districts, and the California Department of Forestry and Fire Protection to incorporate the risk characterizations and soil erosion and sediment control measures of this watershed assessment into wildfire minimization projects such as fuel reduction treatments.

Lastly, the ARWG can work collaboratively to develop an inventory of critical erosion sites that are appropriate to consider for site-specific restoration in priority category 1 and 2 subwatersheds. The sediment source inventory, with an emphasis on sediment delivery and supply rate, can be used to develop a prioritization schema. This inventory and prioritization can be used to seek collaborative funding sources. Although watershed-wide restoration efforts would be most effective if based on an inventory and prioritization process, individual disturbed sites that are substantial sediment contributors can still be appropriate to restore. Similarly, critical erosion sites in priority category 3 subwatersheds are also appropriate for active restoration. The ARWG can encourage site-specific restoration efforts as long as those projects do not interfere with the funding of higher priority projects at the landscape-level.

Volunteers can reduce the implementation cost of restoration efforts and the ARWG can work collaboratively with all groups in the watershed, including schools, to develop a corps of persons or groups interested in assisting restoration efforts.

7.4 Monitoring and Evaluation for Adaptive Management

Monitoring Framework

- *Develop and implement a monitoring program of appropriate intensity and with appropriate diagnostic features to address critical questions and meet the objectives of knowledge-based decision support.*

Chapter 6 provides the framework for developing and implementing a comprehensive monitoring program for adaptive resource management. The ARWG can work towards implementing the coordinated monitoring and collaborative process detailed in Section 6.7. The comprehensive monitoring system would require substantial resources; therefore, the ARWG can work to develop a collaborative monitoring network with federal, state, and regional programs. These include, but are not limited to, the Surface Water Ambient Monitoring Program, the U.S. Geological Survey, the Central Valley Regional Water Quality Control Board, the USDA Forest Service Sierra Nevada Framework monitoring program, the Tahoe and Eldorado National Forests BMP evaluation program, and ongoing research efforts related to the Blodgett Forest Research Station and the Sierra Nevada Adaptive Management Project.

Citizen monitoring can be a useful component of the comprehensive monitoring program. If incorporated, citizen monitoring should be integrated into the monitoring framework and must incorporate a quality management plan. Additionally, the results of citizen monitoring should be evaluated and interpreted by qualified specialists with the appropriate technical background.

Evaluation and Adjustment Process

For the best results, adaptive resource management should be incorporated in implementing any of the recommendations listed in this chapter. The elements of adaptive resource management—monitoring, evaluation, and adjustment—can be designed to increase the probability of achieving desired outcomes for watershed enhancement. The following are recognized components in developing an effective adaptive management program and can be incorporated as next steps by the ARWG.

1. *Decide on the specific indicators to measure and how to measure them to detect changes;*

2. *Establish the criteria to determine when an indicator is within the desired condition range and what to do when it is outside that range; and*

3. *Adopt integrative procedures for the feedback and adjustment loop for continuous improvement in management practices.*

7.5 Information Needs

7.5.1 Background

The North Fork/Middle Fork American River Sediment Study uses a GIS-based, quantitative spatial analysis approach for watershed characterization, modeling and prioritization, and targeting and management. The quantitative spatial analysis used existing GIS data. As a compilation, synthesis, and analysis of existing data and information, this watershed assessment does not fill knowledge and data gaps, but rather identifies and highlights them. The data gaps and limitations may be considered as information needed for finer-filter analysis, or information to be gathered in future inventory, monitoring, and research efforts. None of the data gaps identified during the compilation, synthesis, and analysis for this project limits the conclusions of this watershed assessment.

Data gaps identified in this watershed assessment fall under the following broad categories: (1) knowledge about impact or causation; (2) spatial and temporal information; and (3) data quality (or fitness of use). In this watershed assessment, data gaps and limitations exist when the needed GIS data and maps, or other types of information are unavailable, incomplete, or inaccurate. The GIS data sources and gaps are addressed in Appendix B. The following sections are intended to characterize the different types of information needs to improve the knowledge-based decision making for adaptive resource management.

7.5.2 Inventory and Monitoring Needs

Inventories catalog current resource conditions, whereas monitoring examines changes in resource conditions over space and time. Both inventories and monitoring use science-based and statistical methods for information gathering.

The following are several recommendations for future inventory and monitoring projects to meet essential information needs, presented in order of priority.

1. *Field verify the source (e.g., streams) and analysis (e.g., mass wasting hazard) GIS data layers used in the North Fork/Middle Fork American River Sediment Study. In particular, focus on the data layers that were used to evaluate watershed hazard (erosion and sedimentation potential).*

2. *Assemble the Tahoe National Forest and Eldorado National Forest stream habitat inventories into a consistent database that represents attributes such as physiographic positions, stream types, channel gradients, instream habitat structures and conditions, sediment regimes, and the amounts of subwatershed disturbance. These data would not meet the requirements of a spatially representative sampling network, but they would provide considerable background information to understand the conditions and dynamics of significant portions of the streams in the North Fork/Middle Fork American River watershed. Identify and integrate other stream inventory data that may exist in the watershed.*

3. *Coordinate with the California Department of Conservation Office of Mining Reclamation to inventory abandoned and active mine sites in the North Fork/Middle Fork American River watershed to identify areas that are contributing sediment to streams. Review the existing reports on mine site water quality impacts and assemble their sediment evaluations into the inventory. Evaluate hydraulic mining debris in the North and Middle Forks of the American River to determine if any sites are appropriate for stream bank or other restoration actions to prevent excessive sedimentation.*

4. *Coordinate with the Tahoe National Forest and Eldorado National Forest (and their roads analysis programs) to inventory road locations, types (including all-terrain vehicle trails and historic roads), characteristics (including cross-drain spacing, slope position, cut-fill amounts, and road gradients), uses (including season and volume), and maintenance levels. Identify sources of erosion and sediment delivery both on and off of National Forest System lands, and inventory road-stream connectivity, including near stream roads and road-stream crossings.*

5. *Monitor erosion rates, sediment routing, and biological responses, stratified by land-use practices, in selected subwatersheds of the North Fork/Middle Fork American River watershed. Monitor runoff, sediment-related water quality, and biological responses. A distributed monitoring network (described in Chapter 6) could be implemented to identify the level of disturbance by land-use practices. Monitoring data could be used to help establish cumulative watershed effects of land management practices.*

6. *Perform mass wasting and landslide inventories and assess their stream channel sediment contributions.*

7.5.3 Opportunities for Further Research

Research is necessary to examine key assumptions associated with specific management actions, especially to learn more about their potential impacts and cause-and-effect relationships. The following are several recommendations for sediment-related research objectives in the North Fork/Middle Fork American River watershed.

1. *Evaluate the relationship of mass wasting to Cenozoic volcanic deposits. Develop a more-detailed geologic mapping of these volcanic formations (including mapping the contact between the Mehrten and Valley Springs formations). Evaluate Cenozoic volcanic formations with respect to slope stability to develop a more refined conceptual model of slope instability.*

2. *Research the geologic fault lines, joint angle orientations, and other geologic types (e.g., serpentine) that may affect mass wasting in the North Fork/Middle Fork American River watershed. Inventory mass wasting to determine the relationship between mass wasting type, bedrock or geological material, soils, slope angle, local surface and subsurface drainage characteristics, and disturbance.*

3. *Complete a mass wasting study to evaluate the relationships between landslides, landslide movement, and precipitation amounts and intensities. Conduct watershed-specific hydrometeorological studies to gain a basic understanding of the hydrologic condition and processes. Evaluate the relationship between the hydrologic regime, subbasin morphometry, and the rates of erosion, sediment transport (both hillslope and inchannel), and sediment deposition.*

4. *Use Light-Imaging Detection and Ranging (LiDAR) to map erosion sources and mass wasting areas. Study could be focused on investigating the cause-effect relationships between land-use practices and sedimentation, and between sedimentation and biotic responses.*

5. *Examine road effects on geomorphological and hydrological processes on a watershed scale.*

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