U.S. Environmental Protection Agency
Region IX

Mad River Total Maximum Daily Loads for Sediment and Turbidity

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Date

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CHAPTER 1: INTRODUCTION

1.1. OVERVIEW OF THE TMDL PROGRAM

The primary purpose of the sediment and turbidity Total Maximum Daily Loads (TMDL) for California's Mad River is to assure that beneficial uses of water (such as salmonid habitat) are protected from detrimental increases in sediment and turbidity. The TMDLs set the maximum levels of pollutants that the waterbody can receive without exceeding water quality standards, an important step in achieving water quality standards for the Mad River basin.

The major water quality problems in the Mad River and tributaries addressed in this report are reflected in the decline of salmon and steelhead populations. While many factors have been implicated in the decline of west coast salmon and steelhead, we are concerned here with two water quality considerations: increases in natural sediment and turbidity. The Mad River (along with many other watersheds in California and throughout the nation) has been included in a list of "impaired" or polluted waters. The listing leads to the TMDLs for this watershed, and the TMDLs determine the "allowable" amount of sediment and turbidity for the watershed. Development of measures to implement the TMDLs is the responsibility of the State of California.

Background

The Mad River Total Maximum Daily Loads (TMDLs) for sediment and turbidity are being established in accordance with Section 303(d) of the Clean Water Act, because the State of California has determined that the water quality standards for the Mad River are not met due to excessive sediment and turbidity. In accordance with Section 303(d), the State of California periodically identifies "those waters within its boundaries for which the effluent limitations... are not stringent enough to implement any water quality standard applicable to such waters." In 1992, EPA added the Mad River to California's 303(d) impaired water list due to elevated sedimentation/siltation and turbidity, as part of listing the entire Mad River basin. The North Coast Regional Water Quality Control Board (Regional Board) has continued to identify the Mad River as impaired in subsequent listing cycles, the latest in 2006. The 2006 303(d) listing identifies temperature as an additional impairment to the watershed; the temperature TMDL will be developed by the State of California at a later time, separately from this document.

In accordance with a consent decree (Pacific Coast Federation of Fishermen's Associations, et al. v. Marcus, No. 95-4474 MHP, 11 March 1997), December 2007 is the deadline for establishment of these TMDLs. Because the State of California will not complete adoption of TMDLs for the Mad River by this deadline, EPA is establishing the sediment and turbidity TMDLs for the Mad River.

The purpose of the Mad River TMDLs is to identify the total amount (or load) of sediment and turbidity (expressed as suspended sediment) that can be delivered to the Mad River and tributaries without exceeding water quality standards, and to subsequently allocate the total amount among the sources of sediment in the watershed. EPA expects the Regional Board to develop an implementation strategy that meets the requirements of 40 CFR 130.6. The allocations, when implemented, are expected to achieve the applicable water quality standards for sediment and turbidity for the Mad River and its tributaries.

These TMDLs apply to the portions of the Mad River watershed governed by California water quality standards. They do not apply to lands under tribal jurisdiction, which include the Blue Lake Rancheria. This is because tribal lands, as independent jurisdictions, are not subject to the State of California's water quality standards.

In the Mad River basin, turbidity levels are closely linked with suspended sediment load. Thus, this document focuses on total sediment load as well as suspended sediment load, which are the pollutants associated with excess sediment and turbidity that violate water quality standards.

Summary of Changes to the Final TMDLs

Several changes were made to the final document as a result of public comments. These include:

- Various editorial changes and clarification of details regarding sediment and turbidity issues, the role of the Humboldt Bay Municipal Water District (HBMWD), and current information on the status of salmonid species.
- Additional implementation and monitoring recommendations and background, such as possibilities for prioritizing sediment reduction in coordination with efforts to protect salmonid-bearing streams; acknowledging NMFS' salmonid recovery strategies and the Mad River watershed group; identifying gravel mining and timber harvesting concerns; discussing future information needs; and describing the Regional Water Board's role in future revisions of the TMDLs and in implementation efforts.
- Text to address the western snowy plover, a FWS-listed species present in the Mad River area that nests on gravel bars.
- Updated information on Chinook, steelhead, and coho, including the affects of turbidity.
- Revisions to the Sediment Source Analysis, which is summarized in Chapter 3. Additional detail is found in the revised Sediment Source Analysis (Appendix A). Revisions to the SSA included re-running the models to incorporate more realistic assumptions about road-generated surface erosion (the previous assumptions overpredicted sediment from road sources), improving the area/volume relationships for landslide types, and reviewing a set of landslides that are in the vicinity of, but are not adjacent to roads, to determine if the causal mechanisms assigned to the landslides were correct.
- As a result of the revisions to the Sediment Source Analysis (SSA), the TMDLs and allocations were revised. In general, the TMDLs (loading capacity) have increased, because the estimate of natural sediment increased. As a result, there was some decrease in the sediment reductions needed to achieve the TMDLs. Even with those changes, very significant reductions are needed: 94% in the Lower Mad and 88% in the Middle Mad subareas. In the Upper Mad subarea, which is largely managed by the US Forest Service (USFS), and where roads are fewer and generally constructed on ridgetops, timber harvesting is less intensive and landsliding is less frequent, the needed reductions have been recalculated to be 68%. This reduction is the same as that calculated in the TMDL for the neighboring South Fork Trinity River TMDL, and somewhat higher to that required for the neighboring North Fork Eel River TMDL—both of which also have a considerable presence of US Forest Service (USFS) management and similar geology.

1.2. WATERSHED CHARACTERISTICS

The Mad River flows northwest about 90 miles from its headwaters in Trinity County, at an elevation above 5,500 feet, to its mouth at the Pacific Ocean in McKinleyville (Plate 1). The lower and middle sections of the Mad River watershed are located in Humboldt County. It lies almost entirely east of Highway 101, approximately 300 miles northwest of San Francisco, 15 miles north and east of Eureka. The river flows northwesterly, through or alongside the towns of Kneeland, Blue Lake, McKinleyville, and Arcata within the lower watershed. The smaller town of Maple Creek is found in the middle portion, and communities of Mad River and Ruth lie within the upper watershed, on either end of the Ruth Reservoir, which impounds the Mad River. The Mad River watershed, as defined by these TMDLs, is 480 square miles in area. For the purposes of the analysis, the watershed was divided into 39 subwatersheds (Plate 1).

The watershed is narrow, averaging about six miles in width. In the upper portion of the watershed, it is bounded by the South Fork Trinity River on the north and east, and by the Van Duzen River on the south and west. In the middle and lower portion of the watershed, it is bounded on the south and west by Yager Creek and other tributaries to the Van Duzen River, and tributaries to Elk River and Arcata Bay, including Freshwater Creek and Jacoby Creek. On the north and east, it is bordered by Redwood Creek in the middle portion of the watershed, and by Little River in the lower portion. The Mad River occasionally spills over into Arcata Bay in very high flow conditions via the Mad River Slough, which is not included in the watershed description for the purposes of these TMDLs.

Subareas and Hydrologic Study Areas

The main channel descends from the headwaters with an average gradient of about 0.2-0.3 percent in the upper and lower portions, while the steep, central portion is characterized by a rapid fall of about 1.2 percent. The river is generally divided into four segments, as defined by the four major Hydrologic Study Areas (HSAs). However, consistent with continuous turbidity monitoring and sediment sampling stations (see Sections 3.1 and Appendix A), we have defined three major subareas: the Upper Mad, Middle Mad, and Lower Mad/North Fork (which combines the Lower Mad/Blue Lake and North Fork HSA areas). HSA areas are described below.

Upper Mad River Subarea: Ruth HSA

The upper (southernmost) portion, which corresponds with the Regional Board’s Ruth Hydrologic Study Area (HSA), includes the town of Mad River, Ruth Lake, and the headwaters area. Much of the watershed in this area is occupied by Six Rivers National Forest. The river flows through a steep, narrow, V-shaped canyon. Although the slope decreases near downstream of the Barry Creek tributary, above Ruth Reservoir, the watershed remains very narrow through this hydrologic area. This area is also referred to as the Upper Mad subarea.

Plate 1-a. Subwatersheds

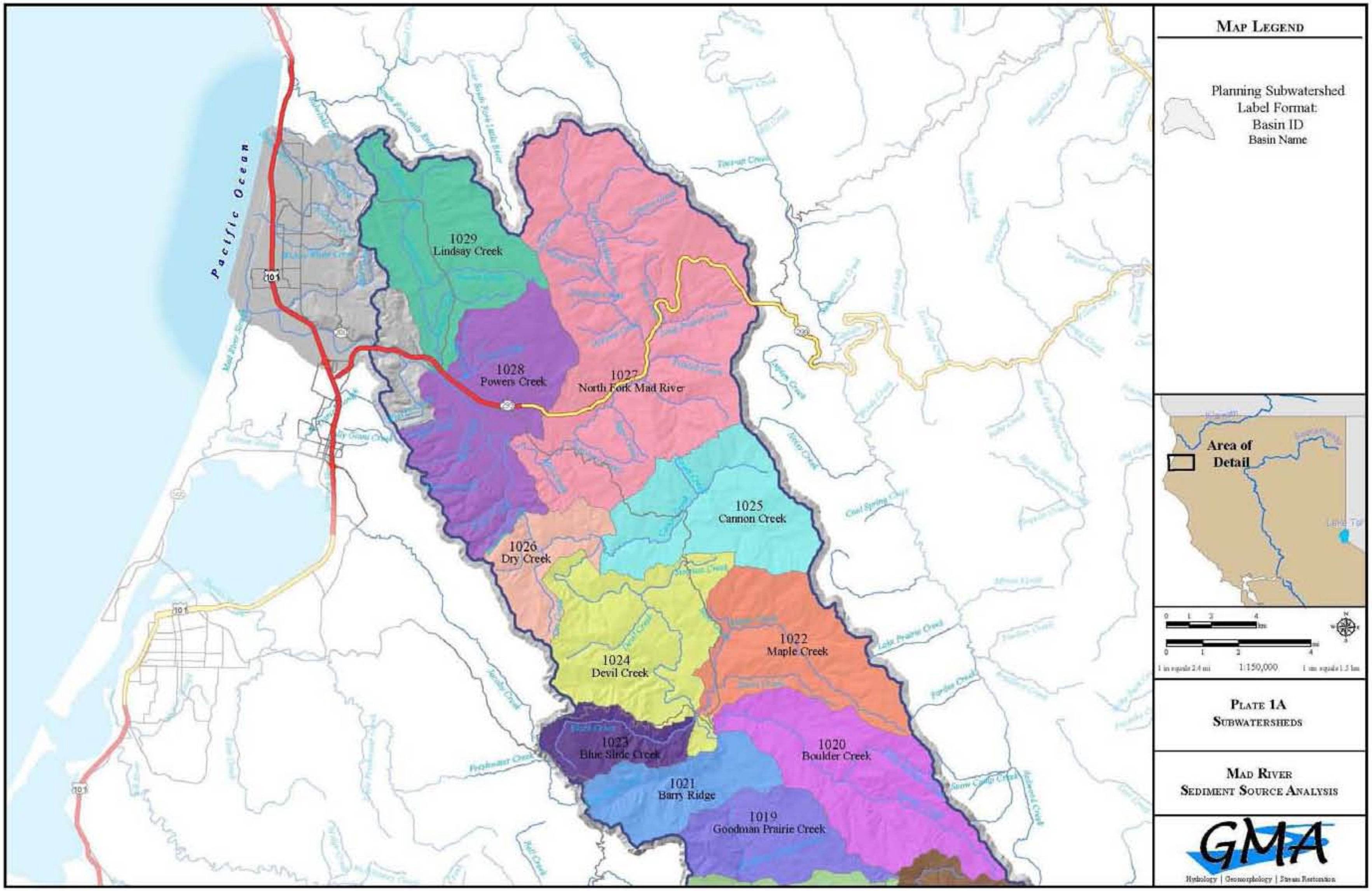


Plate 1-b. Subwatersheds

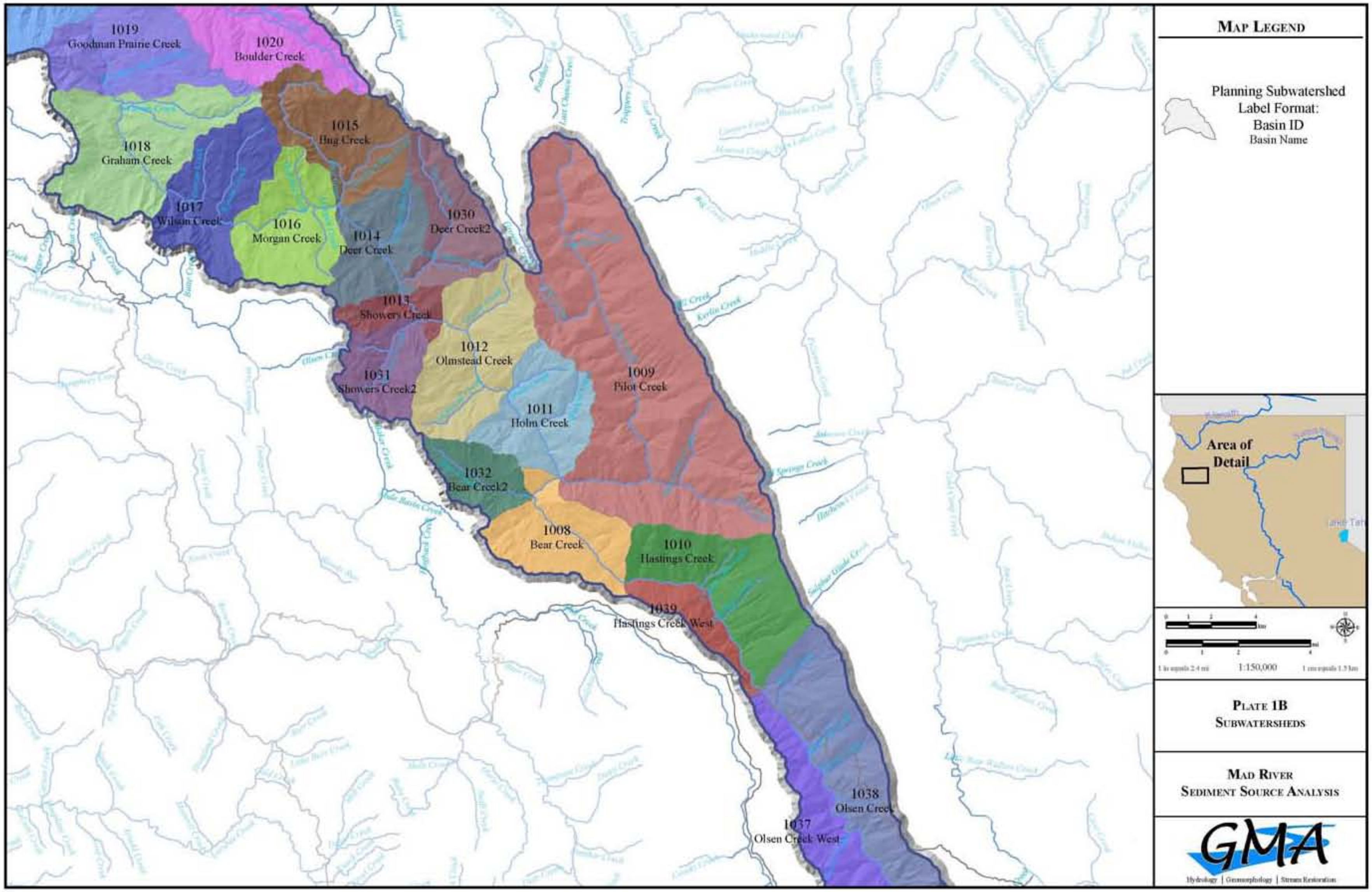
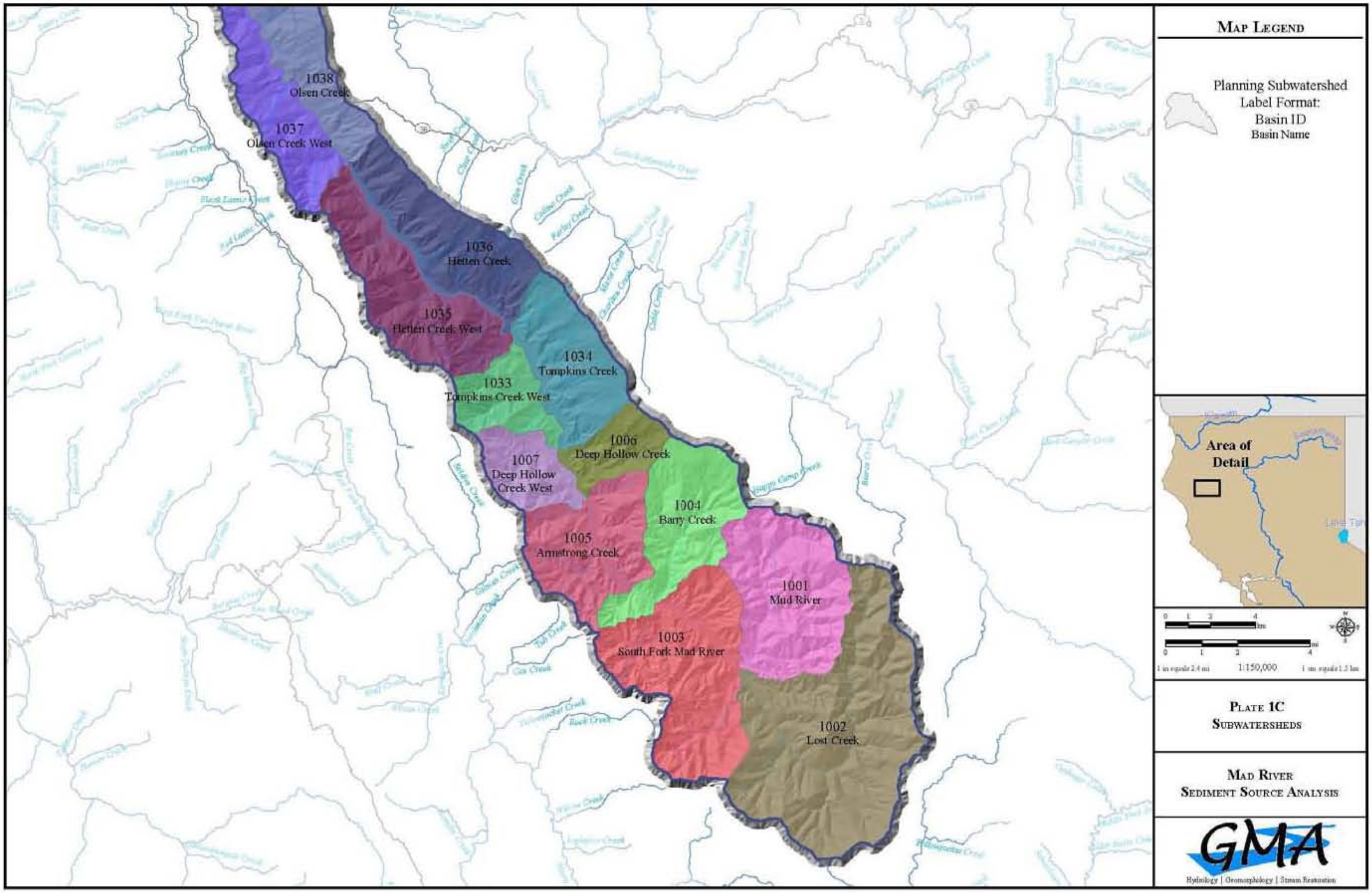


Plate 1-c. Subwatersheds



Middle Mad River Subarea: Butler Valley HSA

The Butler Valley HSA encompasses much of the middle reach of the river and watershed, including the Pilot Creek tributary. The slope of the Mad River steepens downstream of the Pilot Creek tributary, again traveling through a narrow canyon until approximately the Boulder Creek tributary, where the slope decreases considerably. Most of the area, with the exception of the Pilot Creek planning watershed and the Bug Creek planning watershed, which are both within the Six Rivers National Forest, is privately owned. Timber harvest is a significant land use activity in this area, with a large portion of the timber lands owned by Green Diamond. There are also grazing and agriculture land uses in the valleys and the lower portion of this subwatershed. This area is also referred to as the Middle Mad subarea.

Lower Mad River Subarea: Blue Lake and North Fork HSAs

In the Blue Lake HSA, which begins near Blue Lake and comprises all the downstream areas including the communities of Blue Lake, Fieldbrook, and McKinleyville, the slope decreases considerably and the channel widens toward the estuary. The river enters another short canyon between the Arcata and Mad River Railroad (AMRR) Bridge and the Highway 299 bridge, then opens up into the Arcata Bottoms, a historic delta region (Knuuti and McComas 2003).

Most of the tributaries in the North Fork Mad River have very steep slopes descending into the Mad River. The North Fork HSA encompasses the North Fork Mad River tributary, which enters the Mad River near Korbel. Its headwaters are steep, but the slope decreases somewhat through most of its length. This and the Lower Mad/Blue Lake HSAs were combined into a Lower Mad/North Fork subarea.

The analysis for these TMDLs includes all of the major tributaries of the Mad, including the South Fork in the upper watershed, Pilot Creek and Boulder Creek in the central portion, and North Fork in the lower watershed. It also includes the smaller tributaries such as Lindsay Creek and Maple Creek. Most of the information in these TMDLs is aggregated at a subarea level, equivalent to the four major HSAs in the basin; however, the sediment source analysis (Appendix A) also presents all of the information by each of the 39 subwatersheds in the basin (see also Chapter 3).

Land Ownership

Private land ownership is concentrated largely in the middle and lower watershed. Public ownership, primarily the Six Rivers National Forest, is concentrated in the upper portion of the watershed. Blue Lake Rancheria Tribal lands are also within the watershed, partially within and adjacent to the City of Blue Lake, on the north bank of the Mad River. The Rancheria totals 32 acres, and an additional 12 acres are owned by the Tribe or Tribal members along Mad River and Powers Creek (Kier Associates 2005).

1.2.1. Geology and Climate

The area’s geology is underlain by the Franciscan terrain that dominates most of California’s North Coast. Naturally unstable, this type of geology is highly sensitive to human disturbance. Elevations range from sea level in the west to the highest point of 6,072 feet (ft) at Horse Ridge along South Fork Mountain (USDA Forest Service 1998), which borders the watershed on the northeast. The drainage basin is elongate and runs northwesterly, with an average width of 6 miles (mi) and a length of approximately 100 mi.

The climate is typical of many North Coastal watersheds, and is determined by topography and proximity to the coast. Summers are hot and dry inland, generally cool and foggy along the coast. Average annual precipitation, which primarily falls between October and April, totals 45 inches near the coast, increasing with elevation to about 70 inches at 4,000 ft, and a maximum of 75 inches near the headwaters, above 6,000 ft. In the winter, precipitation falls as snow above 5,000 ft, and is a mix of snow and rain below that (Appendix A).

1.2.2. Land Use

Land use activities in the Mad include grazing and other agriculture (primarily in the lower watershed), timber harvest, recreation and residences (with more dense residential development in the lower watershed, from Blue Lake to the mouth of the river at McKinleyville). Gravel mining of the river channel, which corresponds with depositional zones, is primarily in the lower portion of the watershed. Commercial fishing, state and federal highways and roads, and power and gas line operations also occupy the watershed.

Historically, Wiyot Indians used the Mad River as a source of salmon and sturgeon, until European settlers established roads and began logging by the mid to late 1800s (Knuuti and McComas 2003). The Arcata-Mad River Railroad was built along the river in 1892, facilitating intensive timber harvest, leading ultimately to massive erosion and stream aggradation (DWR 1982). Aerial photograph analysis shows that from 1944 to 1975, 35 percent of the basin had been logged, and the number and size of active landslides increased (DWR 1982). In the middle portion, 43 percent of the watershed had been logged in approximately the same period. Land use activities in the upper watershed were minimal; for example, only 12 percent of the watershed had been logged in the same period (DWR 1982).

Gravel Mining

Gravel mining developed concurrently with the logging industry, supplying the materials for road building. Gravel mining has been a significant industry in the area between the Mad River Hatchery near Blue Lake and the Highway 101 bridge near the mouth since at least 1952. In 1992, a memorandum of agreement (MOA) was signed for gravel mining regulation, and a programmatic environmental impact report (PEIR) was completed in 1994. In 1992, a scientific advisory committee, known as the County of Humboldt Extraction Review Team (CHERT) was appointed by the Humboldt County Board of Supervisors to provide scientific oversight of gravel extraction and to establish an adaptive management program to obtain some dynamic equilibrium and channel stability (Lehre et al. 2005). CHERT reviews gravel extraction information and makes recommendations on gravel mining, which is concentrated within a 7.5-mile reach from about 5 to 12.5 miles from the mouth of the river, ending near the Mad River Fish Hatchery (Lehre et al. 2005). Most of the gravel mining occurs in the upper portion, which is braided and bounded by a broad floodplain. The lower portion is confined within a bedrock gorge, then broadens to a wider floodplain (Lehre et al. 2005). The National Marine Fisheries

Service (NMFS) is also involved, and the Army Corps of Engineers (Corps) issues a letter of permission (LOP) to the gravel operators (Knuuti and McComas 2003).

Lehre et al. (2005) provide detailed information for the geomorphology and response of this reach of the river to gravel mining in order to determine a sustainable rate of extraction. In summary, Lehre et al. (2005) acknowledged some uncertainty in several recent studies in the area, concluding that the current extraction rates may be either the maximum sustainable rates or greater than the maximum sustainable rates. Their estimates of sustainable rates were greater than Knuuti and McComas (2003), but smaller than Kondolf and Lutrick (2001, in Lehre et al. [2005]).

Gravel mining can adversely affect river resources, including both FWS and NMFS-listed species. The potential effects of instream gravel mining (including skimming channel bars during low-flow periods) can include channel degradation and instability, stream bank erosion, loss of channel habitat, sedimentation, and short-term increases in fine sediment and turbidity. The effects may not be immediately apparent because active sediment transport is required for many of the effects to propagate upstream and downstream. On the other hand, extracting a quantity of gravel roughly equal to the quantity that is being deposited, utilizing appropriate methods, can reduce excess aggradation and flood risk associated with elevated sedimentation in the watershed. Estimating the "sustainable yield" that will minimize adverse impacts is an inexact science. Ensuring that the methods employed are appropriate, and are carried out as intended, is challenging.

Both NMFS and USFWS identify gravel mining as one of the threats to recovery of endangered species, and NMFS has identified implementation of NMFS guidelines for gravel mining as one of its priorities. The County of Humboldt Extraction Review Team (CHERT), composed of a panel of scientists who annually estimate sustainable yields and determine appropriate extraction methods under the authority of Humboldt County, has conducted extensive analyses focused on historic and current channel conditions in the Mad River. The Humboldt County Planning Department is currently developing a Supplemental Program Environmental Impact Report (PEIR) to address an adaptive management strategy based on the most recent information on mean annual gravel recruitment.

Bridge Stability

The California Department of Transportation (CalTrans) has surveyed channel cross sections at the Highway 101 and Highway 299 bridges since 1928, showing significant bed degradation, although one of the gravel operators also conducted a survey and came to a different conclusion (Knuuti and McComas 2003; Pacific Affiliates 1999, in Knuuti and McComas 2003).

Dams and Diversions

HBMWD owns and operates Robert Matthews Dam, which was completed in 1961 near the town of Ruth in the upper watershed. It stores approximately 48,000 acre-feet (af) in Ruth Reservoir (DHS 2005, Trinity Associates and HBMWD 2004, Kennedy/Jenk Consultants and Winzler & Kelly, no date). Water uses are for industrial and municipal supply.

The reservoir stores water for summer releases into the river until it reaches HBMWD pumping facilities at Essex (near Blue Lake), 9 mi upstream of the mouth of the Mad River (Kennedy/Jenk Consultants and Winzler & Kelly, no date). Sedimentation rates in the upper watershed are very low; Winzler & Kelly (1975, in DWR 1982) noted rates of 0.3 to 0.6 in/yr within the reservoir.

In 2005, HBMWD received an amended domestic water supply permit (DHS 2005), which included acknowledgement of the recently-completed Turbidity Reduction Facility (TRF) to its water treatment system. This eliminated the concerns DHS had previously expressed about the adequacy of the drinking water supply, which is taken from Ranney wells, 60 to 90 feet below the bed of the Mad River near Essex. The groundwater source accessed by the Ranney wells is classified as a "groundwater not under the significant direct influence of surface water" (DHS 2005). Drinking water is collected for treatment from the Ranney wells, and is provided to the cities of Arcata, Blue Lake and Eureka, as well as community services districts for Fieldbrook, Cutten, Manila, and McKinleyville (Kennedy/Jenk Consultants and Winzler & Kelly, no date). DHS was concerned that the high turbidity levels (associated with suspended solids) could "interfere with the disinfection process" (DHS 2005). The TRF now operates to treat domestic water during winter storm flow periods to "less than or equal 1.0 NTU in at least 90 percent of the samples analyzed each month," and no samples exceeding 5.0 NTU (DHS 2005). Thus, turbidity in the Mad River is no longer a domestic water supply problem. Treating the causes of high turbidity in the Mad River basin may eventually reduce the frequency of TRF operations. HBMWD is also concerned about bed degradation that could be caused by gravel mining (Winzler & Kelly 1966, 1998 in Knuuti and McComas 2003; Lehre et al. 1993, in Knuuti and McComas 2003; Trinity Associates and HBMWD 2004).

HBMWD also diverts directly from the Mad River near Essex. The average total annual diversion by HBWMD is approximately 28,000 to 34,000 acre-ft/year, which is about 3% of the total average runoff (Trinity Associates and HBMWD 2004).

Sweasey Dam, which was dismantled and abandoned in 1970, was constructed in 1938 about 7 mi above Blue Lake, below Maple Creek on the Mainstem Mad River. It impounded approximately 2,000-3,000 acre-ft (af) of water (DWR 1982; Knuuti and McComas 2003), and diverted about 3.5 million gallons per day (mgd) via pipeline to the city of Eureka (DWR 1982). The dam's sediment-flushing valve was inoperable by 1941, and the dam was filled in the early 1960s (DWR 1982; Knuuti and McComas 2003). USGS noted that the dam removal did not appear to increase the suspended sediment concentration at the Arcata gauge, and noted only a short period of channel aggradation and widening through the area about 1.5 miles downstream of the dam (USGS 1975, in Knuuti and McComas 2003).

1.3. ENDANGERED SPECIES ACT CONSULTATION

EPA has initiated informal consultation with the National Marine Fisheries and the U.S. Fish and Wildlife Services on this action, under Section 7(a)(2) of the Endangered Species Act. Section 7(a)(2) states that each federal agency shall ensure that its actions are not likely to jeopardize the continued existence of any federally-listed endangered or threatened species.

EPA's consultation with the Services has not yet been completed. EPA believes it is unlikely that the Services will conclude that the TMDLs that EPA is establishing violate Section (7)(a)(2) since the TMDLs and allocations are calculated in order to meet water quality standards, and water quality standards are expressly designed to "protect the public health or welfare, enhance the quality of water and serve the purposes" of the Clean Water Act, which are "to restore and maintain the physical, chemical, and biological integrity of the Nation's water." Additionally, this action will improve existing conditions. However, EPA retains the discretion to revise this action if the consultation identifies deficiencies in the TMDLs or allocations.

1.4. ORGANIZATION

This report is divided into 5 chapters. Chapter 2 (Problem Statement) describes the nature of the environmental problems addressed by the TMDLs: fish population, sediment and turbidity problems, and water quality standards. Chapter 3 (Sediment and Turbidity TMDLs) summarizes the sediment source analysis, which was used to evaluate the management-related and natural sources of sediment contributions in the watershed, and the results of turbidity/suspended sediment data collection and analysis in the watershed. It also identifies the TMDLs and allocations that will achieve water quality standards. (Appendix A is the Sediment Source Analysis, which was used to calculate the TMDLs; this is available as a separate document.) Water quality indicators for sediment are included in this chapter. Chapter 4 (Implementation and Monitoring Recommendations) contains recommendations to the State regarding implementation and monitoring of the TMDLs. Chapter 5 (Public Participation) describes public participation efforts conducted during development of the TMDLs.

CHAPTER 2: PROBLEM STATEMENT

This chapter summarizes what is known about how turbidity and sediment are affecting the beneficial uses associated with the decline of the cold water salmonid fishery in the Mad River and tributaries. It includes a description of the water quality standards and salmonid habitat requirements related to turbidity and sediment.

2.1. WATER QUALITY STANDARDS

In accordance with the Clean Water Act, TMDLs are set at levels necessary to achieve the applicable water quality standards. Under the federal Clean Water Act, water quality standards consist of designated uses, water quality criteria to protect the uses, and an antidegradation policy. The State of California uses slightly different language (i.e., beneficial uses, water quality objectives, and a non-degradation policy). This section describes the State water quality standards applicable to the Mad River TMDLs using the State's terminology. The remainder of this document simply refers to water quality standards.

The beneficial uses and water quality objectives for the Mad River are contained in the Water Quality Control Plan for the North Coast Region (Basin Plan), as amended (NCRWQCB 2007). These are shown below in Table 1.

The water quality objectives pertinent to the Mad River sediment and turbidity TMDLs are listed in Table 2. In addition to water quality objectives, the Basin Plan includes two prohibitions specifically applicable to logging, construction, and other associated sediment producing nonpoint source activities:

- the discharge of soil, silt, bark, sawdust, or other organic and earthen material from any logging, construction, or associated activity of whatever nature into any stream or watercourse in the basin in quantities deleterious to fish, wildlife, or other beneficial uses is prohibited; and

- the placing or disposal of soil, silt, bark, slash, sawdust, or other organic and earthen material from any logging, construction, or associated activity of whatever nature at locations where such material could pass into any stream or watercourse in the basin in quantities which could be deleterious to fish, wildlife, or other beneficial uses is prohibited (NCRWQCB 2007).

Table 1. Beneficial Uses (NCRWQCB 2007)

Beneficial Use	Blue Lake HSA (109.10)	North Fork Mad HSA (109.20)	Butler Valley HSA (109.30)	Ruth HSA (109.40)
Municipal and Domestic Supply	E*	E	E	E
Agricultural Supply	E	E	E	E
Industrial Service Supply	E	E	E	E
Industrial Process Supply	E	E	E	P
Groundwater Recharge	E	E	E	E
Freshwater Replenishment	E	E	E	E
Navigation	E	E	E	E
Hydropower Generation	P*	P	P	E
Water Contact Recreation	E	E	E	E
Non-Contact Water Recreation	E	E	E	E
Commercial and Sport Fishing	E	E	E	E
Warm Freshwater Habitat				E
Cold Freshwater Habitat	E	E	E	E
Wildlife Habitat	E	E	E	E
Rare, Threatened, or Endangered Species	E	E	E	E
Marine Habitat	P			
Migration of Aquatic Organisms	E	E	E	E
Spawning, Reproduction, and/or Early Development	E	E	E	E
Shellfish Harvesting				
Estuarine Habitat	E			
Aquaculture	E	P	P	P
Native American Culture	E		E	
*E = existing beneficial use; P = potential beneficial use				

Table 2. Water Quality Objectives (NCRWQCB 2007)

Parameter	Water Quality Objectives
Suspended Material	Waters shall not contain suspended material in concentrations that cause nuisance or adversely affects beneficial uses.
Settleable Material	Waters shall not contain substances in concentrations that result in deposition of material that causes nuisance or adversely affect beneficial uses.
Sediment	The suspended sediment load and suspended sediment discharge rate of surface water shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.
Turbidity	Turbidity shall not be increased more than 20 percent above naturally occurring background levels. Allowable zones of dilution within which higher percentages can be tolerated may be defined for specific discharges upon the issuance of discharge permits or waiver thereof.

The narrative water quality standards described above focus on not adversely affecting beneficial uses. These TMDLs for sediment and turbidity are being established to protect the cold freshwater habitat beneficial use from adverse effects as the most sensitive beneficial use. The cold freshwater habitat includes the “uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish or wildlife, including invertebrates" (NCRWQCB 2007). In addition, the narrative standards above allow for some increases in the pollutant loads over natural conditions, provided that the beneficial uses are not adversely affected. Thus, the TMDLs focus on the human-related portion of sediment and turbidity conditions.

Although the cold freshwater habitat beneficial use has been identified as the most sensitive beneficial use, municipal and domestic supply is another crucial beneficial use that will benefit from implementation of the TMDLs. Humboldt Municipal Water District (HBMWD) diverts water directly from the Mad River for industrial uses, and derives the drinking water supply for the Humboldt Bay area from Ranney wells 60 to 90 feet below the river bed (see also Section 1.2.2.). A Turbidity Reduction Facility (TRF) was recently completed to remove fine sediments causing high winter turbidity levels in the drinking water supply. Implementation of these TMDLs may eventually reduce the frequency of TRF operations by reducing the sediment loads and corresponding turbidity values in the river and underlying aquifer.

Interpreting water quality standards for turbidity

Turbidity is an optical measure of water clarity. Particles suspended in the water column, such as suspended sediment or organic matter, can reduce the water clarity and increase the turbidity. Turbidity can influence salmonid behavior in ways that are somewhat similar to influences from increased sediment (reduced feeding and growth rates, damage to gills, fatality). Reduced feeding rates, in particular, can be associated with high turbidity levels, as salmonids feed by sight. Turbidity can be measured in several different types of units, including nephelometric turbidity units (NTU), Jackson turbidity units (JTU), and formalin turbidity units (FNU). Although the units are not readily interchangeable, they can be correlated for specific locations (see Chapter 3). In the Mad River, turbidity is highly correlated to suspended sediment concentration (SSC), which is a measure of the concentration of fine sediment suspended in the water column.

By contrast, turbidity can also provide cover for salmonids from predation. The Regional Water Board (2006) summarized much of the current literature on turbidity and discussed potential indices for desired salmonid habitat conditions. Because elevated turbidity levels occur in natural stream conditions during storm flows, it is difficult to point to a specific turbidity value that signifies acceptable or unacceptable for support of beneficial uses. In addition, it is in many cases difficult to identify "naturally occurring background levels." However, it is clear that turbidity levels in disturbed watersheds are higher than those in undisturbed or less-disturbed watersheds, both in terms of short-term values related to storm flows and in chronic conditions, including turbidity levels that remain elevated for longer periods of time in disturbed watersheds. Thus, while short-term (acute) elevations may be tolerated up to some level, long-term (chronic) turbidity can adversely affect salmonids as well.

Newcombe & Jensen (1996) attempted to summarize data on turbidity and SSC found in the literature for a variety of salmonids over a broad range of geographic areas, and came up with a "severity of ill effects" (SEV) scale, which classified effects associated with excess turbidity or suspended sediment according to lethal, sublethal, and behavioral effects. However, the correlations are weak (0.2 – 0.8), so its application to water quality standards is questionable.

In consultation with the Regional Water Board, EPA interpreted the above narrative objectives for the TMDLs by making an estimate of turbidity background levels. This is challenging because no records of background turbidity exist for a watershed of this size. Accordingly, EPA utilized the best available information, represented by a large data set of turbidity data sorted by watersheds and compiled by Klein et al. (unpublished, 2006). Graham Matthews and Associates (GMA) (Appendix A) analyzed turbidity from those reference watersheds—those that were undisturbed by management activity, and were essentially left in a pristine condition—to determine “background” conditions for the same period that turbidity data were collected in Mad River watersheds. Duration exceedence curves were developed from these data, and EPA focused on the 10% value (i.e., the value that is exceeded 10% of the time) as representing chronic turbidity exposure conditions, and the 1% exceedence value (i.e., the value that is exceeded 1% of the time) as representing acute turbidity exposure. In theory, it would be possible to examine a greater range of conditions, but these two values adequately represent short- and long-term turbidity values. Those that occur less than 1 percent of the time are so infrequent that they would represent very extreme floods. Although the data for background conditions were obtained from four very small watersheds (2-8 square miles [mi^2]), they can serve as indicators for good conditions in the watershed (see Section 3.3 –Sediment and Turbidity Indicators).

After analyzing several different methods for determining “naturally occurring background levels” of turbidity, EPA concluded that the most reliable method would be to determine suspended sediment loads as a portion of the total sediment load by developing a traditional sediment budget, with supplemental analysis, modeling, and data collection. EPA used the numeric objective, “turbidity shall not be increased more than 20% over natural background conditions,” as the basis for setting the TMDLs. As discussed in Section 2.3, turbidity in the Mad River is adequately represented by suspended sediment loads; thus, suspended sediment loads are used to express the turbidity TMDLs.

2.2. FISH POPULATION AND ENDANGERED SPECIES CONCERNS

The primary beneficial use of concern for these TMDLs is the cold freshwater habitat, defined as uses that “support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.” These TMDLs focus on salmonids as the aquatic species that are most sensitive to elevated sediment and turbidity conditions, and for which data are available. Many different habitat conditions are crucial for the survival of salmon and steelhead. Salmonid populations are affected by a number of factors, including commercial and sport harvest, food supply, availability of cover and ocean conditions. Timber harvesting and related activities (such as road construction) have likely had the greatest impact on salmon populations and their habitat in the Mad River watershed (NMFS 2004). These TMDLs focus only on the achievement of water quality standards related to sediment and turbidity, which will facilitate, but not guarantee, population recovery.

Salmon Species

Evidence of salmon population declines is contained in the listing of all the major species under the Endangered Species Act by National Oceanic and Atmospheric Association (NOAA) fisheries. Salmon populations are listed under their geographic area. The Endangered Species Act listing that applies to the Mad River is as follows:

- Southern Oregon/Northern California Coast Coho Salmon evolutionary significant unit (ESU)
- California Coastal Chinook Salmon ESU
- Northern California Steelhead Distinct Population Segment (DPS)

Data on population trends for the entire California Coastal Chinook and Northern California steelhead are limited (NMFS 2005). A recent scientific review of the information on salmonid abundance under the Endangered Species Act (NMFS 2005) concluded that the California Coastal Chinook, Northern California steelhead, and California Coastal coho (which include the salmonid populations in the Mad River) are "likely to become endangered in the foreseeable future," thus reconfirming the "threatened" status of the salmon ESUs and the steelhead DPS. Records indicate that the three main species of cold water fish (Chinook, coho, and steelhead) were present in the watershed historically. In years of low flow, salmonids could be speared at the mouth of the Mad River (Arcata Union, 1896, in Trinity Associates and HBMWD 2004). Due to a series of natural barriers, only the lower 35 miles of the Mad River and its adjoining tributaries are regularly utilized by salmon; depending on flow and local conditions, the boulder canyon in the middle portion of the Mad River, where the drops are steep, can prevent salmonid migration to the upper river zone (NMFS 2004; Trinity Associates and HBMWD 2004). Under natural conditions, the upper river frequently had no flow in the late summer and early fall; HBMWD has released water since 1961 from Ruth Lake to provide a consistent flow on the 84 mile reach downstream of Matthews Dam; HBMWD estimates that it provides approximately 450 acres of habitat for aquatic species during the low-flow months (Trinity Associates and HBMWD 2004).

Information indicates that the populations have declined in numbers and their geographic extent has been reduced. Excessive sediment has contributed to salmonid problems in the Mad River watershed. For example, spawning gravel filled with fine sediment has caused decreased survival to emergence, pool filling has reduced juvenile carrying capacity, and high turbidity levels have led to reduced feeding and growth (NMFS 2004). Thus the available information indicates problems with the COLD beneficial use.

Chinook, coho and steelhead populations "continue to exhibit depressed population sizes relative to historic abundance," and trends have continued downward (NMFS 2005, 2007). California Department of Fish and Game (CDFG) has implemented "no harvest" or "catch and release only" rules for Chinook and wild or naturally produced steelhead (Sparkman 2003a). Newer presence/absence studies by the CDFG and the National Marine Fisheries Service (NMFS) on coho indicate that 64% of 22 historic coho streams surveyed in the Mad River had coho presence in 1999-2001. This is a steady decline from 1987-1989, when coho were present in 100% of historical coho streams; however, only eight streams were surveyed at the time of the NMFS study (NMFS 2005).

All three species are threatened by a wide variety of land use and management activities, including agricultural operations, artificial barriers and loss of hydrologic connections, dams, erosion-control and flood-control structures, gravel mining, forestry operations, road crossings, streambed alteration, suction dredging, substandard screens or unscreened water diversions, and illegal harvest (NMFS, 2007). For some species, hatchery operations are employed to facilitate species recovery, and in others, hatchery operations may be hindering recovery (NMFS, 2007).

Chinook

A natural barrier on the Mad River approximately one-half mile below Bug Creek (approximately 50 miles from the ocean) is generally considered the upper limit of Chinook distribution (Trinity Associates and HBMWD 2004). Chinook salmon estimates based on habitat conditions and professional opinion ranged from 5,000 adults in 1965 (approximately 6% of the Chinook population in northwest California streams) to 1,000 adults in 1987 in the Mad River watershed (NMFS 2004, 2005). Chinook counts near Sweasey Dam have declined between the 1930s and 1960s from a peak of approximately 3,000 to well below 1,000 (NMFS 2004; Trinity Associates and HBMWD 2004). NMFS' assessment of the Mad River watershed is that the conservation value for Chinook is high in three HSAs (Blue Lake, North Fork Mad River, and Butler Valley). Chinook did not occupy the Ruth HSA. Fifty-three out of 661 stream miles (or 8% of stream miles) are estimated to be currently used by Chinook for spawning, rearing, and/or migration (NOAA Fisheries 2005).

Spawner surveys conducted on Cañon Creek, tributary to the Mad River, exhibit high variability, but suggest a recent positive trend in Chinook abundance (NMFS 2005). CDFG monitored Chinook angler catches during the months of November through March in 1999-2003. Expanded catch estimates ranged from 158 to 1,566 Chinook salmon (Sparkman 2003a). These population estimates are generally consistent with the 1,000 adults estimated in 1987 (as presented by NMFS 2005). CDFG estimated nearly one million young of year Chinook salmon in 2001. May and June are considered important months for their migration. A population estimate for one-year juveniles was not provided, although original catches were about an order of magnitude less than the young of year (Sparkman 2002). Loss of tidal wetlands and sloughs as well as decreased complexity in estuary habitat due to levee construction and channelization has resulted in reduced rearing habitat for juvenile Chinook (NMFS 2004). Overall, NMFS indicates that "Chinook salmon in the California Coastal Chinook salmon ESU continue to exhibit depressed population sizes relative to historical abundances; this is particularly true for spring-run Chinook salmon" (2005). The presence of spring-run Chinook in the Mad River is largely unknown (Zuspan and Sparkman 2002).

NMFS assigns a recovery priority number to each listed species. This number is based on the magnitude of threat, recovery potential, and the presence of conflict between the species and development or economic activities. There are twelve recovery priority numbers, with one being the highest priority and 12 being the lowest (50CFR 17: Vol. 71 FR pp 24296-24298, June 15, 1990). A Recovery Priority Number of 3 was assigned to the California Coastal Chinook salmon ESU, "based on a high degree of threat, a low-to-moderate recovery potential, and anticipated conflict with development projects or other activity" (NMFS, 2007). It is thought that the spring-run Chinook may have been completely eliminated from this ESU. Population trends in the Mad River appear to be positive, but general trends in California are downward, and some local populations may have been extirpated. There is also concern about limited data (NMFS, 2007). The Mad River Hatchery fall-run Chinook hatchery program is considered to be part of the ESU (NMFS, 2007).

Steelhead

The natural barrier on the Mad River approximately one-half mile below Bug Creek (approximately 50 miles from the ocean) is generally considered the upper limit of anadromous fish distribution; however, some steelhead have been noted just below Deer Creek (53 miles from the ocean) although their number has been declining (Trinity Associates and HBMWD 2004). It is argued that summer- and winter-run steelhead that co-occur within a basin are more similar to each other than either is to the corresponding run-type in other basins (NMFS 2005). Summer-run steelhead are found in the Mad River; however, winter-run steelhead are considered the most numerous. Time-series data collected from 1994 to 2002 resulted in geometric mean population estimates from 162 to 384 for summer-run steelhead (NMFS 2005). More recent data collected from 1996 to 2002 by Halligan (2003, in NMFS 2004) revealed an observed range of eight to 59 adult summer steelhead; however, no population trends are apparent from these data (NMFS 2004). Historical estimates of winter-run steelhead in the Mad River near Sweasey Dam were over 6,000 in the 1940s (Zuspan and Sparkman 2002) and subsequently declined in the 1950s and 1960s to less than 2,000 adults. The dam was destroyed in 1970; therefore, no additional data were collected at this location (NMFS 2005; Trinity Associates and HBMWD 2004). In 1965, CDFG estimated a spawning population of approximately 6,000 in the Mad River watershed, which is 3% of the estimated population of the Northern California Steelhead ESU (NMFS 2004). NOAA Fisheries summarized the steelhead conservation value of the Blue Lake, North Fork Mad River, and Butler Valley HSAs as high and the Ruth HSA as low. Specifically, 169 out of 661 stream miles (26%) were estimated to be currently used by steelhead for spawning, rearing, and/or migration (NOAA Fisheries 2005).

The Mad River is the only stream in Humboldt County where steelhead can be harvested; therefore, it is considered an important location for anglers to catch and harvest steelhead from the Mad River Hatchery (Sparkman 2003a). CDFG monitored winter-run steelhead between 1999 and 2003. Nearly 88% of the steelhead catch were produced from the Mad River Hatchery, which currently raises winter-run steelhead to enhance the sport fishery. Steelhead were caught more frequently than other anadromous fish species in the Mad River. Expanded catch estimates between November and March ranged from nearly 7,000 to over 18,000 in 1999 to 2003, with the peak occurring in the 2001/2002 season, and February typically exhibiting the highest number of catches (Sparkman 2003a). Juvenile populations were estimated during 2001 and 2002. In 2001, over 11,000 one-year steelhead were estimated, while this number increased to over 14,000 in 2002 (June and July were the most important months for out-migration). Two-year juvenile steelhead were estimated at nearly 64,000 in 2001 and over 41,000 in 2002. April and May were important for 2+ year juvenile steelhead out-migration, which supports current Mad River fishing closures during these months to protect steelhead smolts (Sparkman 2002, 2003b). CDFG also reported on the habitat types used by wild and hatchery steelhead. During high-flow periods, runs were the most frequent habitat type and, during drier periods, glides were more frequently used. This study suggests that hydrology influences steelhead habitat use (Sparkman 2003c).

Negative influences from hatchery stocks are a concern (NMFS 2004, 2005). In Oregon, wild steelhead population production has been shown to decrease as more hatchery steelhead intermix with wild populations. Specifically, hatchery steelhead that spawn in the wild have less reproductive success than wild steelhead and a hybridized naturally produced steelhead may also face decreased success (Sparkman 2003a; NMFS 2004). The number of one-year old juvenile steelhead released by the hatchery varies by year (ranging from over 100,000 to nearly 1.5 million individuals between 1990 and 2000). The juveniles have clipped adipose fins to enable differentiation between hatchery- and naturally-produced winter-run adult steelhead (Zuspan and Sparkman 2002). In the Mad River, it is known that hatchery steelhead spawn in the wild. CDFG conducted a juvenile downstream migration study. This study showed minimal downstream migration overlap of hatchery juveniles and wild steelheads in the Mad River. Potential interactions are minimized by the hatchery release schedule (Sparkman 2003b); however, additional study could confirm whether the hatchery steelhead are reproducing with wild populations (Sparkman 2003a; Zuspan and Sparkman 2002).

A Recovery Priority Number of 5 was assigned to the Northern California steelhead DPS, "based on a moderate degree of threat, a high recovery potential, and anticipated conflict with development projects or other economic activity" (NMFS, 2007). Concerns included a lack of data, particularly for the winter run, and abundance and productivity. The steelhead hatchery program on the Mad River was terminated in 2004 due to concerns about the negative influences on the DPS (NMFS, 2007).

Coho

In addition to the threatened status of the Southern Oregon/Northern California coast coho salmon, the Mad River watershed was designated as critical coho habitat in 1999. The Mad River up to Wilson Creek (approximately 45 miles from the ocean) is generally accessible to migrating adults (Trinity Associates and HBMWD 2004). Historically, the entire Mad River basin was thought to have around 2,000 adult coho. Subsequent estimates of coho spawner abundance indicate a decline in population size, with the most recent survey from 1987-1991 indicating 460 coho adult (NMFS 2005). Similar population trends were observed in coho migrating above Sweasey Dam in the 1930s through 1960s. CDFG counted an average of 474 coho passing the dam, with a maximum of over 3,000 in 1962 and a minimum of three in 1958; however, the high count in 1962 is likely caused by CDFG artificially rearing coho and stocking them in the watershed beginning in 1959 (NMFS 2004). More recent studies conducted during the winter months of 1999-2003 by CDFG estimated only 46 coho salmon in the Mad River (Sparkman 2003a), which is significantly lower than previous estimates. Low catches were due in part to difficult hydrology and stream flow conditions (low flow and high muddy streams). Lindsay Creek and Canon Creek, tributaries to the Mad River, support annual runs of coho salmon (Zuspan and Sparkman 2002). Coho observations were generally low in Cañon Creek and North Fork Mad River during surveys between 1985 and 2000 (average of five and ten fish, respectively), with higher counts occurring in the first five years (NMFS 2004; Trinity Associates and HBMWD 2004). Overall, it was assumed that most coho salmon utilized the lower watershed and tributaries, such as Lindsay Creek (NMFS 2004; Trinity Associates and HBMWD 2004).

Juvenile coho salmon (fry and smolts) were historically released from the Mad River Hatchery. Release rates declined from over 370,000 in the late 1980s to just over 82,000 in the late 1990s. Adult returns to the hatchery were low in the 1990s. The hatchery no longer produces coho salmon (NMFS 2005). More recently, in the summer of 2002, hundreds of coho juvenile were rearing in the Mad River watershed, as reported by Halligan in 2003 (NMFS 2004). NMFS noted that recent small increases in coho due to improved ocean conditions are still much lower than historical populations (2004). In the Mad River in general, the decline of coho was recently reconfirmed (NMFS 2005): "Coho populations continued to be depressed relative to historical numbers, and we have strong indications that breeding groups have been lost from a significant percentage of streams within their historical range." Coho salmon are not allowed to be harvested or taken from the water in the Mad River (Sparkman 2003a).

A Recovery Priority Number of 1 was assigned to the Southern Oregon/Northern California Coast ESU, "based on a high magnitude of threat, a high potential for recovery, and anticipated conflict with current and future land disturbance and water-associated development" (NMFS, 2007). Coho populations now occupy only 50 percent of their historic range (NMFS, 2007).

In summary, this information indicates that cold freshwater beneficial uses have declined in the Mad River watershed. Recent reviews under the Endangered Species Act reconfirmed the populations of coho, Chinook, and steelhead in the area as "threatened."

Western Snowy Plover

The western snowy plover (*Charadrius alexandrinus nivosus*), listed as threatened under the Endangered Species Act by the U.S. Fish and Wildlife Service, was not specifically addressed in the draft of this document, but was the subject of comments by the United States Fish and Wildlife Service during the public comment period. Mad River gravel bars may be important snowy plover nesting sites. In its comments, USFWS indicated that attainment of the TMDL targets will not affect, or may be beneficial, to this species, but raised the concern that impacts to this species need to be considered in future planning efforts and development of implementation plans for the TMDLs.

According to the US Fish and Wildlife Service (USFWS) office in Arcata, California, the western snowy plover is listed as threatened, and it is a Bird Species of Special Concern in California. The USFWS describes the range of the Pacific coast population in Del Norte, Humboldt, and Mendocino counties as Recovery Unit 2, which has ranged in population from 60 to 74 adults (http://www.fws.gov/arcata/es/birds/WSP/plover.html). Snowy plovers forage for invertebrates in beach sand, among tide-cast kelp, and within foredune vegetation. Some plovers use dry salt ponds and river gravel bars, and they breed from spring through early fall, laying a clutch of eggs in shallow depressions in the sand, above the high tide line on coastal beaches, sand spits, dune-backed beaches, sparsely vegetated dunes, beaches at river mouths, and salt pans at lagoons and estuaries. Less commonly, this also includes bluff-backed beaches, dredged material disposal sites, salt pond levees, dry salt ponds, and river bars. Threats to the population include human disturbance, predation, and loss of nesting habitat to encroachment of non-native beachgrass and urban development. Human recreational activities, which tend to coincide with the nesting season, are key factors in the ongoing decline in breeding sites and populations (USFWS, 2007, http://www.fws.gov/arcata/es/birds/WSP/plover.html).

Habitat requirements for the western snowy plover are different than those of salmonids. Efforts to achieve water quality standards are not expected to adversely affect these species, and they may also be beneficial (Long, M., U.S. Fish and Wildlife Service, 2007), by facilitating a return to more natural sediment and turbidity conditions.

2.3. SEDIMENT AND TURBIDITY PROBLEMS

Salmon can be adversely affected by many different stream conditions related to sediment. The effects of sediment on the Mad River are evident in the changes in river morphology after the 1964 flood. Like most of the North Coast watersheds, the Mad River's sediment loading is very high and a portion of this loading can be attributed to human activities.

Almost all sources of sediment in the Mad River watershed are from diffuse, nonpoint sources, including runoff from roads, timber operations, and natural background. Additionally, there are two Waste Water Treatment Plants (WWTPs) in the watershed (McKinleyville and Blue Lake), the Mad River Fish Hatchery, and the Korbel Sawmill Complex that are each permitted under the National Pollutant Discharge Elimination System (NPDES). These permits are issued by the Regional Board.

Most residents in the town of Fieldbrook have individual septic systems. Part of the wastewater, for residents not on septic systems, is fed into the Arcata WWTP. Municipal runoff (e.g., the collective effects of people hosing off driveways), municipal and industrial stormwater runoff, runoff from construction sites, and runoff from California Department of Transportation (CalTrans) facilities are diffuse sources of potential sediment that are also permitted under the NPDES. Unpermitted discharges that should be permitted, or are subject to future permitting, are also diffuse sources of sediment.

Salmon requirements related to stream sediment and turbidity

This section presents available information related to sediment problems in streams in the Mad River and tributaries. Salmonids have different water quality and habitat requirements at different life stages (spawning, egg development, juveniles, and adults). Sediment of appropriate quality and quantity is needed for redd (i.e., salmon nest) construction, spawning, and embryo development. Excessive amounts of sediment or changes in size distribution (e.g., increased fine sediment) can adversely affect salmonid development and reduce available habitat.

Excessive fine sediment can reduce egg and embryo survival and juvenile salmonid development. Tappel and Bjornn (1983) found that embryo survival decreases as the amount of fine sediment increases. Excess fine sediment can prevent adequate water flow through salmon redds, which is critical for maintaining adequate oxygen levels and removing metabolic wastes. Deposits of these finer sediments can also prevent the hatching fry from emerging from the redd, resulting in smothering. Excess fine sediment can cause gravels in the water body to become embedded (i.e., the fine sediment surrounds and packs in against the gravels), which effectively cements them into the channel bottom. Embeddedness can also prevent the spawning salmon from building redds.

An imbalance between fine or coarse sediment supply and transport can also adversely affect the quality and availability of salmonid habitat by changing the morphology of the stream. It can reduce overall stream depth and the availability of shelter, and it can reduce the frequency, volume, and depth of pools. Pools provide salmon a resting location and protection from predators.

Excessive sediment can affect other factors important to salmonids. Stream temperatures can increase as a result of stream widening and pool filling. The abundance of invertebrates, a primary food source for juvenile salmonids, can be reduced by excessive fine sediment. Large woody debris, which provides shelter and supports food sources, can be buried. Increased sediment delivery can also result in elevated turbidity, which is highly correlated with increased suspended sediment concentrations. Increases in turbidity or suspended sediment can impair growth by reducing availability or visibility of food sources and the suspended sediment can cause direct damage to the fish by clogging gills.

Sediment yield tends to be concentrated in the middle portion of the watershed, where most of the area is in private land ownership. This represents approximately 70 percent of the total basin area. Historically the area yielded nearly 95% of the basin's sediment (DWR 1982), and it still yields about 75% (Appendix A).

High turbidities in the North Coast streams are generally related to high levels of suspended sediment; thus, the adverse effects of excess sediment and, particularly, suspended sediment, also reflect the adverse effects of high turbidities on salmonids. High turbidity on its own (i.e., with or without the influence of sediment) can affect salmonids. Newcombe and Jensen (1996) reviewed much of the literature and attempted to associate a behavioral effects scale with high turbidity doses. They presented a scale relating turbidity doses and durations relative to anticipated effects on salmonids, from mild behavioral effects, to sublethal and lethal effects. A simplified analysis by EPA comparing the Newcombe and Jensen (1996) SEV (severity of environmental effect) scale to turbidity data collected on North Coast reference streams by Klein (2006, unpublished), suggested that the North Coast reference streams would be classified as approaching sublethal ranges on the Newcombe and Jensen scale. This would suggest that reference streams do not meet the SEV level recently defined by the Regional Water Board as an ideal goal for water quality protection (Fitzgerald, 2001). We concluded that the Newcombe and Jensen scale may not be appropriate for these watersheds if the reference streams are not within the range that is desirable for water quality standards. Newcombe and Jensen (1996) acknowledge that their correlations are weak, and the data on which the scale is built are derived from a wide variety of studies on several salmonid species (and age classes) in varied locations. It is possible that the SEV scale is too subjective to be reasonably applicable.

Obviously, some level of increased turbidity may occur naturally, and salmonids have evolved in these environments. Klein (2003) has summarized much of the current literature on effects of turbidity on salmonids: many of these studies suggest that turbidities as low as 25 NTU and suspended sediment concentrations of 25 mg/l may produce behavioral effects for juvenile salmonids, by reducing the distance at which food can be seen. Increased levels of turbidity may be natural in short durations, and may even have minor beneficial effects in that the turbidity provides a form of cover from predators; however, even slightly elevated turbidities of long durations (i.e., turbidities that remain high long after the end of a winter storm) can significantly diminish feeding ability over long periods, and may have a host of other adverse effects that may function cumulatively.

Turbidity Studies in the North Coast

EPA investigated existing monitoring studies of turbidity in order to consider utilizing monitoring data to develop the turbidity TMDLs. An ongoing study of turbidity in nearby reference and managed watersheds in similar geologies (Klein, 2003, 2006, unpublished) initially appeared to provide an excellent source of data to interpret the Regional Water Board's turbidity standard ("turbidity shall not be increased greater than 20 percent over naturally occurring background levels") in order to set loads for the TMDLs that are clearly linked to the existing numeric water quality standard. While EPA ultimately determined that the data were most appropriate for similarly-sized watersheds (i.e., less than 10 mi^2 in size), and that setting the TMDLs according to the monitoring data would not be appropriate, we did include the information as additional water quality indicators for turbidity, and the targets were identified based on no more than 20 percent greater than the naturally occurring background levels for two different flows in those reference streams. The results of Klein's investigation (2003 and, 2006, unpublished) and applicability to the Mad River TMDLs are summarized below.

Klein (2003; 2006, unpublished) analyzed turbidity data over a multi-year period, correlating it with various factors to determine what factors were most likely to be associated with high levels of "chronic" turbidity (the elevated turbidity levels observed even between storms, defined as the 10% exceedence level). The study included six old-growth redwood forested watersheds, eight with older (legacy) harvest, and 14 actively managed watersheds with varying levels of recent and ongoing harvest. Turbidity at the 10% exceedence (i.e., that which would be exceeded no more than 10% of the time, which approximates long-term flows) level ranged from 3 to 116 FNU for water year (WY) 2005.

Klein (2003; 2006, unpublished) found that the average annual rate of timber harvest, expressed as clearcut equivalent area, was most strongly correlated with higher values for the 10% exceedence turbidity. Turbidity increased substantially at average annual harvest rates above about 1.5% (a 67-year rotation cycle) for Humboldt County streams. This correlation was stronger for harvest rates averaged over a 15-year turbidity record, than for shorter-term averages. Legacy watersheds (not harvested within a 15-year period preceding the study period) had 10% turbidity levels averaging 11 FNU, while actively harvested watersheds averaged 71 FNU. Turbidity in the actively harvested watershed varied from 382% to 1,055% over background levels (Klein 2003; 2006, unpublished). Correlations were also high at Humboldt County sites for road densities (which can also indicate harvest levels). The greatest correlations (Klein 2003; 2006, unpublished, Table 7) were for: clearcut equivalent area (15-year average), mid-slope road density, several precipitation factors (the naturally-caused factor with the highest correlation), tractor yarded area, and basinwide road density. (R^2 for the 15-year clearcut equivalent averaged about 0.66.)

In general, Klein (2003; 2006, unpublished) found that 10% turbidities ranged from 3 to 116 FNU, with several of the more actively managed watersheds exceeding 25 FNU (determined to be a biological threshold) for over 1,800 hours in WY 2004. Other streams, primarily in pristine and near-pristine watersheds located within parklands or those that were harvested decades ago, had much lower turbidities, with several never exceeding 100 FNU. Those in the middle range, which included older second-growth streams without recent harvest, ranged from about 20-40 FNU for the 10% turbidity.

GMA (Appendix A) used Klein's more current data (in review, 2006, in Appendix A) to compare "background" rates from the four pristine basins with those from the Mad River monitoring stations (Table 3). While it is not feasible to directly compare these pristine basins (which range in size from 2 to 8 mi^2) with the Mad River basin without some method to account for the greater drainage basin sizes in the Mad River, the turbidity values for the Mad River sites are orders of magnitude greater than the background rates. The 10% values for the two lowermost monitoring sites are greater than all of the watersheds in the Klein (2003; 2006, unpublished) study. The North Fork site is higher than the middle range of the Klein data, and the Ruth site is within the middle range. It is clear that the Mad River turbidity values are well above what would be considered within the Regional Board's standard of no greater than 20% over background levels.

Sediment conditions in the Mad River

Chapter 3, which summarizes the Sediment Source Analysis, indicates that current loadings of total sediment and suspended sediment (which is closely correlated with turbidity in the basin) average nearly four times the background rates. The lowest sediment delivery rates are found in the Upper Mad subarea, averaging about three times the background rates, and the highest rates are found in the Lower Mad/North Fork subarea, averaging over 11 times the background rates for that subarea.

Many factors may be contributing to the high sediment loadings, including timber harvest and roads. NMFS (2004) indicates that timber harvesting and related road construction (and other related activities) have likely had the greatest impacts on salmon in the Mad River watershed by increasing fine sediment, which can then be delivered to streams by overland flow. In addition, deep-seated landslides are present (particularly in the upper portions of the watershed) and contribute large sediment loads to the mainstem and tributaries (NMFS 2004).

Table 3. Comparison of Background Turbidity Data with Mad River Sites, WY 2005

BACKGROUND SITES					**Exceedance Probability %**				
Site	**Sensor**	**Units**	**Drainage Area (acres)**	**Drainage Area (mi^2)**	**0.10**	**1.0**	**2**	**5**	**10**
Godwin Creek	OBS-3	FBU	947	1.5	29	12	8	5	3
Upper Prarie Creek	OBS-3	FBU	2,662	4.2	60	24	16	8	4
Little Lost Man Creek	OBS-3	FBU	2,317	3.6	116	32	21	12	7
Prarie Creek ab Boyes	DTS-12	FNU	4,915	7.7	45	19	14	7	4
		Average:			63	22	15	8	5
		Std Dev:			38	8	5	3	2

MAD RIVER SITES					**Exceedance Probability %**				
Site	**Sensor**	**Units**	**Drainage Area (acres)**	**Drainage Area (mi^2)**	**0.10**	**1.0**	**2**	**5**	**10**
Mad R Hatchery Rd Br	DTS-12	FNU	310,326	485	3,790	1,610	865	542	344
Mad R Butler Valley Ranch	DTS-12	FNU	217,387	340	3,180	1,270	858	497	351
N Fork Mad R Korbel Bridge	DTS-12	FNU	28,468	44	1,050	273	177	90.1	46.1
Mad R above Ruth Reservoir	DTS-12	FNU	59,911	94	565	225	145	70.1	37
Average Existing turbidity		Average:			2,146	845	511	300	195
		Std Dev:			1,578	702	405	254	177

Source: Klein 2006 unpublished, GMA 2007 (Appendix A, Table 13).

Note: 1% = large floods; 10% = chronic turbidity. Data are compared over identical periods.

CHAPTER 3: SEDIMENT AND TURBIDITY TMDLS

This chapter presents the sediment and turbidity TMDLs for the Mad River watershed, along with the technical analysis. The first section summarizes the results of the revised sediment source assessment. The second section presents the TMDLs and assumptions used to set the TMDLs. The TMDLs are the total loading of sediment that the Mad River and its tributaries can receive without exceeding water quality standards for sediment and turbidity. The third section identifies water quality indicators, which are interpretations of the narrative water quality standards. These indicators can also be used to evaluate stream conditions and progress toward or achievement of the TMDLs.

The sediment source analysis for the Mad River watershed was conducted for EPA by Graham Matthews and Associates (GMA) under subcontract to Tetra Tech, Inc. The analysis concludes that current sediment loading (based on average 1976 – 2006 rates) is almost 300% of natural loading, with loading in the Middle Mad almost five times greater than natural loading. This is in excess of the TMDLs, which are set at 120% of the natural sediment load (averaged over time to account for large storms). Sediment delivery and erosion from human disturbance is primarily related to roads—both landslides and surface erosion—and, to a much lesser extent, timber harvesting; for the watershed as a whole, only 36% of the total sediment load is not associated with anthropogenic activity.

3.1. SEDIMENT SOURCE ASSESSMENT

Almost all sources of sediment in the Mad River watershed are from diffuse, nonpoint sources, including runoff from roads, timber operations, and natural background. This section summarizes the sediment source assessment of the diffuse, nonpoint sources (Appendix A). The purpose of the sediment source assessment was to provide the information needed to determine appropriate sediment load allocations for the TMDLs. In addition, it includes an analysis of turbidity, and the relationships between turbidity and fine sediment in the watershed. This section is a summary of the methodology, results, and interpretation of the sediment source assessment. Appendix A contains additional details on the results by geology, subwatershed, and type of sediment delivery, as well as a detailed description of methodologies and assumptions. The sections below summarize (and are largely abstracted from) the sediment source assessment (Appendix A).

In addition to the nonpoint sources there are permitted point sources of sediment. There are two Waste Water Treatment Plants (WWTPs) in the watershed (McKinleyville and Blue Lake), the Mad River Fish Hatchery and the Korbel Sawmill Complex, each with NPDES permits issued by the Regional Board.

The Blue Lake and Korbel Sawmill Complex NPDES permits do not allow discharges to surface waters, so the permits do not include effluent limits for total suspended solids (TSS) and suspended solids (SeS). The Korbel Sawmill Complex NPDES permit refers to the turbidity water quality objective, stating that "turbidity shall not be increased greater than 20 percent over naturally occurring background levels." The sediment generated on this site is from diffuse sources: primarily runoff from bare ground, discharged as overland flow with rainfall. Thus, it functions similarly to a nonpoint source.

The monthly average TSS and SeS effluent limits in the NPDES permits for McKinleyville and Mad River Fish Hatchery are:

McKinleyville:	TSS 95 mg/l; SeS 0.1 mg/l
Mad River Fish Hatchery:	TSS 8 mg/l; SeS 0.1 mg/l

Municipal runoff (e.g., the collective effects of people hosing off driveways), municipal and industrial stormwater runoff, runoff from construction sites, and runoff from California Department of Transportation (CalTrans) facilities are diffuse sources of potential sediment that are also permitted under NPDES. These potential loads are expected to generate and deliver sediment at rates that are similar to nonpoint sources.

3.1.1. Sediment Source Analysis Methodology

Summary

The sediment source analysis consists of several components: 1) a landslide analysis; 2) suspended sediment and turbidity monitoring; 3) Watershed Erosion and Prediction Project (WEPP) WEPP modeling; and 4) NetMap modeling. Because the development of the sediment budget is complex, and because the components are both complex and interconnected, we will summarize it here. Additional detail can be found in the revised SSA document (Appendix A).

The sediment source analysis accounts for chronic and episodic sediment input to the stream network. Data were derived from the US Geological Survey (USGS), US Forest Service (USFS), California Department of Water Resources (DWR), Humboldt Bay Municipal Water District (HBMWD), the Blue Lake Rancheria (BWR), Green Diamond Resource Company, Inc. (GD), Klein (2006, unpublished, in the SSA), and monitoring data collection and analysis by EPA's contractor, Graham Matthews Associates (GMA). Additional information from the Washington State Watershed Analysis Manual (WDNR, 1995), for similar geologies, was used to refine some assumptions, where existing data were inadequate. The SSA characterizes the sediment conditions of the watershed and develops a sediment budget, from which the TMDLs are set.

Sediment Budget Categories

The sediment budget breaks the components of sediment production into three categories of natural, or background, sediment (background creep, background landslides, and bank erosion); and four categories of management-related sediment (road-related and timber harvest-related landslides and surface erosion). The draft TMDLs aggregated background creep, derived from both dormant (slow-moving) and active (fast-moving) earthflows, together with bank erosion. For the Final TMDLs, we have separated those two sources. These were developed using the NetMap model.

Landslide Analysis

The landslide air photo assessment was conducted for all land in the watershed, including the USFS lands of the Six Rivers National Forest and private lands. Some information, particularly for small sources, was not available for private lands. GMA summarized and compiled data from the California Department of Water Resources (CDWR, 1982), California Department of Mines and Geology (DMG, 1999), Green Diamond Resources, Inc. (GD, 2006), and USDA, Forest Service (USFS) landslide data. The DWR (1982) data is the most comprehensive map and covers the entire Mad River from 1974 aerial photographs. The DMG (1999) data covers the lower watershed, and the USFS data covers the upper and middle watershed. The GD data covers a limited portion of the middle and lower watershed. Dormant and active landslides were included in the landslide database. Active pre-1975 landslides mapped by CDWR (1982) were used to create the pre-1975 active landslide map. The post-1975 landslide map includes data from all of the sources listed above in addition to landslides mapped as part of this study. Like CADWR (1982), GMA mapped active landslides with obvious activity from the most recent sets of remote sensing data (i.e., 2003 aerial photographs and 2005 digital ortho photographs). For USFS lands, publicly available aerial photographs were used, and on private lands the digital orthophotographs and hillslope relief maps were used to map active landslides.

Landslides that were initiated or enlarged between 1975 and 2003/2005 were mapped as contributing to the sediment budget from 1976-2006. A portion of the mapped landslides was field checked to validate the desktop evaluation, and to determine depth/volume relationships and other factors. Although approximately 15% of the landslides were field checked, the extent of the field work was limited by access: for example, if landowners denied entry, steep topography or roadless areas prevented travel, or active logging operations were underway. For the Final TMDLs, several changes were made in response to public comments. This included reviewing some landslide features to determine whether management associations were correct, and changing assumptions for road-related causes. In the draft, roads within 100 ft of a landslide feature were assumed to be associated with the landslide without actually checking for causal links; for the final, only roads that actually crossed a landslide feature were determined to be associated with that feature. The database was re-examined for this process as well, to ensure that no landslides were inadvertently reclassified as having natural causes. As a result, six features were reclassified from road-related to natural causes.

Area/volume relationships were also re-examined. Using the database of field-verified landslide areas and volumes, we examined the statistical relationship between depth and area, and found a strong correlation. However, when we applied this to the remainder of the database, it suggested unreasonably high sediment delivery rates, similar to those found in very active terrain in New Zealand, but not found in the North Coast We determined that the number of extremely large, deep-seated slides that were field-verified, was disproportionately high, throwing off the correlation. Accordingly, we adjusted the area/volume relationships, based on the assumption that the relationships would not reasonably yield volumes higher than the Redwood Creek watershed adjacent to the Mad River basin. These changes resulted in some increases and some decreases to the sediment loads of both natural and management-related landslides, depending on the landslide type and size: volumes of large landslides were previously underestimated, because the assumed landslide depth was too small to be representative; and volumes of smaller landslides were overestimated, because the assumed landslide depth was too large. Additional area/depth relationships that more accurately represented the various types of landslides improved the landslide volume estimates overall.

Suspended Sediment and Turbidity Monitoring

Turbidity and suspended-sediment concentration (SSC) data were collected at several monitoring sites to characterize the watershed, and were analyzed by developing relationships for SSC versus turbidity and SSC versus discharge for all sites. Suspended-sediment discharge and load estimates were computed using either turbidity or discharge as a surrogate for suspended-sediment concentration, based on the developed correlations. This was used to identify which areas of the Mad River basin are more or less disturbed, and it allowed us to estimate sediment loads in each subarea based on the measured data. These estimates were also used to calibrate the NetMap model (described below). Perhaps most importantly, the strongly-correlated relationships developed between turbidity and SSC allowed us to set the turbidity TMDL as suspended sediment loads.

WEPP Modeling

The most significant change in the sediment source analysis and TMDLs between the draft and the final was made in the Watershed Erosion and Prediction Model (WEPP) modeling, which was used to generate the road surface erosion and the harvest-related surface erosion, as well as to provide input into the NetMap model, which was used primarily to estimate fluvial erosion and hillslope creep, as described below. Two commentors took exception to our modeling assumptions and results in the draft analysis. WEPP is known to overestimate sediment production, and the results from our initial analysis showed that road-related surface erosion was extremely high.

GMA consulted with Bill Elliot, of the USFS Intermountain Research Station, who was one of WEPP's developers. Our roads database, which is the best available to date, does not have complete information on road parameters other than surface type. Many variables influence sediment delivery to streams from roads: surface type, level of use and maintenance, geology and topography, hillslope position (e.g., ridge top versus canyon bottom), road drainage, stream crossings, and road prism types, for example. Based on Elliot's recommendations, we ran the model several times with varied assumptions, and determined that the main parameter driving the model was whether the inboard ditch was vegetated or unvegetated. In our draft analysis, we assumed that all roads were constructed with an inboard, unvegetated ditch. This was a worst-case, conservative assumption, which we realized would overestimate road-related surface erosion. We used this in the absence of better data, in order to err on the side of caution. However, in considering the public comments that the erosion was significantly overestimated, and in considering that the estimates were greater than our measured sediment yield estimates by a factor of four, we determined that it was appropriate to re-run the model using more realistic assumptions. For the final, we ran the model assuming that roads had vegetated inboard ditches (again, in consultation with Elliot). Even this appeared to over-predict sediment, so we also set an upper threshold for road-related surface erosion based on the Washington State Manual (WA DNR, 1995), based on similar soil and climate types.

These changes resulted in reductions to the estimates of road-related surface erosion between the draft and final TMDLs, by about 55% overall. The reductions ranged from a high of 83% in the

Upper Mad subarea, where most roads are ridgetop roads that contribute far less erosion to streams, to a low of 48% in the Lower/North Fork subarea, where miles of roads and road densities are greatest. Some uncertainty remains in the roads database and in the WEPP model itself, but EPA is confident that the revisions result in a closer prediction of road-related erosion. Road-related erosion still comprises the bulk of the management-related erosion: 62% of sediment production basinwide is associated with roads, and only 2% of sediment production is associated with timber harvest, while 36% is thought to be associated with natural causes, primarily associated with unstable Franciscan, mélange, and schist terrain.

NetMap Modeling

NetMap is a complex tool used for watershed characterization, sediment budgeting and routing. For the Mad River TMDLs, NetMap was used to develop estimates of background surface erosion (creep from active and inactive, or slow-moving, earthflows), bank erosion, and for watershed characterization (topographic indices, Digital Elevation Models, or DEMs, developing mean annual flow, and channel classification). In the sediment budget portion of the SSA, it contributes the estimates of background creep and bank erosion.

NetMap can be used to develop a sediment budget at the smallest scale (e.g., a GIS pixel) in the watershed; the program models the delivery of that sediment to the stream and the routing of that sediment through the stream system. In the draft SSA, EPA intended to use GMA’s NetMap model to develop the sediment budget; however, several problems were encountered. For example, as described in the original SSA and draft TMDL, the results of the NetMap sediment budget diverged widely from the sediment yield estimates derived from measured suspended sediment concentration (SSC) and associated suspended sediment load (SSL) estimates. Accordingly, the SSA relies primarily on the development of a classical sediment budget to estimate sediment production and delivery to the stream system in the Mad River basin. EPA revised the text in the final TMDL document to distinguish between what NetMap *was* used for (contributing creep and bank erosion to the classical sediment budget, and assisting with watershed characterization) and what it *could be* used for in the future (e.g., developing sediment budgets based on different design flows, for example, and targeting areas for watershed improvement). We also included text in Chapter 4 to suggest its further development and use as a tool for implementation.

Two methods were used to model NetMap for the Mad River basin. The first uses a Generic Erosion Potential, or GEP factor. It is based on the DEM, and factors in topographic slope (steepness) and slope convergence, which are two factors that are known to contribute to the initiation of landslides. This method does not work well in hummocky terrain, such as the large landslide-prone, earthflow terrain comprised of unstable Franciscan and Schist found in parts of the Mad River basin. GEP is driven by slope convergence, which is not an equally strong factor in earthflow terrain. These areas are driven more by other factors. Thus, for these terrains, NetMap is used without GEP. The second method uses a modified GEP developed from average sediment delivery by slide type and geology.

The final SSA and TMDL document use revised inputs to NetMap based on other revisions to the SSA inputs. For example, NetMap uses surface erosion estimates from the WEPP model to modify the GEP in the NetMap model. It also uses the revised area/volume relationships developed in the landslide analysis. The revised assumptions are probably a reason that the NetMap results now being much closer to the monitored results (see Appendix A).

Because it can be used to develop a sediment budget based on different flood flows, NetMap is used in the SSA (and in the TMDL) to illustrate the differences in sediment delivery between a small storm and a less frequent storm, and can account for the effects of the reservoir; Figure 10 in the TMDL and Figure 44 in Appendix A show this relationship between a 2-year and a 10-year storm. While it is used in the TMDL document simply to characterize the watershed and illustrate the differences between acute and chronic storm flows, this is also essentially one of the initial steps that can be taken to further develop NetMap to refine the sediment budget in the future, if that is desired by the Regional Water Board or other organizations in the implementation phase.

The sediment source analysis accounts for chronic and episodic sediment input to the stream network. Data were derived from the US Geological Survey (USGS), US Forest Service (USFS), California Department of Water Resources (CDWR), Humboldt Bay Municipal Water District (HBMWD), the Blue Lake Rancheria (BWR), Klein (2006, unpublished, in Appendix A), and GMA's monitoring data collection and analysis. In addition, for the Final SSA, GMA consulted with W. Elliot, of the USFS Intermountain Research Station (Elliot, personal communication with J. Fitzgerald, in Appendix A), the Green Diamond HCP (Green Diamond Resource Company, 2006 and USFWS & NMFS, 2006), and other USFS sources.

Drainage Basin Characteristics

The 39 subwatersheds delineated as part of this sediment source analysis are listed in Table 4 and are shown on Plate 1. The shape, texture, drainage pattern, and drainage efficiency of the subwatersheds were used to qualify and quantify the frequency and magnitude of upland sediment flux and instream sediment transport and storage. Watershed morphometry features, measured from topographic maps, aerial photos, and 10-meter Digital Elevation Models (DEMs) are used to quantify drainage area, maximum and minimum elevations, basin length, and stream network length and channel type. The NetMap model was used to measure the longitudinal profile, distribution of hillslope parameters like gradient, and drainage efficiency of each subwatershed.

Mainstem Sediment Storage and Bank Erosion

The relative amount of sediment storage within the mainstem Mad River was measured to help verify sediment budget results and verify bank erosion estimates. This methodology estimates the volume and composition of sediment stored in the sampled reach and follows procedures described by Llanos and Cook (2001, in Appendix A) and Montgomery and Buffington (1993, in Appendix A). The sediment volume and composition is estimated for chronic and episodic sediment transport and storage active within the Mad River watershed. The reach types range from steep narrow bedrock channels to low gradient alluvial channels. The reach locations (Mad River near Blue Lake; Mad River above Maple Creek; Mad River near Highway 36; and Mad River above Ruth Lake) were non-randomly selected to represent the lower, middle, and upper Mad River stream network.

Reach length was typically a minimum of 45 times bankfull channel width. The active channel was defined as the bankfull channel with recent scour and/or deposition and is generally free of riparian vegetation. The upper bank, lower bank, and channel bottom were walked and measured moving upstream with left and right bank defined looking downstream. The reach was broken into active and inactive feature types or "sediment reservoirs."

The volume of sediment stored is summed for each reach by the state of activity. For this analysis, the active and semi-active sediment reservoirs were used to verify sediment budget results. In addition, these data were used to evaluate relative stream bank stability and average annual erosion rates. Using the field-estimated data by reach as an input, the total amount of fluvial bank erosion was estimated for the Mad River by stream order assigned using NetMap and erosion rates (tons/mi^2/year) used by Raines (1998, in Appendix A).

Streamflow, Suspended Sediment and Turbidity Monitoring and Analysis Methods

Five continuous turbidity sites were originally established by GMA, and turbidity and suspended sediment samples were collected, analyzed, and correlated with samples from other agencies (Table 5). At all monitoring sites, water level or stage was measured at 15-minute intervals. Data collected at the Blue Lake Rancheria site, maintained by the Blue Lake Rancheria Tribe, are summarized with the MRALM data, which is a USGS site. Additional continuous gaging records used for the analysis were collected and computed from USGS records. Records at the NFMKB site were developed by GMA. A concerted effort was made to obtain discharge measurements over a wide range of flows, primarily during periods of sediment transport, to improve accuracy. Four sites, MRHRB, NFMKB, MRBVR, and MRRTH, had 15-minute discharge records produced either synthetically from USGS gage relationships or from a site-specific rating curve.

Depth-integrated turbidity and suspended-sediment concentration (SSC) sampling was performed at all monitoring stations. Continuous turbidity sensors were installed and operated at MRHRB, NFMKB, MRBVR, MRRTH, and MR36. Turbidity and SSC data were analyzed by developing relationships for SSC versus turbidity and SSC versus discharge for all sites. (Correlations were also developed on a site-specific basis for sites with turbidity values collected by different entities and using different measurement units).

Turbidity and suspended-sediment concentration data were analyzed by developing relationships for SSC versus turbidity and SSC versus discharge for all sites. Data pairs were plotted against each other and a computer generated power equation was produced in order to define the relationship. Results from WY2006 and 2007 sampling were compared to historic data from the USGS and DWR. Continuous records of turbidity at the various sites were analyzed for magnitude and duration and compared to reference streams and the Severity of Ill Effects methodology (Newcombe and Jensen 1996).

Table 4. List of Mad River Subwatersheds and Drainage Areas

NAME	BASIN ID	DRAINAGE AREA (mi^2)	SUBAREA LOCATION
Mud River	1001	13.2	Upper
Lost Creek	1002	26.1	Upper
South Fork Mad River	1003	15.9	Upper
Barry Creek	1004	10.2	Upper
Armstrong Creek	1005	9.9	Upper
Deep Hollow Creek	1006	4.1	Upper
Deep Hollow Creek West	1007	4.6	Upper
Bear Creek	1008	8.1	Middle
Pilot Creek	1009	39.7	Middle
Hastings Creek	1010	11.1	Middle
Holm Creek	1011	8.0	Middle
Olmstead Creek	1012	11.3	Middle
Showers Creek	1013	2.7	Middle
Deer Creek	1014	6.9	Middle
Bug Creek	1015	9.7	Middle
Morgan Creek	1016	8.7	Middle
Wilson Creek	1017	9.4	Middle
Graham Creek	1018	13.1	Middle
Goodman Prairie Creek	1019	10.0	Middle
Boulder Creek	1020	19.0	Middle
Barry Ridge	1021	9.1	Middle
Maple Creek	1022	15.6	Middle
Blue Slide Creek	1023	6.1	Middle
Devil Creek	1024	19.0	Lower/North Fork
Cannon Creek	1025	16.4	Lower/North Fork
Dry Creek	1026	7.0	Lower/North Fork
North Fork Mad River	1027	48.8	Lower/North Fork
Powers Creek	1028	20.8	Lower/North Fork
Lindsay Creek	1029	17.7	Lower/North Fork
Deer Creek2	1030	7.1	Middle
Showers Creek	1031	5.2	Middle
Bear Creek2	1032	4.1	Middle
Tompkins Creek West	1033	4.9	Middle
Tompkins Creek	1034	8.9	Middle
Hetten Creek West	1035	11.9	Middle
Hetten Creek	1036	10.7	Middle
Olsen Creek West	1037	9.1	Middle
Olsen Creek	1038	12.8	Middle
Hastings Creek West	1039	3.2	Middle
Average		**12**	
TOTAL		**480**	

Source: Appendix A

Table 5. Mad River turbidity and SSC sampling site list

Site Code	Watershed Code	Site Description	Drainage Area (mi2)	Elevation (feet)
MRALM [1]	C1	Mad River near Arcata below Highway 299 Bridge	485.0	31
MRHRB [2]	C1A	Mad River at Hatchery Road Bridge	447.1	78
MRBVR [2]	C2	Mad River near Maple Creek below Butler Valley Bridge	351.4	323
NFMKB [2,3]	C3	North Fork Mad River at Korbel Bridge	44.5	128
MR36 [2]	C4	Mad River at Highway 36 Bridge	138.4	2,457
MRRTH [2]	C5	Mad River above Ruth Lake at County Road 514 Bridge	93.6	2,690
LCGRB	S1	Lindsay Creek at Glendale Road Bridge	17.8	57
MCMCB	S2	Maple Creek at Maple Creek Road Bridge	12.2	449
BCMCB	S3	Boulder Creek at Maple Creek Road Bridge	18.8	405
LMC36	S4	Lamb Creek	3.1	2,470
OCLM	S5	Olsen Creek	1.6	2,495
TB3LM	S6	Unnamed Tributary 3	0.3	2,568
HCLM	S7	Hobart Creek	1.6	2,693
BCLM	S8	Blue Slide Creek	1.0	2,715
ACLM	S9	Anada Creek	1.0	2,699
CCRTH	S10	Clover Creek	0.5	2,707

[1] dropped -- assumed redundant with MRHRB

[2] continuous turbidity station

[3] continuous streamflow station

Source: Appendix A, Table 2

Hydrology

Precipitation, streamflow, and sediment transport data were used to characterize flood magnitudes, particularly focusing on frequent flooding (recurrence interval of 2 years, or Q_2, which represents the flood that is likely to occur, on average, every two years), infrequent (Q_{25}), and large storms (Q_{100}). Large floods tend to trigger landform-scale erosion and sediment delivery to the drainage network and increase the fine and coarse sediment load.

USGS operates two gages on the Mad River: one near Arcata (near the mouth), which has a 57-year record, and one above Ruth Reservoir. GMA also operated a continuous streamflow gage on the North Fork Mad River during WY 2006-2007, which is the study period for this analysis. Synthetic streamflow records for ungaged sites were developed, based on drainage area, from USGS records of the two Mad River sites, or for the Little River near Trinidad, which is a small coastal stream just north of McKinleyville.

Streamflow duration analyses were conducted and relate mean daily discharge to its frequency of occurrence, based on the complete record of mean daily flows. Streamflow durations are used in parallel with duration analyses of turbidity, suspended sediment concentration, and suspended sediment discharge to describe flow and sediment characteristics at a given site, or to compare sites. Four sites, MRHRB, NFMKB, MRBVR, and MRRTH, had fifteen minute discharge records produced either synthetically from USGS gage relationships or from a site-specific rating curve. Discharge record methods and procedures are explained for each site in Appendix A.

Landslide Inventory

The GMA landslide inventory was performed in two phases. The inventory was completed using desktop and field methods, and it focused on mapping natural and management-related active landslides. The first phase of the landslide inventory was desktop-based and obtained existing data and landslide maps. GMA summarized and compiled data from the California Department of Water Resources (DWR, 1982), California Department of Mines and Geology (DMG, 1999), Green Diamond Resources, Inc. (GD, 2006), and USDA, Forest Service (USFS) landslide data. The DWR (1982) data is the most comprehensive map and covers the entire Mad River. The DMG (1999) data covers the lower watershed, and the USFS data covers the upper and middle watershed. The GD data covers a limited portion of the middle and lower watershed. Dormant and active landslides were included in the landslide database. Active pre-1975 landslides mapped by CDWR (1982) were used to create the pre-1975 active landslide map. The post-1975 landslide map includes data from all of the sources listed above in addition to landslides mapped as part of this study.

Like CDWR (1982), GMA mapped active landslides with obvious activity from the most recent sets of remote sensing data (i.e., 2003 aerial photographs and 2005 digital ortho photographs). For USFS lands, publicly available aerial photographs were used, and on private lands the digital orthophotographs and hillslope relief maps were used to map active landslides. All of the active landslides included in the pre-1975 time period were assumed to have failed between 1944 and 1975, and the total mass of sediment delivery was averaged for this time period. The post-1975 time period includes landslides that continued to enlarge (originally mapped as pre-1975) as well as new landslides that were triggered within the last 31 years. Only the portion of a landslide that was initiated or enlarged in the post-1975 period that included in the 1975-2005 inventory.

The second phase of the landslide inventory was field-based and inventoried a representative sample (15.5 percent) of the aerial photo mapped landslides. Data were collected on landslide dimensions and the percentage of sediment entering streams. This fieldwork included documentation, measurement, and description of the smaller landslides (less than 3,000-5,000 square feet) that cannot be identified with certainty on aerial photos. The results were used to help verify aerial photo measurements and interpretations, and to document the size of landslides that can reasonably be identified on aerial photos. The sample size was primarily a function of access (i.e., permission, distance from road access, etc.). The landslide characteristics mapped during the field inventory include the following:

- Landslide area, volume, and surface erosion estimates as appropriate.
- Land use associated with landslide activity (e.g., forest harvesting, road fills and cuts).
- Triggering mechanisms that contributed to the initiation or reactivation of landslides (e.g., overloading, saturation from redirected surface water, root strength deterioration).
- Delivery of landslide sediment to streams.

Landslides were classified by type, and displaced volume was estimated and converted to mass. For this analysis, the mechanisms that triggered a given landslide were classified into three categories: natural; road-related, or timber harvest-related. Temporally, the landslides are assumed to deliver the evacuated volume over a 31-year period from 1975-2006. Landslide volumes were converted from cubic yards (yd^3) to tons based on soil bulk density data (i.e., 1.3

tons/yd^3). This allows comparison of sediment inputs to sediment transport values, which are usually computed in terms of weight rather than volume.

In response to public comments, area/volume relationships were also re-examined. Using the database of field-verified landslide areas and volumes, GMA examined the statistical relationships, and found a high correlation. However, this would have suggested volumes that were unreasonably high; the rates were similar to those found in very active terrain in New Zealand or Japan, but are not found in the California north coast. It may be that the numbers of field-verified slides were inadequate for the various types of slides. Using professional judgment, the area/volume relationships were adjusted, with the assumption that the relationships would not reasonably yield volumes higher than the Redwood Creek watershed adjacent to the Mad River basin.

Surface and Fluvial Erosion

The surface and fluvial erosion analysis relied on readily available information with limited field inventory, and predicts the amount of erosion from roads and timber harvest activities. (Hillslope creep is discussed under the NetMap discussion.) Public and private roads were digitized in ArcGIS from the 2005 NAIP digital orthophotographs and historic aerial photographs. Not every road or disturbance activity was verified on the aerial photographs, and there are several line errors, missing roads, or roads in coverage that are not present on the ground. In other words, there are unquantified errors in the road data sources, but it is currently the best information available. The road mapping scale ranged from 1:3,500 to 1:24,000. The timber harvest history was developed from publicly available information, which included: USDA Forest Service, CDF Forestry Resource Assessment Project (FRAP), and Multi Resolution Land Cover (MRLC) data.

Road Erosion

GMA completed a rapid reconnaissance of the road system and drove about 300 miles of roads within the Mad River watershed. There are about 2,187 miles of mapped road within the Mad River watershed, so GMA rapidly inventoried about 14% of the road system. Ocular observations were made of road surface type, width, gradient, shape, cutbank height and vegetation cover, soil texture, bedrock type, traffic patterns, and erosion severity. These data were used to improve the road layer where possible; however, most of the road system was not field verified and the model relied on existing information.

Given the large road network (over 2,000 miles of road), GMA classified the road system using the available data by surface type and lithotopo unit, which included bedrock geology, slope stability, and topographic steepness and position. Using GIS, GMA segregated the data into 58 unique road types. The number of road types was reduced from the original analysis, which included 166 road types, by aggregating similar bedrock geology types.

The relative erodibility of the aggregated geology types was categorized using road surface type and bedrock geology. The likelihood of sediment delivery was categorized using topographic position and steepness, where canyon bottom roads deliver more sediment than ridge top roads. Given the size of the watershed, the large road network, and limitations on data availability, GMA had to generalize road types with the goal of identifying the relative sediment contributions from different road types. No data were available on road shape (insloped versus outsloped), condition, traffic levels, or drainage features other than stream-road crossings.

The probability and volume of sediment delivery to the stream network from surface and fluvial erosion was estimated as an average during flood events for background and existing watershed conditions. The Watershed Erosion and Prediction Project (WEPP) Road Batch (Elliot et. al., 2000) was used to estimate the amount of sediment delivery from the different sources.

The WEPP model uses the following physical processes to predict the probability of erosion and sediment delivery: infiltration and runoff, soil detachment, transport, deposition, and revegetation with time. WEPP does not route sediment that is estimated to be delivered to the stream network, and it has an error of plus or minus 50% (Elliot et. al., 2000). There are seven input variables to include: climate, soil texture, type of treatment, gradient, horizontal length, percent cover, and percent rock. Within the model, ground cover is a driving variable, where erosion decreases as ground cover increases. Like other erosion models, WEPP is best used as a comparative tool between different land disturbances (e.g., background versus existing conditions).

The WEPP Road Batch model was originally used in the draft SSA for the 166 road types. It was *re-run* for the 58 aggregated road types for a unit road length (i.e., 500'). The model estimated relatively high unit sediment delivery rates by road type; however, these results are comparable to sediment delivery rates reported in other surface erosion investigations (e.g., Washington Department of Natural Resources, Surface Erosion Module, 1995 and USDA Forest Service, 1991). This analysis used WEPP to develop an understanding of the relative input of sediment from roads and timber harvest activities by roughly quantifying the amount of sediment delivered to streams by disturbance type and lithotopo unit. The road and timber harvest surface erosion estimates are compared to the estimated sediment delivery rates for natural and other erosion sources associated with land management activities (i.e., bank erosion and creep).

GMA reran WEPP using different assumptions for road design, condition, and traffic levels. The model was first run as a sensitivity analysis to determine which factors were most influential in sediment production. GMA completed four WEPP runs to define a range of potential sediment delivery values by road type. The assumptions for the sensitivity runs, and ultimately for developing the final sediment budget in the SSA, were adopted in consultation with Bill Elliot, one of the developers of WEPP (Elliot, personal communication, 2007). GMA found that vegetated versus unvegetated inboard ditches were the main drivers. (Runs with variations in the other parameters did not produce much variation in the results.)

In order to ensure that the results were still realistic (because WEPP is known to overestimate road erosion), GMA decided to use a combination of WEPP model results and road erosion values reported in the Washington Department of Natural Resources, Surface Erosion Module (1995) to predict road erosion. The revised road surface erosion sediment delivery rates are reported in Appendix A and were used to revise the overall sediment budget for the Mad River.

For the original model runs, the average road surface erosion sediment delivery rate was 20 tons/acre/year for all road types; the revised results averaged 8 tons/acre/year for all road types. The highest erosion rates (30-45 tons/acre/year) are for mélange and schist terrain.

The approach used to estimate the surface erosion rate for a given type of road was to examine road segments for characteristics of the road prism, drainage system, and traffic as they influence the delivery of sediment to the stream system, and calculate road sediment load based on them. Factors were applied for differing conditions of the road tread, cut-slopes, and traffic use that increase or decrease the estimated sediment load of that segment. The result is an estimate of sediment load for each road segment. The sediment *load* estimate was further modified according to the estimated sediment *delivery* to the stream network along that segment.

Data were compiled for the following factors and road attributes that influence the amount of sediment delivered to streams from roads:

- The erodibility of the soil/geology the road is built upon
- Precipitation amount, frequency, and intensity (used Forest Glenn weather station)
- The age of the road was not available
- Road drainage pattern (insloped/outsloped/crowned) all roads were insloped with a ditch
- Probability that sediment from road reaches stream (depends on distance and slope between road drain and stream, amount of obstructions to trap sediment, and road area that collects water and sediment)
- Length of road that delivers to stream
- Width, surface type and durability, traffic use, and slope of road tread

The total amount of erosion from each drainage segment is calculated as the sum of tread erosion, cut-bank erosion, and other sources of erosion using the WEPP model. Total erosion is then divided by the planar road area. Total erosion from each site was then summed for each of the road types and lithotopo units, and the results were used to develop surface erosion rates (tons/acre/year). These were applied to data extracted from the project GIS.

Timber Harvest Surface Erosion

Surface and fluvial erosion from areas disturbed by timber harvest activities is most often related to several different surface disturbance activities, primarily skid trails and harvest operations that result in impervious surfaces and increased rainfall-runoff. WEPP was used to predict erosion from harvested areas for high, medium, and low disturbance levels. The rate varied by the type of harvest (e.g., clearcut versus thin), the yarding method (e.g., tractor versus cable), and type of lithotopo unit. Surface and fluvial erosion from harvest areas was estimated for a 31-year period.

Model Assumptions

The following is a list of the assumptions made as part of the erosion potential modeling process.

- A large portion of the material generated during frequent flooding is delivered to the stream network.
- Background surface erosion rates are based on undisturbed conditions, and active landslides associated with land use are not included.

- Roads that cross dissect erodible bedrock and soils have higher sediment delivery.
- Upland sediment delivery potential is a function of slope steepness, slope position, and proximity to the stream network.
- The volume (yds^3) of sediment delivered is converted to weight (tons) using the bulk density of partially saturated loose earth (i.e., 1.3 tons/yds^3).

NetMap Model

Overview

NetMap is a complex tool used for watershed characterization and sediment budgeting. For the Mad River TMDLs, NetMap was used to develop estimates of background surface erosion (creep from active and inactive, or slow-moving, earthflows), bank erosion, and for watershed characterization (topographic indices, Digital Elevation Models, or DEMs, developing mean annual flow, and channel classification). In the traditional sediment budget portion of the SSA, it contributes the estimates of background creep and bank erosion.

NetMap can be used to develop a sediment budget at the smallest scale (e.g., a GIS pixel) in the watershed; the program models the delivery of that sediment to the stream and the routing of that sediment through the stream system. EPA had originally expected to use GMA's NetMap model to develop the sediment budget; however, several problems were encountered. For example, as described in the original SSA and draft TMDL, the results of the NetMap sediment budget diverged widely from the sediment yield estimates derived from measured suspended sediment concentration (SSC) and associated suspended sediment load (SSL) estimates. Accordingly, the SSA relies primarily on the development of a traditional sediment budget to estimate sediment production and delivery to the stream system in the Mad River basin since these results matched the measured values more closely. EPA revised the text in the final TMDL document to distinguish between what NetMap *was* used for (contributing creep and bank erosion to the traditional sediment budget, and assisting with watershed characterization) and what it possibly *could be* used for in the future (e.g., developing sediment budgets based on different design flows, for example, and targeting areas for watershed improvement—these suggestions are included in Chapter 4).

Two methods were used to model NetMap for the Mad River basin. The first uses a Generic Erosion Potential, or GEP. It is based on the DEM, and factors in topographic slope (steepness) and slope convergence, which are two factors that are known to contribute to the initiation of landslides, surface, and fluvial erosion. This method does not work well in hummocky terrain, such as the large landslide-prone, earthflow terrain comprised of unstable Franciscan and Schist found in parts of the Mad River basin. GEP is driven by slope convergence, which is not an equally strong factor in earthflow terrain. These areas are driven more by other factors. Thus, for these terrains, NetMap is used without GEP. The second method uses a modified GEP developed from average sediment delivery by slide type and geology.

The final SSA and TMDL document use revised inputs to NetMap based on other revisions to the SSA inputs. For example, NetMap uses surface erosion estimates from the WEPP model to modify the GEP in the NetMap model. It also uses the revised area/volume relationships developed in the landslide analysis. The revised assumptions are probably a reason that the NetMap results are now much closer to the monitored results (see Appendix A).

Because it can be used to develop a sediment budget based on different flood flows, NetMap is used in the SSA (and in the TMDL) to illustrate the differences in sediment delivery between a small storm and a less frequent storm, and can account for the effects of the reservoir. While this is used in the TMDL document simply to characterize the watershed and illustrate the differences between acute and chronic storm flows, it is also essentially one of the initial steps that can be taken to further develop NetMap to refine the sediment budget in the future, if that is desired by the Regional Water Board or other organizations in the implementation phase.

Data Sources and Model
NetMap is a terrain model that uses a generic erosion potential (GEP) to predict the probability of erosion and, using the upland (classical) sediment budget lithotopo units and inventoried sediment sources, routes sediment through the stream network. Hillslope gradient and convergence are used with the measured basin sediment load to predict erosion potential and sediment delivery to the stream network (Benda et. al., in press, in Appendix A). NetMap aggregates sediment supply rates downstream to the basin outlet. Channel attributes like stream power are used to predict sediment transport, storage, and load (Benda et. al., in press, in Appendix A). The total cumulative sediment load is estimated at the basin outlet and for each of the subwatersheds.

NetMap consists of two components: 1) a set of base parameters and 2) an ArcGIS analysis tool kit. The base parameters are created using digital elevation model (DEM) data, climate data, and measured streamflow and sediment load data. The programs estimate 26 base terrain parameters categorized into three domains: hillslope and erosion; basin, valleys, and networks; and channel environments. The first domain predicts hillslope erosion and sediment supply potential and the influence of topographic features on the stream network. The second domain summarizes basin shape, stream network patterns, stream channel confluence effects, and valley geometry. The third domain estimates channel geometry attributes at all points in the network.

For this analysis, the geology, landslide, and land use layers were intersected into one layer and each litho-land use type was assigned a disturbance factor that adjusts the GEP. The factors were developed using the upland sediment budget and the relative amount of sediment delivery estimated for each litho-land use type. The disturbance factors created for each geologic, landslide, and land use type are summarized in Appendix A.

The NetMap model was used to develop the background creep and fluvial bank erosion component of the classical sediment budget, which is used to set the TMDLs. NetMap was also used to develop a separate sediment budget, which is used primarily to characterize the watershed.

NetMap produces the following sediment loads (again, using inputs from the geology, land use, and landslide layers, and scaled with the measured suspended sediment loads): 1) local sediment supply to channel segments, 2) local sediment supply routed downstream and decayed, 3) cumulative sediment supply – scaled by drainage area, and 4) cumulative (total) sediment load.

The Q_2 and Q_{25} loads are calibrated using measured data from this study for average flooding (Q_{25}) and Lehre (1993, in Appendix A) for infrequent flooding (Q_2). NetMap's GEP predictions are converted into actual sediment loads (tons/mi^2/year) using the predicted total sediment load per water year type. Frequent flooding (i.e., Q_2, or the annual maximum flood that is likely to occur 50 percent of the time) is used to quantify chronic fine sediment delivery that tends to occur on an annual basis and increases the suspended sediment loads (for example, from road surface erosion). Infrequent flooding (i.e., Q_{25}, or the annual maximum flood that is likely to occur 4 percent of the time) is used to quantify acute sediment delivery. Large flood events tend to trigger landform-scale erosion and sediment delivery to the drainage network and increase the fine and coarse sediment load.

Methods for Stable and Unstable Terrain

Two methods are used with NetMap, depending on the terrain. The first, which is the standard application, allows NetMap to generate a parameter referred to as generic erosion potential (GEP), an erosion index that is based on slope gradient and slope curvature. The second is an alternative for hummocky, landslide-prone terrain, such as the unstable Franciscan and Schist, for which erosion is not driven by slope gradient and curvature.

NetMap was used to model upland sediment delivery and instream sediment load for natural (background) and existing (disturbed) conditions. The background and disturbed model runs are for a 31-year period over which average (i.e., frequent) and infrequent flooding and sedimentary events occur. This model, like the rest of the sediment source analysis, estimates the sediment load for average conditions, although we recognize that episodic events deviate significantly from the average over the modeled time period.

The GEP is used to predict the probability of surface and fluvial erosion for landforms that are stable or have shallow debris flow potential (small features not recognizable at the landslide inventory mapping scale). For locations on the landscape where surface and fluvial erosion are the dominant erosional processes, the GEP is modified using results from the upland sediment budget. For large landslide prone areas, which include dormant and active landslides, the landslide sediment delivery rates measured as part of the landslide inventory are used instead of GEP. This eliminates the problem of using GEP on large landslide prone terrain where slope steepness and convergence are not driving erosion and sediment delivery.

NetMap Sediment Budget

The predicted basin average sediment load ($Q_{SL(Basin)}$) for the Mad River is the sum of sediment delivery from GEP terrain ($Q_{SD(GEP)}$) (sediment delivery Method 1) and large landslide prone terrain ($Q_{SD(Landslide)}$) (sediment delivery Method 2). The sediment load is calculated using the following equation:

$$Q_{SL(Basin)} = Q_{SD(GEP)} + Q_{SD(Landslide)}$$

To calculate surface and fluvial erosion ($Q_{SD(GEP)}$), the GEP is adjusted using an erosion potential factor (F). This factor is calculated by dividing the average sediment delivery for a given lithotopo unit ($Q_{SD(unit)}$) by the measured or estimated basin average sediment load $Q_{SLM(basin)}$ where:

$$F = Q_{SD(unit)} / Q_{SLM(basin)}$$

This analysis used the following estimated and measured sediment loads for background and disturbed conditions, respectively:

$$Q_{SLM(basin)} = 780 \text{ tons/mi}^2\text{/year (background)}$$

$$Q_{SLM(basin)} = 2{,}600 \text{ tons/mi}^2\text{/year (“disturbed,” i.e., existing conditions)}$$

The background sediment load was estimated at 30% of the existing sediment load using results of the upland (classical) sediment budget’s natural versus management related sediment delivery. The existing sediment load was the average load measured as part of this study. These values are the basis used to scale the basin sediment delivery ratio and converting GEP to units of sediment delivery. The $Q_{SD(unit)}$ is calculated for each lithotopo unit and is varied depending on surface and fluvial erosion potential: For background or natural conditions, F ranges from 1 (i.e., unadjusted GEP) to 108 with an average of 66. Franciscan and Franciscan mélange geologic types have the highest factors (>100) (Appendix A). On naturally stable vegetated hillslopes where very little natural surface or fluvial erosion occurs except after wildland fire, the GEP remains unadjusted. For disturbed or managed conditions, F ranges from 1 to 32 with an average of 17. On natural or disturbed erodible hillslopes (e.g., convergent slopes in mélange) with no landslide activity, the GEP is adjusted using the factor (F>1) to account for the erodibility of different rock types. For lithotopo units with a $Q_{SD(unit)} < Q_{SLM(basin)}$, F =1.

The GEP of each lithotopo unit is then converted into sediment delivery units using the following scaling factor:

$$Q_{SD(GEP)} = Q_{SLM(basin)}/GEP_{(basin)}, \text{ where}$$

$$GEP_{(basin)} = \text{basin average GEP}$$

For landslide prone areas, the GEP is not used to predict erosion and sediment delivery. The average landslide sediment delivery rate estimated from the landslide analysis ($Q_{SDR(Landslide)}$) by landslide type, bedrock geology, and disturbance type is used to develop the non-GEP portion of the sediment budget. The sediment delivery rate was held constant for each type of landslide prone lithotopo unit. The sediment delivery from each landslide was calculated using the following equation:

$$Q_{SD(Landslide)} = Q_{SDR(Landslide)} * A_{(Landslide)}, \text{ where}$$

$$A_{(Landslide)} = \text{mapped landslide area.}$$

NetMap takes the predicted sediment delivery from Methods 1 and 2 and delivers sediment to the channel network. It then routes the delivered sediment through the network to the basin outlet. NetMap does not predict sediment storage within the network; rather, it assumes equilibrium conditions between sediment supply and storage. As stated above, for stable terrain, slope steepness and convergence are used with the measured basin sediment load to predict erosion potential and sediment delivery to the stream network (Benda et. al., 2007). For large landslide-prone terrain, NetMap uses average unit sediment delivery by landslide type and geology. NetMap aggregates sediment delivery rates downstream to the basin outlet. The total cumulative sediment load is estimated at the basin outlet and for each of the subwatersheds and erosion source type.

Traditional Sediment Budget and Synthesis

The various components of data collection and analysis were synthesized into a sediment budget, identifying average annual sediment load over the 31-year budget period for each of the 39 subwatersheds. The results are tabulated by three categories of natural sediment production (background creep, background landslides, and bank erosion), and four categories of management-related sediment production (road-related landslides, road-related surface erosion, harvest-related landslides, and harvest-related surface erosion).

3.1.2. Results

3.1.2.1 Hydrology, Sediment Transport, and Turbidity Monitoring

Streamflow

The streamflow magnitude, frequency, duration, intensity, and timing are used to help qualify and quantify the sediment transport and storage potential of the Mad River. The largest recorded instantaneous discharge for the Mad River near Arcata occurred in December 1964 (WY1965), when the river crested at 81,000 cubic feet per second (cfs), according to USGS records. Other very large storms (greater than 70,000 cfs) occurred in December 1955 (WY1956) and in WY1953. Three other events, in 1972, 1996, and 1997, exceeded 50,000 cfs. The largest recorded instantaneous discharge for the Mad River above Ruth Reservoir occurred in February 1986 (WY1986), when the river crested at 15,000 cfs, according to USGS records. The correlation between the gage near Arcata and the gage above Ruth Reservoir is not that strong, suggesting that the precipitation that drives flood events is variable in geographic distribution. Flow through Ruth Reservoir may also influence peak flows. Flood frequency analysis is a method used to predict the magnitude of a flood that would be expected to occur, on average, in a given number of years (recurrence interval) or to have a specific probability of occurrence in any one year (1% chance event, for example). The results of a Log Pearson III (LPIII) analysis on the two USGS gages are summarized in Table 6 below. For example, the Q_2 event at MRRTH is predicted to be 6,100 cfs, while at MRALM it is 27,000 cfs.

Historic Floods

Although the Mad River has a relatively short period of streamflow records, the dates of significant floods years are generally known, due to regional data. Known large flood events in the region or the watershed have occurred in Water Years 1861, 1881, 1890, 1914, 1938, 1953, 1956, 1965, 1972, 1996, and 1997. The largest of these were likely to have been the 1861 and 1965 events, followed by the 1956 and 1953 events. For this study, which subdivides sediment production into pre and post 1975 time periods, it is important to note that the peak events were much larger between 1951 and 1975, than after 1975.

The range of possible flows during the winter is extreme: in a very wet year, mean daily flows could exceed 30,000 cfs, while in a very dry year they could be well under 1,000 cfs. High flows during storms are of very short duration, one to two days at most generally, and flows rapidly return to typical winter base flow within one week after the peak. Almost all significant runoff events occur between December and April.

Table 6. Log Pearson III Analysis of Annual Maximum Peak Discharges

Return Period	Exceedence Probability	MRRTH Predicted Discharge	MRALM Predicted Discharge
(years)	(%)	(cfs)	(cfs)
1.2	83.3%	3,100	13,700
1.5	66.7%	4,500	20,300
2	50.0%	6,100	27,000
2.33	42.9%	6,800	30,100
5	20.0%	10,200	44,200
10	10.0%	13,100	57,000
25	4.0%	16,900	69,800
50	2.0%	19,800	79,900
100	1.0%	22,700	89,600

Source: Appendix A, Table 5

Flow Duration

A flow duration analysis was performed using mean daily discharge for the two USGS gages for their respective periods of record, 1951-2007 for MRALM, and 1981-2007 for MRRTH. 2007 values are provisional. This analysis shows, for example, that there is a 50% probability that the mean daily flow will exceed 305 cfs at MRALM, while only 33 cfs at MRRTH. A flow of 2000 cfs occurs about 2% of the time at MRRTH, but 20% of the time at MRALM. Relatively little sediment transport probably occurs below 6000 cfs at MRALM, thus all of the geomorphic work accomplished by the river occurs in less than 5% of the time, with most concentrated in the top 1% of the flows.

Annual Runoff

Annual runoff has been measured in the Mad River watershed with the various USGS streamflow gages. The mean annual runoff MRALM for the WY1951-2007 period is 1,009,000 acre-feet. Large volumes of runoff are often associated with both large flood years and years with high annual precipitation. The largest annual runoff years were 1983, followed by 1953, 1998, and 1995. Wet periods include 1951-1958, 1969-1975, 1981-1984, and 1995-1998. One particularly dry period stand is 1985-1994. The 1976-1980 dry period was not nearly as severe.

Watershed Morphometry

The slope elements, shape, texture, and drainage pattern of the stratified subwatersheds are used to characterize sediment delivery and transport and to quantify sediment load. The average subwatershed slope or relief ratio is 17 percent and ranges from five to 23 percent. The headwaters above Ruth Lake have a smooth, concave longitudinal profile, whereas the mid-watershed displays several flat benches, steep inflections and a convex profile, which ultimately transitions to a smoother, concave profile in the lower watershed (Figure 1). The benches appear to be created by large deep seated earthflows that confine the valley bottom, creating vertical control points.

There are 1,073 miles of stream channel draining the Mad River watershed. The watershed has a contorted drainage pattern that trends along more resistant rock types, contacts, and fault zones. Areas with a steep and dense drainage network result from heavy precipitation, shallow erosion-resistant bedrock, and tectonic uplift, whereas areas with gentle to steep slope and immature drainage patterns result from large earthflows. The DEM network represents the active drainage network during large flood events and is used as a measure of drainage efficiency. The Mad River has high drainage efficiency, which means that the majority of the stream network produces and transports sediment and a small percentage stores massive quantities of delivered sediment.

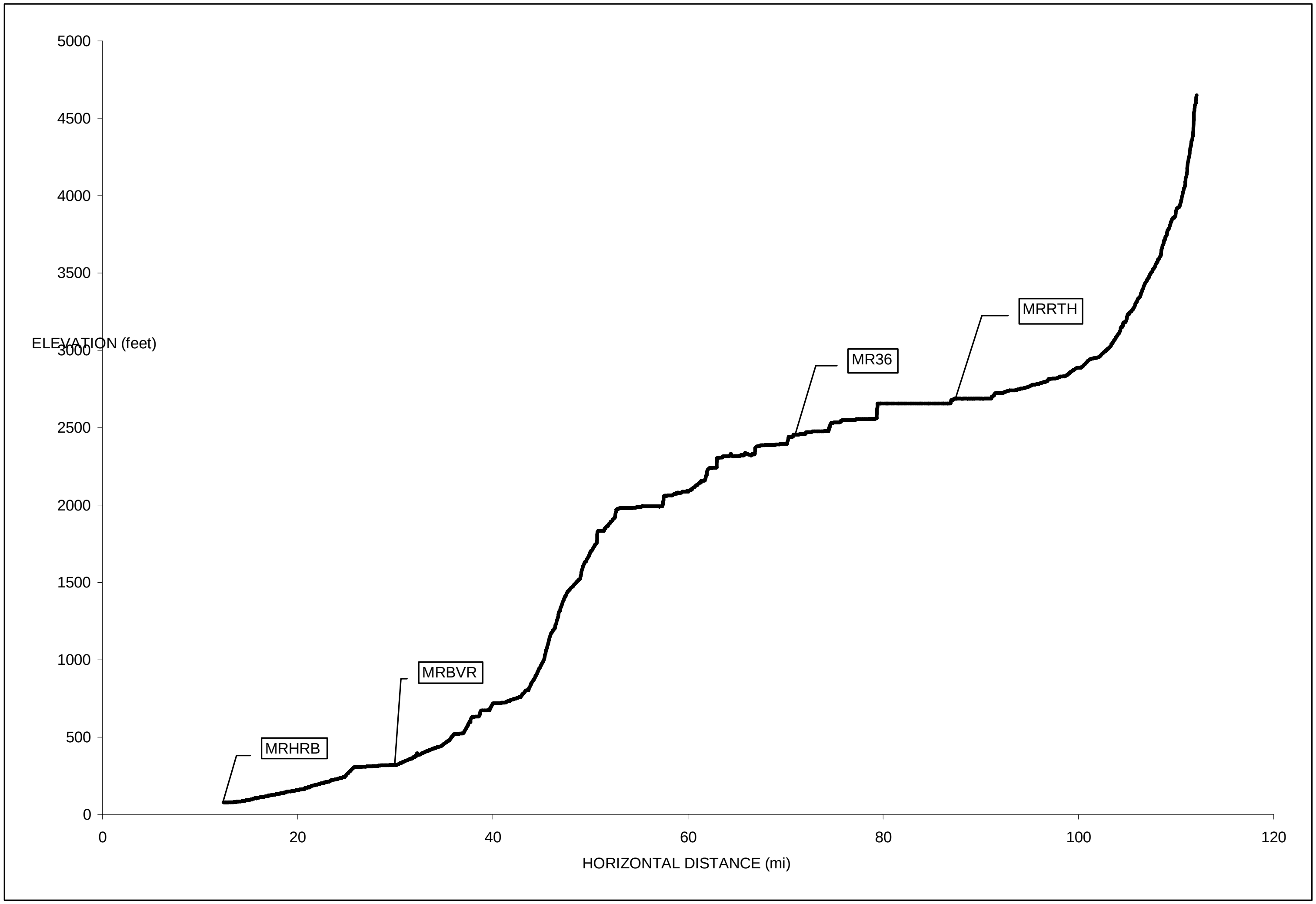
In the headwaters, the drainage network is primarily made up of steep *source-type* channels (i.e., slope > 10 percent) with narrow valleys, where the potential stream energy exceeds upland sediment delivery. As a result, most of the sediment delivered to the headwaters drainage network is rapidly transported downstream. Upper and lower bank erosion and failure are common. About 13 percent of the drainage network is made up of *transport-type* channels (i.e., slope between 1.5 and 10 percent). These channels tend to transport and store punctuated coarse sediment inputs as a function of large woody debris dams and bedrock constrictions. During flooding, the stream power of Mad River source and transport channels can move six-foot boulders as bedload. The *response-type* (i.e., *storage*) channels (slope < 1.5 percent), with wide valleys, make up a small percentage of the drainage network but store a large portion of total sediment input.

Because the volume of sediment input exceeds the transport capacity in these reaches, the response channels tend to be wide and braided with natural levees and meanders.
These observations are critical to understanding the sediment delivery, transport, and load dynamics of the Mad River, and show that both natural and management-related upland sediment sources have a high probability of being delivered to the low-gradient channels.

Mainstem Sediment Storage

The sediment storage inventory data show that the low gradient alluvial reaches in the upper and lower watershed store the majority of the active and semi-active instream sediment. Two reaches, one just above Ruth Reservoir and a second in the lower Mad River near Arcata, had the highest *total* sediment storage: between 2 and 6 tons/ft/mi^2 over the river reach length. The lower Mad River had the highest *active* sediment storage volume at about 500 tons/ft/mi^2. The middle reaches with higher stream gradient and confined valleys had substantially less *active* sediment storage with between 0.1 and 0.2 tons/ft/mi^2. These results were used to calibrate the sediment load predictions made as part of the NetMap model.

Figure 1. Longitudinal Profile for the Mainstem Mad River Showing GMA Continuous Monitoring Sites



Source: Appendix A, Figure 10.

Turbidity, Suspended Sediment, and Suspended Sediment Load

Measured Streamflow
GMA's suspended sediment and streamflow monitoring spanned two water years and measured SSC and turbidity for both winter periods. Water Year 2006 was wet and produced above normal runoff. The lower Mad River near Highway 299 (MRALM) peaked at 47,500 cfs, a 6-year flood, and the upper Mad River above Ruth Lake peaked at 14,800 cfs, a 15-year flood. This storm series, which occurred from December 27-31, 2005, proved to be the dominant event during the study period. WY 2007 was dry and produced below normal runoff. The lower Mad River near Highway 299 peaked at 15,300 cfs, a 1.3-year flood, and the upper Mad River above Ruth Lake peaked at 2,080 cfs, a 1-year flood.

The relative recurrence intervals for the WY 2006 peak illustrate that the storm was much bigger in the upper watershed. The downstream site has a much longer period of record than the site above Ruth Lake (57 vs. 26 years), and thus the recurrence intervals may not be directly comparable. An examination of the last 26 years of record shows that the Ruth Lake site has received one other peak flow comparable to WY 2006 (15,000 cfs in 1986) while three more occurred at the Arcata site, indicating that even though the recurrence intervals may not be directly comparable, the WY 2006 peak flow magnitude was greater for the upper watershed than for the lower.

Measured Turbidity
Considerable turbidity data were collected for the Mad River SSA during the two-year study period. Continuous turbidity data were collected at four stations: MRRTH (above Ruth), MRBVR (Butler Valley), and MRALM (near Arcata) on the mainstem, and NFMKB (North Fork), on the largest tributary. Instream turbidimeters (continuously recorded in FNU) and DIS/Box/Grab samples (lab-processed in NTU) were used to evaluate turbidity for both water years' winter-storm periods. Turbidity data from manual samples was transformed from NTU to FNU using site-specific log-log regressions ($R^2 = 0.94\text{-}0.99$, Appendix A).

The storm occurring from December 30-31, 2005 produced most (but not all) of the highest turbidities observed during the study. In general, turbidity increased in the downstream direction. The highest turbidities measured in the mainstem Mad River occurred at the lowest site near Arcata with a maximum of 4,820 FNU recorded on the continuous turbidimeter at MRHRB. The North Fork continuous turbidimeter recorded a maximum of 1,580 FNU for the Dec 30-31, 2005 event. Boulder Creek at Maple Creek Road Bridge (BCMCB) was the most turbid tributary. Anada Creek (ACLM) had the highest sampled turbidity reading in the upper watershed, (2,850 NTU); the mainstem site MR36 had the lowest measured turbidity (120 NTU). In the upper watershed, synoptic sites LMC36, HCLM, BCLM, and ACLM within the South Fork Mountain Schist geology had measurably higher turbidity values, ranging from 930 to 2,850 NTU. The maximum observed values for these same stations in WY 2007 ranged from 5 to 120 NTU, although very few samples were collected in WY 2007 due to infrequency of sediment-producing storms.

Some storms produced higher turbidities in the upper watershed than in the lower, such as the February 8-9, 2007 storm. This was a small storm, peaking at 503 and 1,850 cfs above Ruth

Lake and at Highway 299, respectively. Continuous turbidimeters recorded 248, 50, and 111 FNU in the mainstem from upstream to downstream. The downstream reduction and subsequent increase in turbidity from upstream to downstream illustrate the sensitivity of turbidity as a metric for detecting temporal and longitudinal variation in sediment production that is not associated with the progressive downstream increase in discharge.

Figures 2 and 3 show continuous turbidity records for the 3 sites (MRRTH, MRBVR, and MRHRB) for WY 2006 and WY 2007, respectively. The turbidity at MRRTH is an order of magnitude or more lower than the other two sites and recovers to levels of 5-10 FNU between storms, while the lower sites only recover to the 70-200 FNU range depending on storm. In this period, the turbidity at MRBVR mostly peaks lower than MRHRB and is sometimes higher on the falling limb and other times lower. Generally, however, these sites track fairly closely.

Turbidity and Suspended Sediment Concentration Relationships

Turbidity vs. SSC relationships proved adequate for computing suspended sediment discharge at all mainstem sites. Some sites required multiple equations to accommodate inflections in the datasets (Table 7). The Mad River's geologic character (particle size composition within suspended sediment) contributes to favorable relationships with turbidity (R^2 ranges from 0.82-0.99, averaging 0.92).

Measured Suspended Sediment Concentration, Suspended Sediment Discharge

Suspended sediment and streamflow monitoring spanned two water years and measurements of SSC were collected during both winter periods, with an emphasis on WY 2006. Water Year 2006 was very wet and produced above normal runoff and suspended sediment concentrations, while WY2007 was dry and produced relatively little sediment transport. Suspended sediment concentration observations followed a similar pattern as was observed with turbidity; concentrations generally increased in a downstream direction. The highest sampled concentration at the downstream-most site (MRHRB) was 5,149 milligrams per liter (mg/l), while the highest concentration at the upstream-most mainstem site (MRRTH) was only 223 mg/l (different sampling events). The wide range of sample values collected over a variety of sediment-producing events enhanced turbidity-SSC relationships and facilitated temporal adjustments to load computations.

Computed suspended sediment discharge (SSD) totals for the period December 30, 2005 to January 2, 2006 reveal the importance of this event, in the upper watershed especially: 63% of the load for the two-year period of record at MRRTH occurring during this one storm. The North Fork shows a relatively smaller percentage (13) of its load generated during the period, reflecting spatial variability of storm intensity.

The downstream-most site (MRHRB) describes the cumulative expression of basin-wide sediment production with the highest average annual load of over two million tons over the two-year period of record. It also illustrates how little suspended sediment was produced in WY 2007: 90% of the SSL in the period of the study was generated in WY 2006. More useful for comparing sub-watersheds is *yield* (tons per square mile), and the North Fork clearly produces less suspended sediment per unit area than the mainstem sites other than MR36, which is less than 10 mi downstream of Ruth Reservoir (Table 8). The mainstem sites show the same downstream progression in load magnitude as was observed in turbidity and suspended sediment concentration.

Comparison of Turbidity and Suspended Sediment Concentration and Load Relationships to Historic Data

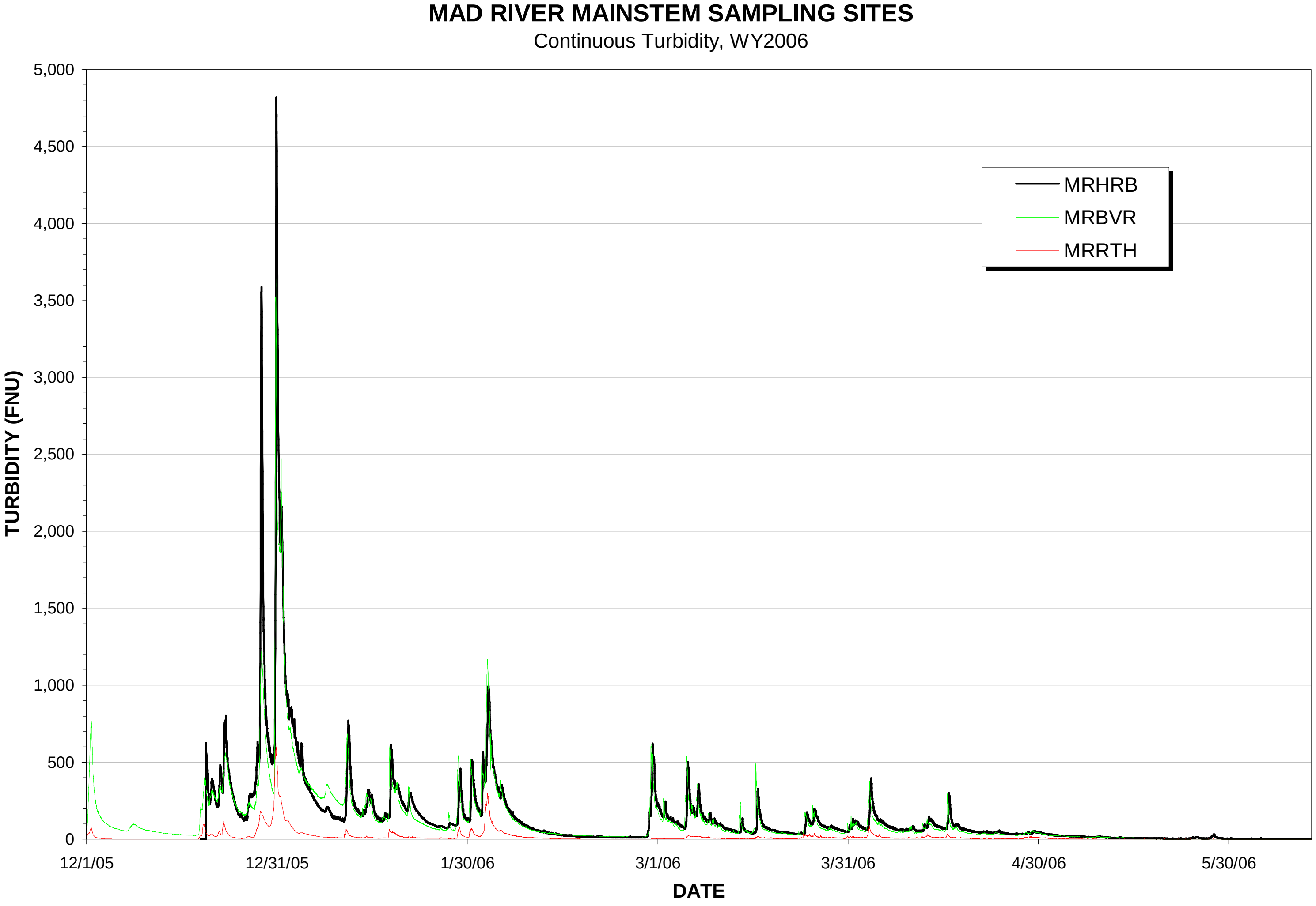
The USGS collected various water quality data at the Mad River near Arcata site from 1958 to 1980. These data were compared with the data from the recent effort and suggest that the SSC vs. discharge relationship and turbidity vs. SSC relationship shifted. Historically, 10,000 cfs produced roughly 2,400 mg/l, whereas the current curve predicts only about 800 mg/l. Whether this apparent reduction in sediment production is real or an artifact of different sampling locations (Highway 299 vs. Hatchery Road Bridge) remains unknown, though the magnitude of the apparent shift suggests that it is real.

Annual suspended sediment loads at the Mad River near Arcata gage have been computed by the USGS (Brown 1973, in Appendix A) for the period of 1958-1974 and by Lehre (1993, in Appendix A) for the period 1962-1992. Comparison of the overlapping years (1962-1974) for these two datasets reveals considerable discrepancies, apparently due to differing computational methods. However, GMA computations show that WY2006 was quite similar to WY1958 both in the magnitude of the peak discharge and the annual runoff, but the 2006 annual suspended load is 32% less than the 1958 load, likely reflecting the change in the discharge vs. SSC relationship.

Comparison of Turbidity, Suspended Sediment Concentration, and Suspended Sediment Discharge Duration Analyses for 12/24/05 through 2/25/06

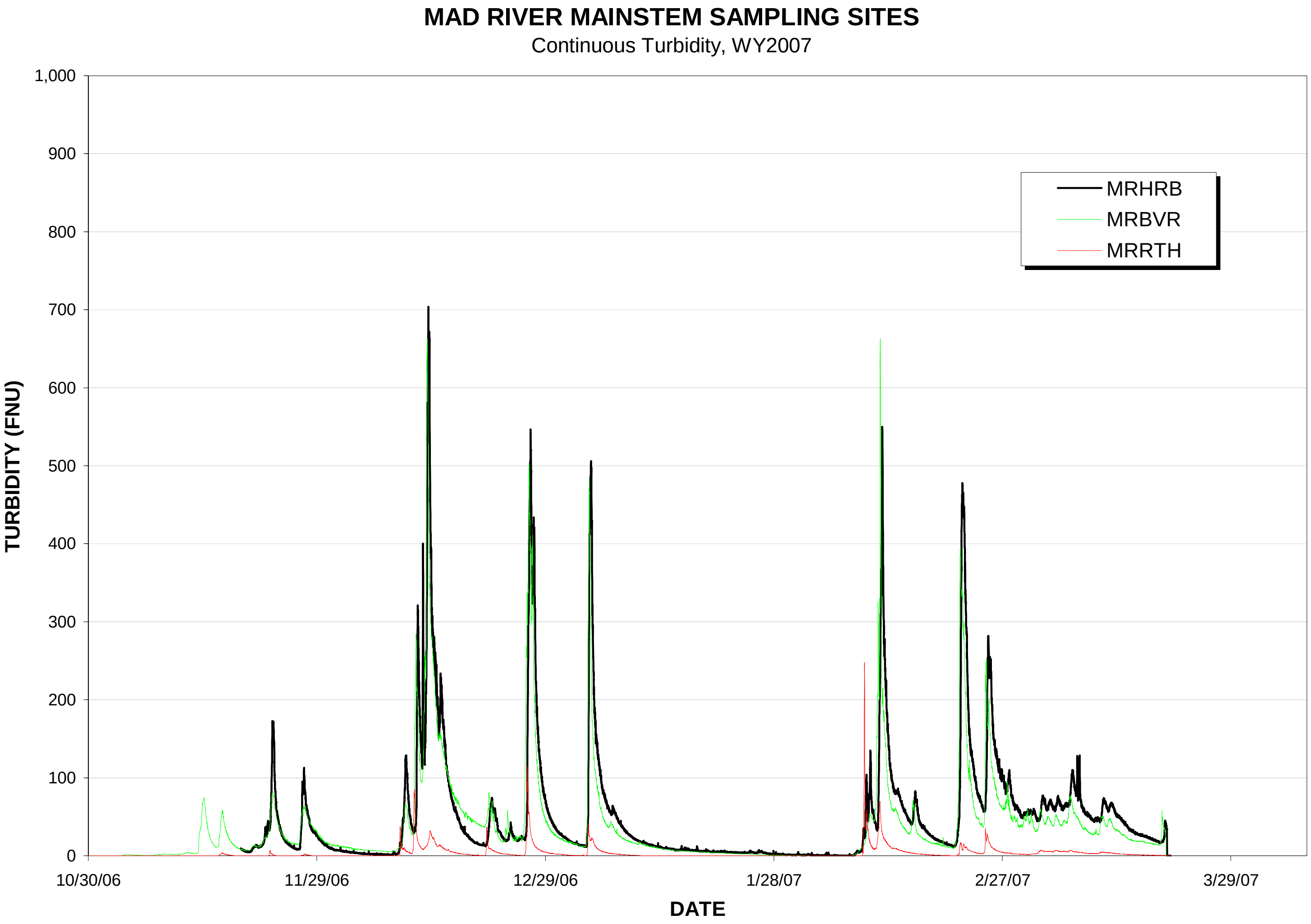
Four continuous turbidimeters were operated on three mainstem sites and the North Fork in WY2006 and 2007. Significant numbers of samples were collected at additional sites during the high flows of December 2005, which allowed development of continuous turbidity records for the period of 12/24/05 through 2/24/06 using the sedigraph method. This period contained by far the largest event in the study period and 30-75% or more of the total sediment transport for the study period. The durations for all of these sites have been computed for the identical periods.

Figure 2. Mad River Mainstem Sampling Sites, Continuous Turbidity, WY 2006



Source: Appendix A, Figure 15

Figure 3. Mad River Mainstem Sampling Sites, Continuous Turbidity, WY 2007



Source: Appendix A, Figure

Table 7. Relationship between Turbidity and Suspended Sediment Concentration for Mainstem Mad River Sites

TURBIDITY vs SUSPENDED SEDIMENT CONCENTRATION

Formulae For Continuous Stations

Site Code	Site Description	Notes	Turbidity vs. SSC (y=)	r^2
MRHRB	Mad River at Hatchery Road Bridge		4.3978x0.8813	0.95
MRBVB	Mad River at Butler Valley Ranch	< 300 FNUs	0.449625 * (T)^ 1.3343	0.90
		>300 FNUs	11.1306 * (T)^ 0.76434	0.90
NFMKB	North Fork Mad River at Korbel Bridge		1.4326x1.0465	0.93
MRRTH	Mad River above Ruth Reservoir	< 7 FNUs	1.07089 * (T)^ 0.742104	0.99
		7-49 FNUs	0.140323 * (T)^ 1.78901	0.99
		>49 FNUs	9.56007 * (T) - 317.323	0.82

Source: Appendix A, Table 7

Table 8. Suspended Sediment Loads for WY2006 and 2007 Periods of Record

SUSPENDED SEDIMENT LOADS FOR PARTIAL WATER YEARS
PERIOD OF RECORD RANGES FROM 12/01/05 - 3/20/07

		WY2006		WY2007		AVERAGE 2006-2007	
SITE	WSA (mi^2)	SSL (tons)	SSY (tons/mi^2)	SSL (tons)	SSY (tons/mi^2)	SSL (tons)	SSY (tons/mi^2)
MRHRB	446	2,050,000	4,596	254,000	570	1,152,000	2,583
NFMKB	44.5	31,800	715	10,500	236	21,150	475
MRBVR	352	1,400,000	3,977	140,000	398	770,000	2,188
MCMCB	12.2	12,300	1,006	6,210	508	9,255	757
BCMCB	18.8	45,300	2,415	23,600	1,258	34,450	1,836
MR36	141.5	89,500	632	7,240	51	48,370	342
OCLM	1.64	1,550	945	10	6	780	476
TB3LM	0.28	38	134	1.2	4.4	19	69
LMC36	3.12	17,500	5,609	88	28	8,794	2,819
CCRTH	0.47	16	33	1.8	3.8	9	18
BCLM	1.05	1,900	1,810	7.1	6.8	954	908
ACLM	1.02	10,600	10,392	709	695	5,655	5,544
HCLM	1.62	2,190	1,352	21	13	1,105	682
MRRTH	93.6	232,000	2,479	2,500	27	117,250	1,253

Source: Appendix A, Table 9

Continuous turbidigraphs for two additional tributary sites, Anada Creek (ACLM) from the upper watershed, but just downstream of MRRTH, and Maple Creek (MCMCB) from the middle watershed and just upstream of MRBVR, were developed from the sample data and the sedigraph method. The differences are instructive: Anada Creek drains a watershed underlain by South Fork Mountain Schist and has extremely high turbidity and sediment, while MRRTH is relatively clean in comparison; Anada Creek is several orders of magnitude more turbid than

MRRTH. In contrast, Maple Creek has only slightly more than half the turbidity of its nearby mainstem site, MRBVR, indicating the extremely high sediment delivery from the middle watershed upstream of MRBVR. Maple Creek is still a significant sediment producer, just less than Anada Creek or the watershed areas draining to mainstem upstream of MRBVR.

Figure 4 provides a turbidity duration analysis for the three tributaries with a continuous record for the 12/24/05 to 2/25/06 period: Anada Creek, Maple Creek, and the North Fork Mad River. Turbidity values for most exceedence probabilities for Anada Creek are 3-50 times higher than those of the North Fork and 2-10 times higher than Maple Creek (Table 9). At the 0.1% exceedence probability for this period, all three sites are fairly similar (i.e., near the peak of the large storm event), but Anada Creek remains quite turbid essentially throughout the period (i.e., well after the peak).

Figure 5 compares the continuous turbidity records for four mainstem sites (MRRTH, MR36, MRBVR, and MRHRB, in downstream order) for the same time period. The turbidity duration curves for MRBVR and MRHRB are very similar for this period, and are quite different from MRRTH and MR36, often by about an order of magnitude. MRRTH is more turbid than MR36 for the peak events, but the MR36 curve crosses the MRRTH curve at an exceedence probability of around 25%. From then on, MR36 is more turbid than MRRTH, which clears up much more rapidly. These are classic effects from a reservoir: the peak concentrations are reduced downstream of the dam as a portion of the sediment is deposited in the reservoir; however, the reservoir stores a significant amount of turbid water which is then released more slowly, for some time after the large event. The turbidity for the 1% exceedence probability is 310 FNU at MRRTH, 108 FNU at MR36, 2020 FNU at MRBVR, and 2650 FNU at MRHRB for the period examined (Table 9). At the 50% exceedence probability, the values are 11, 21, 159, and 155 FNU, respectively. Obviously, the lower river remains quite turbid for an extended period after a large storm event. Table 10 provides the suspended sediment concentration exceedence probabilities for the sites.

Continuous records of turbidity (T), suspended sediment concentration (SSC), and suspended sediment discharge (SSD, or the total quantity of suspended sediment that is discharged) were analyzed for duration by site for the partial period of 12/24/05 to 2/24/06 for all gages for which continuous SSC records were developed. Results are summarized by site in Table 11.

MRRTH cleared up reasonably quickly, even after a large event. SSD is higher than SSC for most of the period simply because SSD is determined by both SSC (which includes high concentrations for short periods of time and lower concentrations for shorter periods of time) and streamflow duration; in other words, the upper watershed produced a significant amount of runoff from this large event, both in peak and in duration, which resulted in greater total discharge of sediment and lower concentrations over a longer period of time.

In contrast, at Anada Creek (ACLM), turbidity and SSC remain very high, with turbidity remaining over 100 FNU for essentially the entire period. The SSD duration curve for Anada Creek has an initial steep decline then diminishes throughout the period, reflecting a steady drop in streamflow rates to low levels.

Mainstem sites Mad River at Highway 36 (MR36), Mad River at Butler Valley Ranch (MRBVR), and Mad River at Hatchery Road Bridge (MRHRB) generally behave similarly except that the T, SSC, and particularly SSD duration curves for the lower two sites (MRBVR and MRHRB) are shifted upward almost an order of magnitude compared to MR36, indicating high sediment discharge for the entire period.

Tributary sites Maple Creek at Maple Creek Bridge (MCMCB) and the North Fork Mad River at Korbel Bridge (NFMKB) were somewhat similar, except that T and SSC cleared up faster on NFMKB than for MCMCB.

Figure 6 compares the SSD duration curves for the four mainstem sites over the 12/24/05 to 2/25/06 period. Although the turbidity duration was lower at MRHRB than at MRBVR for part of the time, the suspended sediment discharge was always higher at MRHRB than at MRBVR, due to the greater streamflow at MRHRB. In fact, the curves separate and MRHRB is twice as high or greater from the 60-99% exceedence probabilities. The difference between SSD at MRRTH and MR36 also diverges, with higher loads at MR36, although the shapes of both curves are similar, with higher T and SSD values at MRRTH in the lowest exceedence probabilities (i.e., the larger, but less frequent events), and higher values at MR36 for exceedence probabilities greater than about 25% (T) and 16% (SSD), suggesting that sediment and corresponding turbidity can be higher at MRRTH for high-intensity events, but they drop off quickly relative to MR36, where the values remain high for longer periods.

Figure 7 compares all unit SSD curves for all seven tributary and mainstem sites. ACLM is higher than all other sites, including the lowermost mainstem sites, MRBVR and MRHRB. After about 30% exceedence probability, MRRTH has the lowest loads, indicating how quickly (compared to others) this portion of the watershed “cleans up.” NFMKB has the lowest loads from 3-30% exceedence, and over 30% is the site next higher than MRRTH. MR36 is next, followed by MCMCB. A large gap then exists between these sites and the sites with the highest unit sediment discharges (MRBVR, MRHRB, and ACLM).

Suspended Sediment Load or Concentration vs. Drainage Area Relationships

Figure 8 was developed to evaluate the relationships when unit sediment load is used instead of total sediment load. In Figure 8, larger differences between the sites are apparent and a qualitative subdivision of the data has been included to identify the degree of impairment.

A similar analysis using unit suspended sediment concentration is shown in Figure 9. This analysis is based on the maximum observed SSC measurement at each site normalized by drainage area (Table 12). The results are generally similar to unit load, but tend to differentiate sites even further because discharge is not included (sediment loads are computed from SSC by multiplying by the discharge) and are simply the maximum sediment concentration.

Turbidity and Suspended Sediment-Reference Watersheds; Comparison with Mad River

Data and relationships from four reference watersheds (R. Klein, personal communication, 2007, in Appendix A) were used to develop reference turbidity, suspended sediment concentration, and suspended sediment discharge duration curves. The reference watersheds were selected from a more extensive dataset of Klein as being the only pristine (i.e., essentially completely undisturbed) watersheds in the area. The analysis of these “reference” watersheds did not include watersheds that were recovered or minimally managed.

The results of the turbidity, SSC, SSD, and unit SSD duration analyses from these reference watersheds were summarized by comparison with data from the Mad River for the winter periods in WY 2006 and 2007 of values at several exceedence probabilities: 0.1%, 1%, 2%, 5%, and 10%. While the lower exceedence probabilities (e.g., 0.1%, 1%) include primarily moderate to large (and infrequent) stormflow conditions, the 10% exceedence probability extends the data to include lower stormflows and late recessional flows that would better reflect chronic turbidity and sediment concentrations/loads. The analysis of the reference data used the same period as was available for the continuous GMA gages in the Mad River watershed. Average values for each parameter (turbidity, SSC, SSD, unit SSD) and each exceedence probability were computed from the four reference sites.

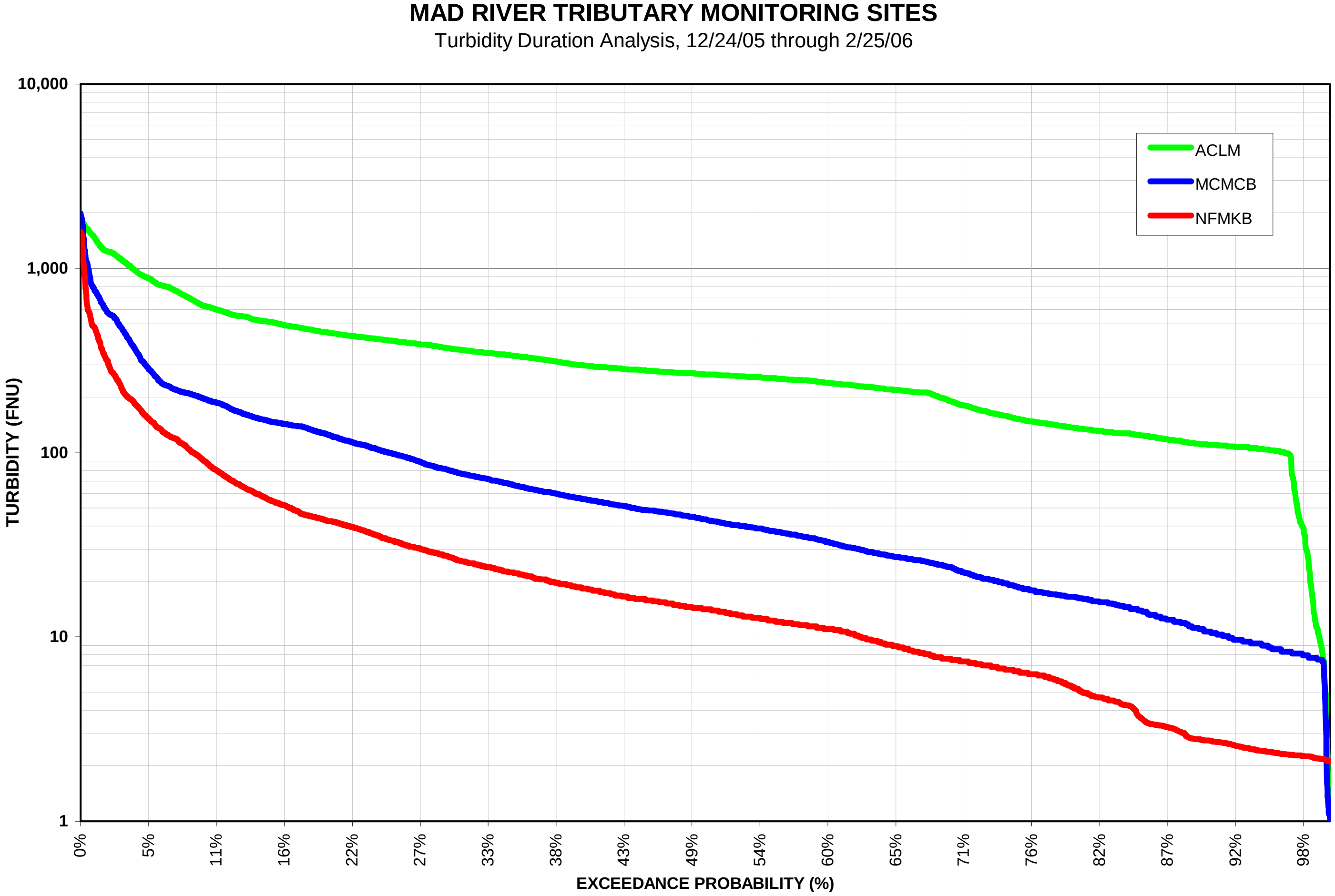
Table 11 compares the four mainstem Mad River continuous sites to the Klein et al. (personal communication, 2007, unpublished, in Appendix A) reference sites for the different turbidity, SSC, load, and unit load exceedence probabilities and their averages. There are substantial differences between the background parameters and those found in the Mad River mainstem, with the Mad values all significantly greater than these pristine reference conditions.

This approach is presented for comparison, but was not used to set the TMDLs, due to some readily apparent limitations:

(1) The drainage basin size disparity between the reference sites and the Mad River watershed sites is very large. Of course, there are essentially no watersheds the size of the Mad River that do not have a substantial amount of disturbance in them, so comparable reference watersheds do not exist. However, the size disparity casts a considerable amount of uncertainty on the appropriateness of the comparison.

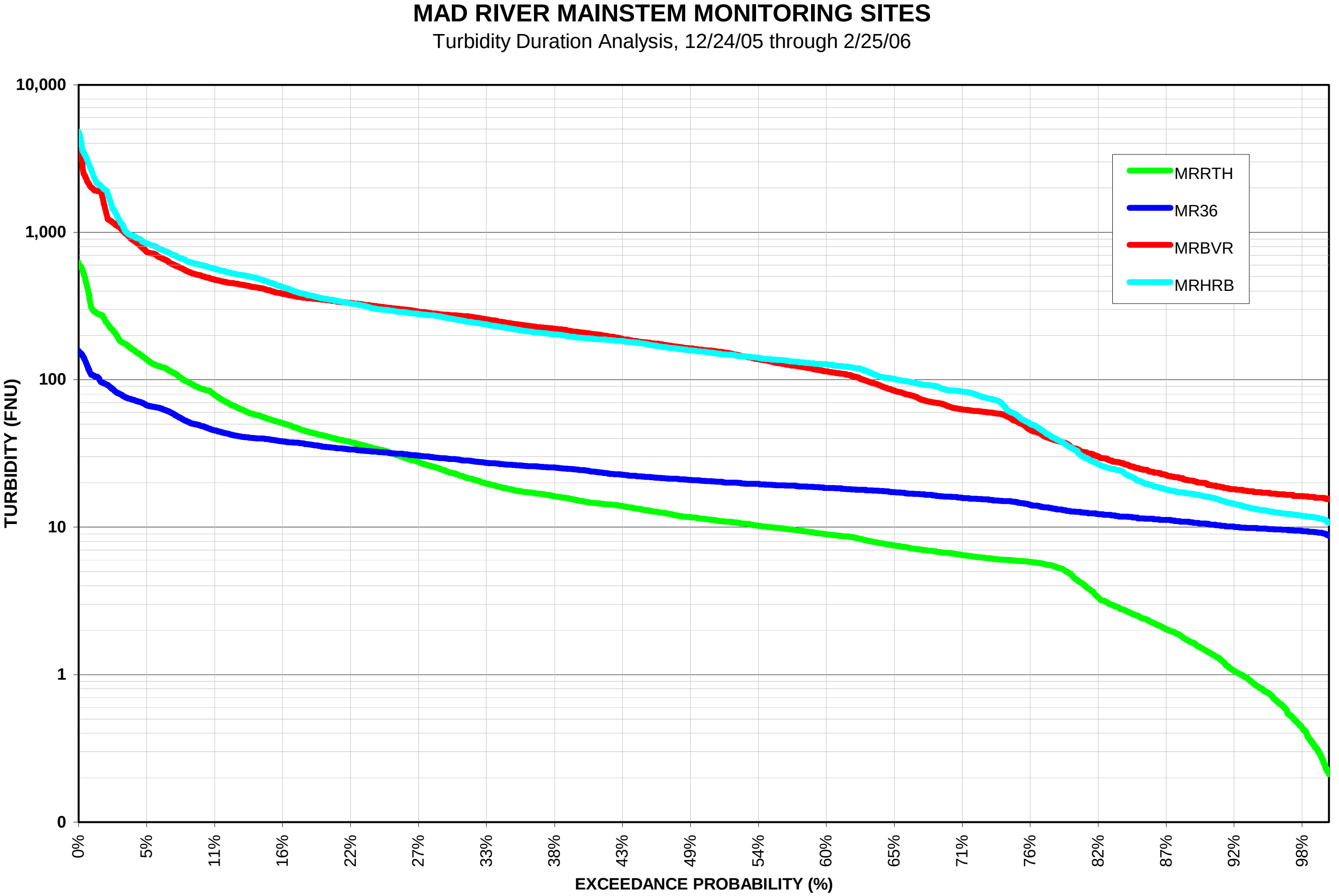
(2) Although the time period for background and Mad River sites is identical, as required by the analysis, this short period of record raises questions regarding the nature of the period on which the analysis is based. Such a short period of record would obviously bias the results relative to the characteristics of the study period, compared to that which would be obtained from a longer period of record.

Figure 4. Mad River Tributary Monitoring Sites Turbidity Duration Analysis, 12/24/05 through 2/25/06



Source: Appendix A, Figure 30

Figure 5. Mad River Mainstem Monitoring Sites Turbidity Duration Analysis, 12/24/05 through 2/25/06



Source: Appendix A, Figure 31

Table 9. Turbidity Exceedence for Tributary and Mainstem Sites

TURBIDITY EXCEEDANCE FOR TRIBUTARY AND MAINSTEM SITES

TURBIDITY (FNU)

Partial Record Period 12/24/05 to 2/25/06

	Exceedance Probability (%)						
SITE	**0.1**	**1**	**2**	**5**	**10**	**50**	**90**
Tributaries							
ACLM	1800	1510	1250	912	623	266	111
MCMCB	1800	791	603	312	195	44	10.7
NFMKB	1470	486	329	163	89	14	2.8
Mainstem							
MRRTH	590	310	261	146	86	11	1.5
MR36	152	108	95	70	48	21	10.6
MRBVR	3520	2020	1600	797	501	159	19.9
MRHRB	4470	2650	1970	887	595	155	16.3

TURBIDITY EXCEEDANCE FOR SITES IN UPSTREAM TO DOWNSTREAM ORDER

TURBIDITY (FNU)

Partial Record Period 12/24/05 to 2/25/06

	Exceedance Probability (%)						
SITE	**0.1**	**1**	**2**	**5**	**10**	**50**	**90**
MRRTH	590	310	261	146	86	11	1.5
ACLM	1800	1510	1250	912	623	266	111
MR36	152	108	95	70	48	21	10.6
MCMCB	1800	791	603	312	195	44	10.7
MRBVR	3520	2020	1600	797	501	159	19.9
NFMKB	1470	486	329	163	89	14	2.8
MRHRB	4470	2650	1970	887	595	155	16.3

Source: Appendix A, Table 10

Table 10. Suspended Sediment Concentration Exceedence for Tributary and Mainstem Sites

SSC EXCEEDANCE FOR TRIBUTARY AND MAINSTEM SITES

SUSPENDED SEDIMENT CONCENTRATION (mg/l)

Partial Record Period 12/24/05 to 2/25/06

SITE	Exceedance Probability (%)						
	0.1	1	2	5	10	50	90
Tributaries							
ACLM	9640	7540	5700	4060	2300	5940	237
MCMCB	2690	1150	849	490	304	65	14.0
NFMKB	2960	928	616	295	158	23	4.1
Mainstem							
MRRTH	5320	2650	2180	1080	504	11	1.4
MR36	506	408	319	237	144	44	19.7
MRBVR	5720	3740	3130	1840	1290	389	24.3
MRHRB	7260	4570	3520	1740	1220	374	51.5

SSC EXCEEDANCE FOR SITES IN UPSTREAM TO DOWNSTREAM ORDER

SUSPENDED SEDIMENT CONCENTRATION (mg/l)

Partial Record Period 12/24/05 to 2/25/06

SITE	Exceedance Probability (%)						
	0.1	1	2	5	10	50	90
MRRTH	5320	2650	2180	1080	504	11	1.4
ACLM	9640	7540	5700	4060	2300	5940	237
MR36	506	408	319	237	144	44	19.7
MCMCB	2690	1150	849	490	304	65	14.0
MRBVR	5720	3740	3130	1840	1290	389	24.3
NFMKB	2960	928	616	295	158	23	4.1
MRHRB	7260	4570	3520	1740	1220	374	51.5

Source: Appendix A, Table 11

Table 11. Comparison of WY2006 Mad River Turbidity, SSC, and SSD Data with Reference Sites

COMPARISON OF WY2006 MAD RIVER TURBIDITY, SSC, AND SSD DATA WITH REFERENCE SITES

BACKGROUND SITES (Klein, pers com. 2007			Turbidity Exceedance Probability (FNU)					Estimated SSC (mg/l)					Estimated SSD (tons/day)					Estimated SSD (tons/mi2/day)				
Site	**Drainage Area (acres)**	**Drainage Area (mi^2)**	**0.10**	**1.0**	**2**	**5**	**10**	**0.10**	**1.0**	**2**	**5**	**10**	**0.10**	**1.0**	**2**	**5**	**10**	**0.10**	**1.0**	**2**	**5**	**10**
GOD	947	1.5	29	12	8	5	3	50	13	7	4	3	5	1.2	0.6	0.2	0.1	3.3	0.8	0.4	0.2	0.1
PRU	2,662	4.2	60	24	16	8	4	91	36	24	12	6	58	16.3	9.4	4.1	1.7	14.0	3.9	2.3	1.0	0.4
LLM	2,317	3.6	116	32	21	12	7	227	50	31	18	11	72	10.1	5.3	2.1	0.9	20.0	2.8	1.5	0.6	0.3
PAB	4,915	7.7	45	19	14	7	4	50	19	13	6	4	19	6.5	3.7	1.5	0.6	2.5	0.8	0.5	0.2	0.1
		avg	63	22	15	8	5	105	30	19	10	6	39	9	5	2	1	10.0	2.1	1.1	0.5	0.2
		std dev	38	8	5	3	2	84	17	11	6	4	32	6	4	2	1	8.5	1.5	0.9	0.4	0.2

MAD RIVER SITES (GMA, 2007)			Turbidity Exceedance Probability (FNU)					Estimated SSC (mg/l)					Estimated SSD (tons/day)					Estimated SSD (tons/mi2/day)				
Site	**Drainage Area (acres)**	**Drainage Area (mi^2)**	**0.10**	**1.0**	**2**	**5**	**10**	**0.10**	**1.0**	**2**	**5**	**10**	**0.10**	**1.0**	**2**	**5**	**10**	**0.10**	**1.0**	**2**	**5**	**10**
MRHRB	310,326	485	3790	1610	865	542	344	6270	2960	1700	1130	756	758094	243643	90170	37324	19036	1563	502	186	77	39
MRBVR	217,387	340	3180	1270	858	497	351	5290	2620	1940	1280	982	452000	182000	86500	30300	18400	1331	536	255	89	54
NFMKB	28,468	44	1050	273	177	90.1	46.1	2090	507	323	159	79	22600	2700	1280	404	141	508	61	29	9	3
MRRTH	59,911	94	565	225	145	70.1	37	5090	1830	1070	353	90	191000	36900	16200	2600	421	2040	394	173	28	4
		avg	2146	845	511	300	195	4685	1979	1258	731	477	355924	116311	48538	17657	9500	1361	373.3	160.6	50.8	25.3
		std dev	1578	702	405	254	177	1805	1090	723	557	462	321079	115097	46380	18895	10648	640.5	217.0	94.9	38.4	25.5

Notes:

GMA Acronym and Site Name

Site	Site Name
MRHRB	Mad River at Hatchery Rd Bridge
MRBVR	Mar River at Butler Valley Ranch
NFMKB	N Fork Mad R at Korbel Bridge
MRRTH	Mad R above Ruth Reservoir

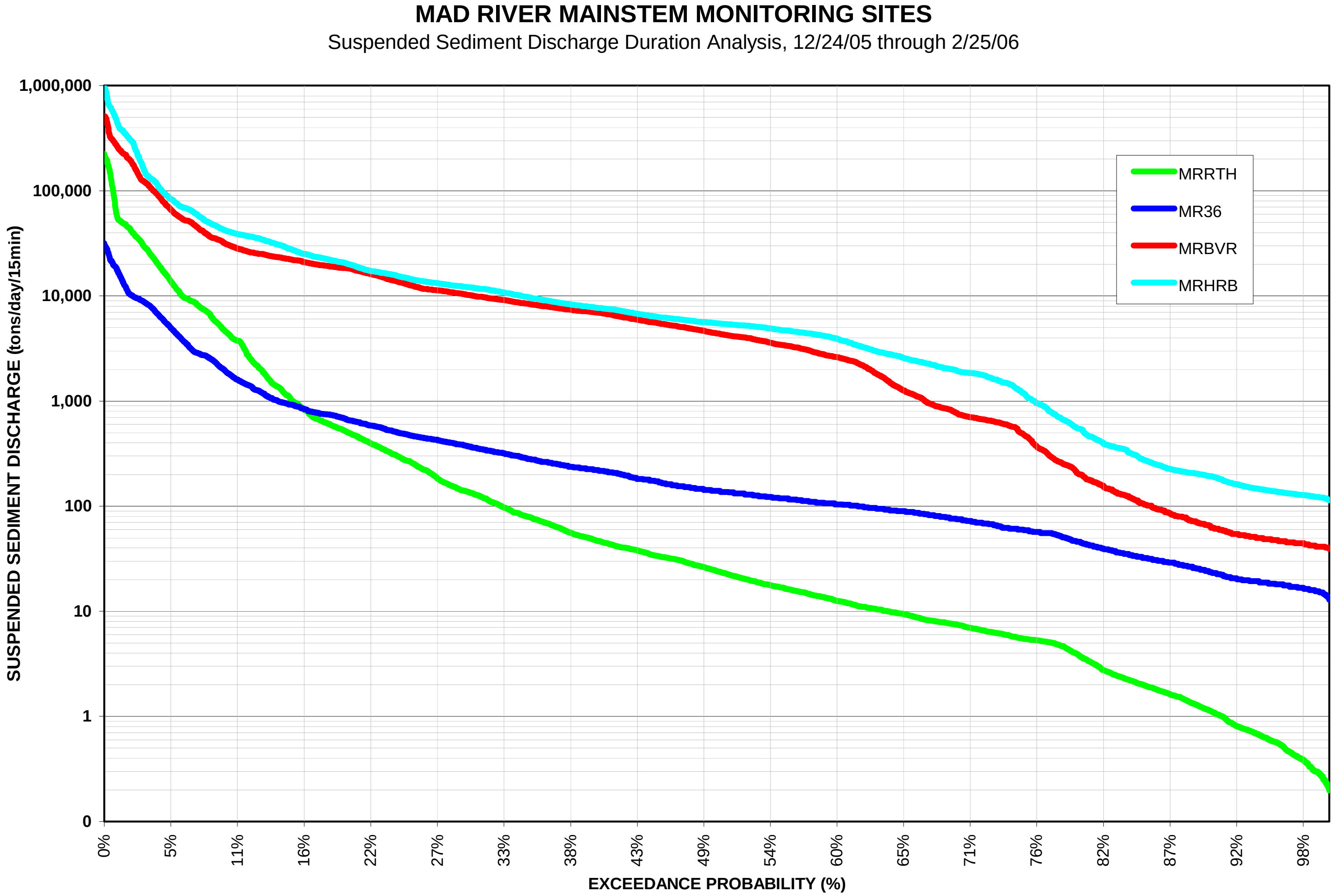
Background Sites

Site	Site Name
GOD	Godwin Creek
PRU	Upper Praire Creek
LLM	Little Lost Man Creek
PAB	Prairie Creek above Boyes

Background data from Klein et al (in review) (Klein, per com. 2007)
based on WY2005 SSC Estimation Equations

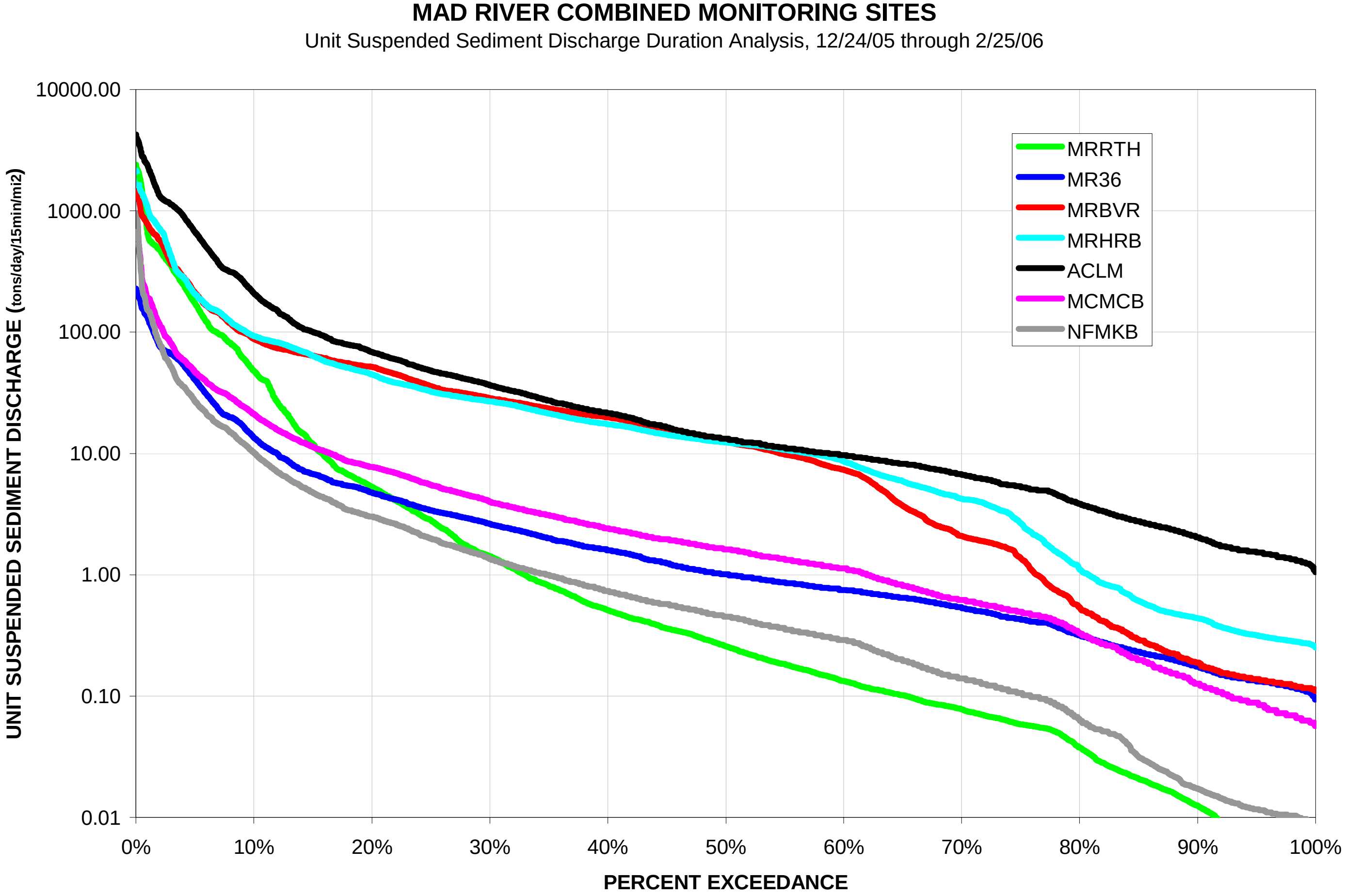
Source: Appendix A, Table 13

Figure 6. Mad River Mainstem Monitoring Sites SSD Duration Analysis, 12/24/05 through 2/25/06



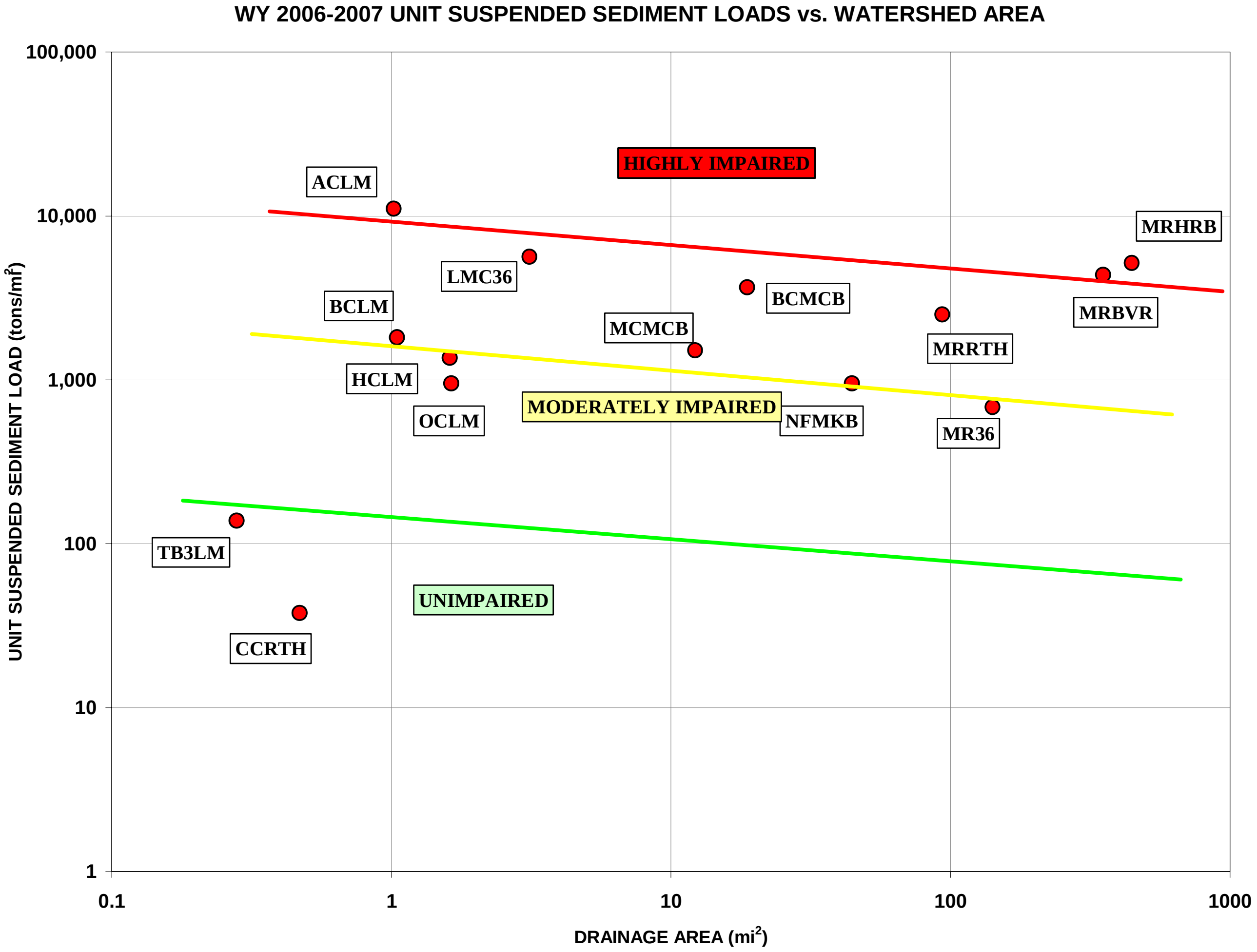
Source: Appendix A, Figure 39

Figure 7. Mad River Unit SSD Duration Analysis, 12/24/05 through 2/25/06



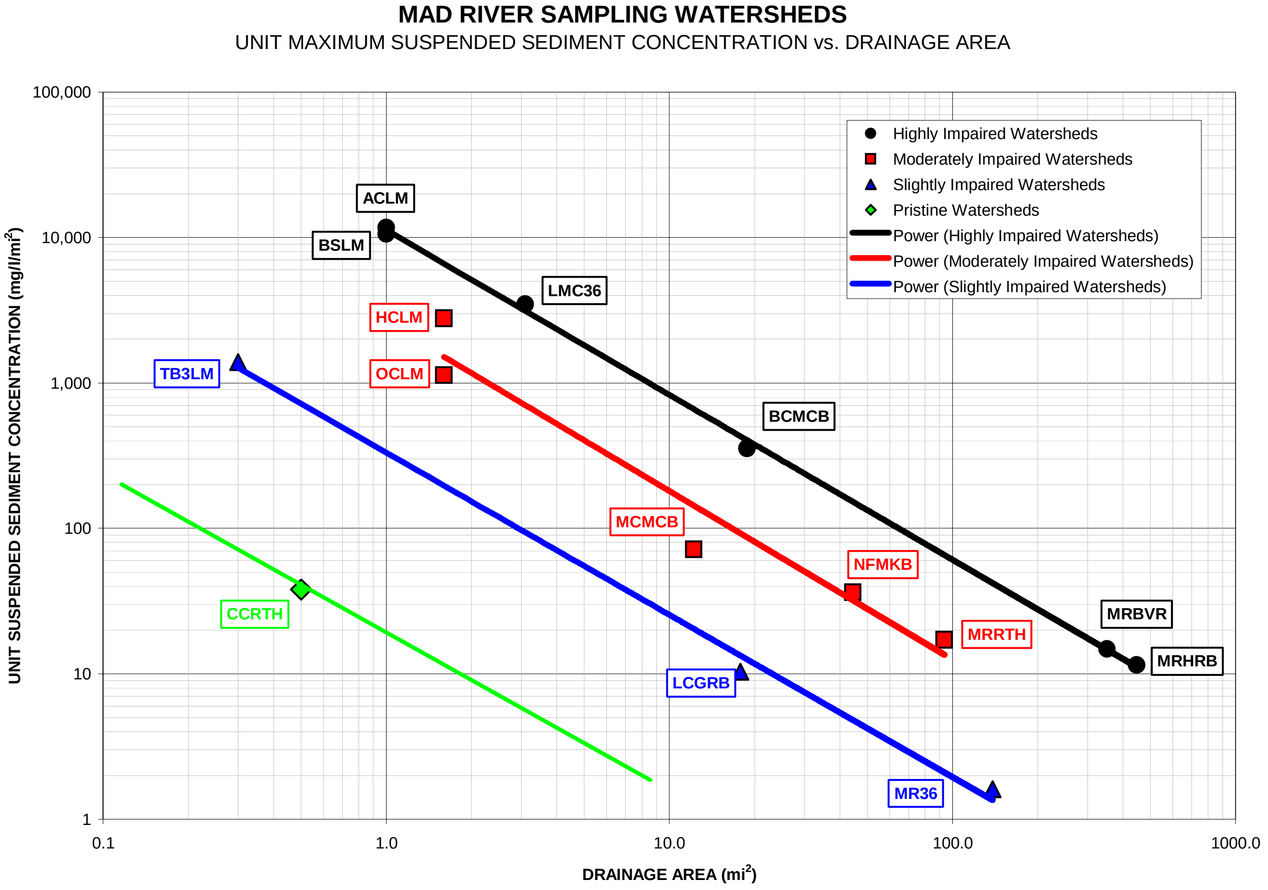
Source: Appendix A, Figure 41

Figure 8. WY 2006-2007 Unit Suspended Sediment Loads vs. Watershed Area



Source: Appendix A, Figure 42a

Figure 9. Unit Maximum Suspended Sediment Concentration vs. Watershed Area



Source: Appendix A, Figure 43

Table 12. GMA Sampling Site Observed Maximum Turbidity and SSC

GMA SAMPLING SITE OBSERVED MAXIMUM TURBIDITY AND SSC

Site Code	Watershed Code	Site Description	Drainage Area (mi^2)	Maximum Turbidity (NTU) [4]	Maximum SSC (mg/l)	Unit Max SSC $(mg/l)/mi^2$
MRHRB [2]	C1A	Mad River at Hatchery Road Bridge	447.1	4,383	5,149	12
MRBVR [2]	C2	Mad River near Maple Creek below Butler Valley Bridge	351.4	3,421	5,213	15
NFMKB [2,3]	C3	North Fork Mad River at Korbel Bridge	44.5	668	1,620	36
MRRTH [2]	C5	Mad River above Ruth Lake at County Road 514 Bridge	93.6	370	1,609	17
MR36 [2]	C4	Mad River at Highway 36 Bridge	138.4	223	223	2
LCGRB	S1	Lindsay Creek at Glendale Road Bridge	17.8	170	184	10
MCMCB	S2	Maple Creek at Maple Creek Road Bridge	12.2	345	879	72
BCMCB	S3	Boulder Creek at Maple Creek Road Bridge	18.8	4,382	6,686	356
LMC36	S4	Lamb Creek	3.1	1,950	10,776	3,476
OCLM	S5	Olsen Creek	1.6	200	1,817	1,136
TB3LM	S6	Unnamed Tributary 3	0.3	40	417	1,390
HCLM	S7	Hobart Creek	1.6	1,800	4,461	2,788
BCLM	S8	Blue Slide Creek	1.0	930	10,619	10,619
ACLM	S9	Anada Creek	1.0	2,850	11,745	11,745
CCRTH	S10	Clover Creek	0.5	20	19	38

[2] continuous turbidity station

[3] continuous streamflow station

[4] maximum turbidity and SSC did not always come from the same sample

Source: Appendix A, Table 12

3.1.2.2 Landslide Inventory, Surface, and Fluvial Erosion

<u>Landslide Source Analysis</u>

For the post-1975 time period, GMA mapped and digitized 200 active landslides. Landslides mapped from aerial photos were given a certainty of recognition rating with 33 percent definite, 56 percent probable, and 11 percent questionable. Of the 200 post-1975 mapped active landslides, 31 landslides (or 15.5 percent) were field verified. All of the “definite” and “probable” field inventoried landslides were indeed slides. Each field verified landslide was mapped, and dimensions (width, length, and thickness) were measured. With the exception of debris torrents, the observed thicknesses fall within the ranges of other recent sediment source analyses on the North Coast.

This landslide analysis was conducted at the basin scale, and includes 172 active landslides. This is not intended to be a site-specific or project-specific analysis (e.g., to mitigate landslide hazards associated with timber harvest planning). Rather, GMA used the methods similar to those of DWR (1982) and DMG (1999, in Appendix A), since the mapping scale and area were similar. For site-specific landslide investigations in the future, data at a higher mapping resolution would be more appropriate.

Pilot Creek Subwatershed Sediment Budget and USFS Geomorphology Layer

GMA used the USFS Geomorphology layer (USDA Forest Service, 2006) that was readily available and mapped consistently at the Provincial Level. GMA reviewed the Pilot Creek active landslide map (Dresser, 2003) and found that the landslides were mapped at a finer scale and split features more frequently than this method would allow. For example, the Pilot Creek landslide inventory broke out individual gullies within active earthflows, whereas this inventory lumped the gullies as larger earthflow features and used the lateral extent of the feature to digitize the boundaries, then estimated a percentage of delivery. In addition, landslides smaller than five acres could not be accurately mapped, given the mapping resolution of this landslide inventory. GMA did not have access to most of Pilot Creek during field verification due to ongoing logging operations on USFS lands, so field verification there was limited. However, where GMA did gain access, along the inner gorge of lower Pilot Creek, they found substantial differences between the USFS landslide data and conditions measured on the ground for the following landslides several (see Appendix).

GMA found that large earthflows, active within the last 31 years, appear to be reducing the Mad River valley width, pushing stream energy against opposite stream banks and causing inner gorge debris flows (Plate 12a, 12b, and 12c). Downstream of the Bug Creek subwatershed (ID#: 1015), located in the middle Mad River (Plate 1b), landslide sediment input exceeds the transport capacity of the river, resulting in a locally aggraded channel. Large pulses of sediment delivery during wet water year (e.g., 1996) have episodically dammed this reach of the Mad River. Most inner gorge debris flows and rock slides occur on steep slopes (i.e., > 65%) and have high sediment delivery potential. Whereas, dormant Quaternary landslides commonly occur on mélange terrain with parallel drainage pattern and relatively low relief.

Within the Pilot Creek subwatershed (ID#: 1009), one of the larger earthflows is dissected by several roads, causing a small amount of gully erosion. GMA reviewed this feature, since it was predicted to produce a substantial amount of material relative to other landslides within this subwatershed. Further review of the remote sensing data showed that the stability of this feature has not been reduced as a result of the road network. Though this feature has not been field verified, GMA revised the assigned triggering mechanism in the finalized database (i.e., for the Final TMDL analysis), changing it from road related to natural. This change greatly reduced the management related sediment contribution from landslides in Pilot Creek. This made a substantial difference between the original and revised sediment budget for this subwatershed, but it did not substantially alter the overall sediment budget. Pilot Creek is not a major sediment producer relative to downstream subwatersheds.

Landslide Inventory Results

The landslide database was sorted by certainty and all of the questionable slides were eliminated from further analysis unless they were field verified and determined to be slides. The database was filtered again based on the analysis of sediment delivery, and features mapped as non-delivering were eliminated. The majority of the planar land area occupied by mapped active landslides (81%) were earthflows, followed by debris flows. Relative to the other landslide types, earthflows have delivered most of the landslide-associated sediment to the stream network over the last 31 years.

Three geology types (all Franciscan types) explain 99% of landslides (by spatial area). About 57% of the planar land area occupied by landslides occur in the Franciscan mélange. Most of those in this geology type are mainly earthflows, although earthflows also occur in other geology types (primarily Franciscan, and a lesser amount in South Fork Mountain Schist). The Franciscan mélange geology type covers about 37% of the Mad River watershed, but accounts for 57% of the landslides. Most of those slides are concentrated in the lower-gradient, moderately dissected lithotopo units. About 40% of the landslides occurred in other Franciscan rock, while 2% occur in South Fork Mountain Schist, and only 0.5% occurred in other geologic types.

The landslide data were also sorted by triggering mechanism and related land use (Table 13). The inventory shows that over half of the total number of mapped active landslides were triggered by natural processes. Roads have produced about 33% of the slope failures, and timber harvest activities about 8%. The percentage attributable to timber harvest is within the range reported in other sediment source inventories (e.g., Raines 1998, Sidle and Ochiai, 2006, and Green Diamond, 2006, Appendix F, in Appendix A).

Table 13. Count of Landslide Type Sorted by Triggering Mechanism Related to Land Use

	Natural		Road		Timber Harvest		Grand Total	
Landslide Type	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**
Debris Flow	49	49%	21	37%	7	50%	77	45%
Debris Slide	15	15%	12	21%	4	29%	31	18%
Earthflow	21	21%	19	33%	2	14%	42	24%
Inner Gorge	8	8%	5	9%	1	7%	14	8%
Rock Fall	7	7%		0%		0%	7	4%
Rock Slide	1	1%		0%		0%	1	1%
Total	101	59%	57	33%	14	8%	172	100%

Source: Appendix A, Table 16

The frequency and volume of sediment derived from active landslides varies spatially within the Mad River watershed. Unit Landslide Volumes for the post-1975 period by associated land use (triggering mechanism) are listed by subwatershed in Table 14 (Section 3.1.2.4). The Holm Creek, Showers Creek, Goodman Prairie Creek, Deer Creek, Bug Creek, Morgan Creek, Bear Creek2, Graham Creek, Dry Creek, Tompkins Creek, Olsen Creek, Wilson Creek, Boulder Creek, Bear Creek, Barry Ridge, and Devil Creek subwatersheds have the highest frequency of landslides per unit drainage area, and landslides in those subwatersheds deliver at least 2,000 tons/mi^2/year (Tables 14 and 15 below). The top three—Holm Creek, Showers Creek, and Goodman Prairie Creek—delivery over 10,000 tons/mi^2/year of landslide-generated sediment. Of the sixteen largest, virtually all of the larger producers of landslide-related sediment come from the central portion of the watershed: 19 of the 21 subwatersheds that produce more than 1,000 tons/mi^2/year in landsliding sediment are in the Middle Mad subarea.

Overall, 39% of the total annual landslide sediment delivery is from background sources, comprised of naturally-occurring slides and creep from deep-seated features; 59% of the sediment is from road –related landslides, and less than 2% from harvest-related landslides. Thus, management-related landslides resulting 61% of the total annual average landslide sediment delivery.

Given the mapping scale and available data, the confidence in this analysis is medium to high where at least 15% of the mapped active landslides were field verified. There are several sources of uncertainty in the landslide inventory. The active landslides were mapped from aerial photos at different scales. There was no one consistent set of aerial photographs for the entire Mad River watershed except for the 2005 NAIP Digital Orthophotographs. For areas without complete aerial photograph coverage, this analysis relied on remote sensing data and DEM generated hillslope relief maps. Landslide inventory field verification improved the reliability of the landslide data as described above.

Comparison to mass wasting rates developed in other North Coast California watersheds with similar geology suggests that the results of this analysis are reasonable (Sidle and Ochiai, 2006, in Appendix A). Recent work within the adjacent South Fork Trinity River, the Van Duzen River, and Redwood Creek watersheds provides the best basis for comparison. Raines (1998, in Appendix A) estimated rates of mass wasting for the South Fork Trinity River watershed at between 21 and 1,985 tons/mi^2/year for four planning watersheds for a 47-year period between 1944 and 1990. In Grouse Creek, Raines and Kelsey (1991, in Appendix A) estimated rates at 4,330 tons/mi^2/year for budget period of 1960-1989. PWA (1999, in Appendix A) estimated average sediment rates from all sources of 2,690 tons/mi^2/year for the Van Duzen River. Redwood National Park estimated mass wasting in Redwood Creek at 2,050 tons/mi^2/year for the period 1954-1997. The average rate for this analysis about 2,895 tons/mi^2/year with a maximum of 11,178 tons/mi^2/year. The maximum value is above the reported averages, however, it is similar to those reported in Redwood Creek to the north (Sidle and Ochiai, 2006, in Appendix A).

Surface and Fluvial Erosion Analysis

The surface and fluvial erosion analysis included a screening level erosion source inventory that focused on roads and a modeling exercise intended to predict the relative amount of sediment coming from background sources (i.e., fluvial bank erosion), roads, and timber harvest areas.

GMA completed an inventory of fluvial bank erosion on four reaches of the mainstem and several headwater tributaries. The measured rate of fluvial bank erosion varied by watershed area, with the highest rates occurring along stream channels within mélange terrain. These results are incorporated into the traditional sediment budget presented later.

GMA also completed a rapid reconnaissance of the road system, driving about 300 miles of the road network within the Mad River watershed. There are about 2,187 miles of mapped roads within the Mad River watershed; about 14% of the road system was inventoried. The inventory results show that the roads layer used in the analysis is accurate for the main road system on both public and private lands. Data for low level roads associated with timber harvest activities were found to be less accurate or missing. For example, several of the spur roads shown on the map were not recognizable in the field and were removed from the GIS database. Roads not included in the GIS database were found along the powerline corridors and areas that were recently harvested. To the extent possible, the missing roads were added to the database; however, it is likely that there are quite a few more roads that are not included in the analysis.

Road densities vary from 0.8 to 8.4 miles/mi^2, and average 4.2 miles/mi^2 for the entire watershed. 74% of the roads are native, 20% are rocked, and 6% are paved. Road surface type listed in the GIS database was found to be a reliable indicator of road width and was used as a surrogate for road width in the WEPP model. The road condition was found to be a function of the bedrock geology and traffic level. Heavily traveled native surface roads that dissect the Franciscan mélange tended to have the most erosion and drainage problems and commonly caused gully erosion. Gully erosion was especially present were roads drained into active earthflows within the lower Mad River. As a result, roads that dissect mélange terrain were assigned a higher erosion rate within the WEPP model. Within the upper Mad River above Ruth Lake, the road system was found to be very stable and very few erosion problems were measured.

GMA also measured erosion directly from the Lower Mad Road during storm runoff in December 2005. Results of this sampling show that the measured load from cutbank and ditch erosion ranged from 361 to 6,925 tons/mi^2/year (3 samples). These results were used to help verify erosion rates used in the road erosion model. The highest erosion rates were measured on a road that had been recently used or maintained.

Fluvial Erosion Model Results (using NetMap)

Fluvial erosion was estimated using NetMap; no management sources of bank erosion were included in this analysis. NetMap calculates fluvial erosion by generating the locations of channel heads, representing the points where runoff concentrations initiate gully erosion. The stream density calculated from this later is relatively high when compared to the stream density calculated using the USGS blue line stream layer; the NetMap stream layer shows that mélange and South Fork Mountain Schist have lower stream density than the Franciscan complex. Steep and convergent slopes have higher stream density. Bank erosion is estimated at 26 tons/mi^2/year on average throughout the basin. It is estimated to be nearly twice that rate in the Upper Mad subarea.

WEPP and Washington State Surface Erosion Module

Surface erosion from roads and timber harvest was estimated using WEPP. Results from the road erosion modeling (i.e., WEPP and Washington State Surface Erosion module) show that most of the surface and fluvial erosion occurs on native surface roads that dissect the Franciscan mélange (Appendix A). About 75 percent of the mapped road system has a native surface type, and about 50 percent of the native surface roads dissect mélange terrain. The frequency of native surface roads on mélange results in the relatively higher sediment delivery predictions. Roads on the South Fork Mountain Schist also have higher average erosion rates by surface type, but the miles of road that dissect this geology type are less than 3% of the total road system, resulting in relatively lower total sediment delivery for that geology type.

The initial WEPP model results appeared high relative to measured values. Due to the lack of data on road design and condition, the road system was broken into similar types as described above. Generalizing the entire road system into a limited number of categories limits the accuracy of model results and initially produced very high erosion rates. To define the range of sediment delivery potential, the WEPP model was subsequently run for different road condition scenarios (e.g., high versus low traffic, steep versus gentle slope, etc.). The average erosion rate was reduced about 30% by changing the traffic level from high to low and reducing the road slope categories by 50%. Changing the roads from inboard ditch without vegetation to inboard vegetated ditch had the greatest effect on model results. The erosion rates were reduced by at least 50%. Regardless of changes in the model assumptions, erosion from roads on mélange remained high (200 tons/acre/year). These results did not correlate with measured loads, nor were they within the ranges reported for nearby watersheds. Thus, for these road types, measured road sediment delivery and erosion rate values reported in the Washington State Surface Erosion module (WA DNR, 1995, in Appendix A) were used instead of the WEPP results.

Surface and fluvial erosion from areas harvested for timber is low relative to background and road erosion sources, and accounts for a small fraction of the total sediment delivery. Like other portions of the sediment budget, these results should be viewed as relative indicators of erosion. These results are combined with the other portions of the sediment budget.

Confidence

The confidence in this analysis is medium, the modeled precision is high, and all calculations are repeatable. As with most models of this sort, the error may be as much as 150%. There are several sources of uncertainty in the input data to the surface and fluvial erosion model. Due to the large watershed area, the 2,000 plus miles of road, and the lack of various types of road data, the physical shape and condition of the road system had to be generalized. Site-specific road condition inventories and analysis by subwatershed would greatly improve the accuracy of model results and provide land managers a clearer picture of sediment sources associated with roads and timber harvest. For this analysis, however, the model precision is high and all calculations are repeatable.

3.1.2.3 NetMap Sediment Budget

In the original sediment source analysis (GMA, September 2007, or Appendix A to the Draft TMDLs), the NetMap model was used to develop an element of the traditional sediment budget (bank erosion) as well as its own sediment budget for background and existing unit sediment load for both the Q_2 flood event (i.e., chronic delivery) and the Q_{25} flood event (i.e., episodic delivery). In the revised sediment source analysis (Appendix A to the Final TMDLs, December 2007), the NetMap model is now used for several components of the traditional sediment budget (background creep and bank erosion), but its own sediment budget was limited to an average annual frequency event generally representative of the range of events that would occur over the 31-year sediment budget period, incorporating both chronic and episodic elements. This also allowed the NetMap sediment budget to be “calibrated” to the average measured sediment loads for the 2006-2007 period developed as part of this study (Section 3.1.2.1).

The NetMap model was rerun for the Mad River using the revised surface and fluvial erosion and landslide sediment delivery rates, and the GEP was not used for landslide prone terrain. Also, the model output was summarized differently to help quantify the relative types, importance, and sources of erosion potential. The sediment load by lithotopo unit was distributed to the upland sources creating a polygon layer of erosion sources and potential. The final sediment source map displays the sediment load by lithotopo unit and disturbance type (i.e., background versus management).

The average measured unit sediment loads, by monitoring site, agree reasonably well with the NetMap model results (Table 14). The percent difference between the modeled and measured sediment load increases as the drainage area decreases. For subwatersheds that drain more than 50 mi^2, the modeled results are +/- 20% of the measured sediment load. For smaller subwatersheds, the error is as much as 125%, which likely results from the landslide mapping scale and use of average sediment delivery rates. Most of the difference is from averaging sediment delivery rates by lithotopo unit over the basin. There are 169 different lithotopo unit types within the Mad River, and there are 24,482 discrete unit polygons within the basin. Averaging over this scale will result in more error (Table 22 of Appendix A). This model should be field verified and refined as needed at larger scales (subwatersheds draining <50 mi^2). For example, model results indicate that the North Fork Mad River has a substantial amount of surface and fluvial erosion from roads (Table 22a of Appendix A); however, the measured sediment load for the study period is substantially less than the modeled load.

Table 14. NetMap Sediment Budget by Monitoring Subarea Vs. Measured Load

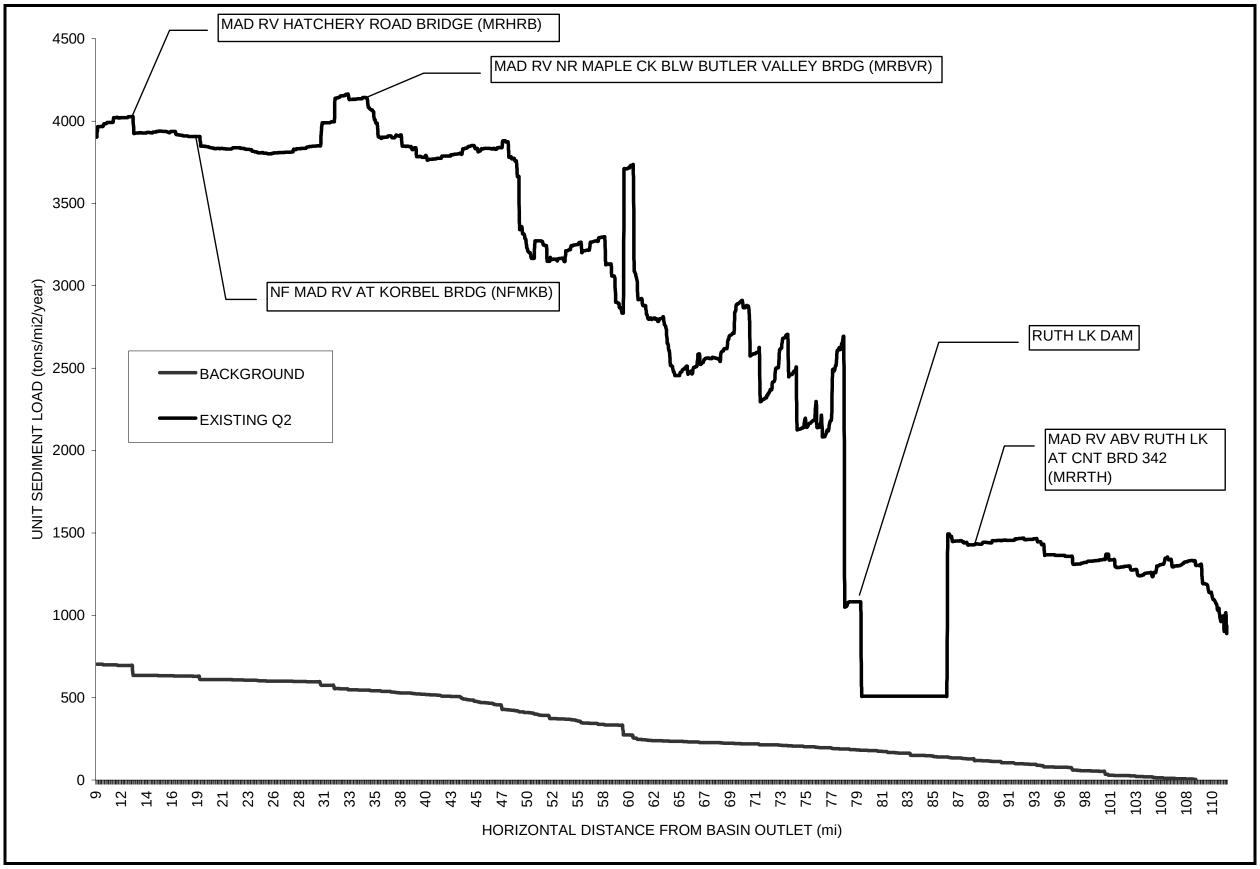
BASIN_ID	Watershed ID	Drainage Area (mi2)	Average Modeled Sediment Load (tons/mi2/year)	Average Measured Sediment Load (tons/mi2/year)
1	MRRTH	94	1,289	1,253
2	ACLM	1	2,460	5,544
3	CCRTH	0	2,883	18
4	BCLM	1	3,585	908
5	HCLM	2	1,308	682
	Above Ruth Lake	98	1,333	1,278
6	TB3LM	0	2,678	69
7	OCLM	2	4,233	477
8	MR36	39	1,582	1,249
	Above Highway 36	140	1,440	1,258
9	LMC36	3	4,042	2,818
10	BCMCB	19	2,317	1,837
11	MCMCB	12	2,403	755
12	MRBVR	179	3,759	4,293
	Above Butler Valley Road	354	2,725	2,832
13	NFMKB	44	4,153	475
14	MRHRB	49	3,903	NA
	Basin Outlet	446	2,998	2,584

Source: Appendix A, Table 22.

The revised sediment load estimates generated using NetMap indicate that the average background and existing unit sediment load of the Mad River near Arcata are 798 and 2,900 tons/mi^2/year, respectively. The total average annual sediment load predicted using NetMap is 1,336,795 tons/year. For comparison, the average measured sediment load at the basin outlet is 1,152,000 tons/year, which is a 16% difference. About 26% of this load is attributable to background erosion sources, 55% from roads, and 19% from timber harvest. The background portion of the load varies by sub area (Appendix A).

The modeled background unit sediment load increases gradually downstream, whereas the modeled existing unit sediment load increases sharply due to management contributions (Figure 10). For background and existing conditions, the slope of the longitudinal profile increases 60 miles upstream from the basin outlet (Figure 10). The unit sediment load increase occurs where Franciscan mélange becomes the dominant bedrock type and active landslides become more frequent (See Appendix A for more detail).

Figure 10. Longitudinal Plot of Unit Sediment Delivery for the Mad River



Source: Appendix A, Figure 44a

Confidence

The confidence in this analysis is medium and the error may be up to 150% for subwatersheds less than 50 mi^2 and 20% for subwatersheds greater than 50 mi^2. There are several sources of uncertainty in the input data to the NetMap model. NetMap is able to rapidly summarize and precisely analyze large datasets; however, the data generalized as part of this analysis limit the accuracy of the results. The landslide data has the highest level of accuracy, whereas the road and timber harvest data have the lowest. As mentioned above, the model accuracy could be improved with better road inventory data, especially since road erosion represents a large fraction of the total surface and fluvial erosion sediment delivery.

This analysis attempted to allocate the fine sediment load amongst upland sediment sources and use the results to allocate turbidity and suspended sediment load reductions. Due to the lack of detailed road data and the inherent uncertainty associated with sediment budget modeling, this analysis could not accurately make a connection between the measured background and existing suspended sediment load (and corresponding turbidity level) to upland sediment sources. NetMap is a relativistic model and the output should be used to compare the contribution of sediment from different sources both natural and management related. To date, the model is not intended to predict the "actual" sediment load per flood event; therefore it cannot be used to help develop load allocations for the 20% over background water quality objective for turbidity. Instead, the upland sediment budget is used to set the TMDLs (see next section).

3.1.2.4 Traditional Sediment Budget

Upland Sediment Budget Results

An alternative method of evaluating the sediment budget data collected in this study involves the development of a traditional sediment budget. This was used to set the TMDLs, in part because this method provided improved confidence in the sediment budget results over the NetMap model. By combining unit sediment loads from the landslide analysis with unit sediment loads from road surface erosion modeling and harvest-related surface erosion, and with unit sediment loads from bank erosion, the major sources of sediment delivery by sub-watershed can be evaluated by type and by percentage of the total.

Table 15 presents the 39 sub-watersheds with the various categories of landslide related sediment delivery combined with surface erosion from roads. The total unit sediment delivery by subwatershed is computed and the percentages of the combined total by type are also presented. Percentages by background and management related sources are computed for each subwatershed. Appendix A presents these same data sorted and ranked in various ways, which allows the relative importance of various sediment delivery mechanisms to be easily compared by subwatershed.

Totals for the 39 subwatersheds range from a low of 98 tons/mi^2/year for the Mud River (Basin #1001, above Ruth Lake) to 11,242 tons/mi^2/year for Holm Creek (Basin # 1011, in the middle reach of the mainstem Mad River). The largest producers are Holm Creek, Showers Creek, Goodman Prairie Creek, Deer Creek, Bug Creek, Bear Creek 2, and Morgan Creek, all of which deliver over 8,000 tons/mi^2/year. Landslide-related erosion accounts for the bulk of the sediment in all of these high unit sources, although the relative importance of background slides, road-related slides, and harvest-related slides varies between the subwatersheds. The eight subwatersheds with the highest unit sediment production are in the Middle Mad subarea, and 13 of the top 14 sediment-producing watersheds are all in the middle Mad, from Ruth Lake downstream to Butler Valley. Dry Creek, in the Lower Mad River, is the only subwatershed not in the Middle Mad subarea that produces over 3,000 tons/mi^2/year. Unit sediment production in the Middle Mad River averages 3,705 tons/mi^2/year; in the Lower/North Fork subarea it averages 1,398 tons/mi^2/year, and in the Upper Mad, sediment production is very low, at 234 tons/mi^2/year.

The subwatersheds producing the most sediment have high landsliding rates, and high rates of road-related sediment. Showers Creek, Goodman Prairie Creek, Bear Creek2, and Holm Creek stand out as large sources of road-related unit sediment. Of the 15 highest subwatershed sources of road-related landslide sediment delivery, these slides account for 50-99% of the total sediment produced by each subwatershed. Sixteen subwatersheds do not have any road-related landslides.

Management-related unit sediment delivery is closely related to road delivery; in 36 of the 39 subwatersheds, road-related sediment accounts for more than 92% of the total management-related sediment. In the remaining three subwatersheds (Lost Creek in the Upper Mad, Olsen Creek in the Middle Mad, and Powers Creek in the Lower Mad), road-related sediment is still high, and accounts for 85%, 87% and 70% of total management-related sediment, respectively. Twenty of the sub-watersheds have over 60% of their total sediment production from management-related sources. The highest producers from road surface erosion are in the Lower Mad/North Fork subarea; half of the subwatersheds produce more than 200 tons/mi^2/year from road surface erosion, and they are all in the Lower and Middle subareas. Road-related sediment deliveries range from a low of 18 tons/mi^2/year (Mud River and Deep Hollow Creek) to 653 to 683 tons/mi^2/year (North Fork Mad River and Cannon Creek).

Landslides are typically the main mechanism of sediment production, accounting for over 90% of the total sediment load in over half the subwatersheds. Landsliding accounts for less than 50% of the total sediment load in only eight of the subwatersheds; in these subwatersheds, where landslides are not important sources of sediment, naturally-occurring creep and bank erosion are the dominant background erosion sources, and surface erosion from roads is the dominant source of management caused erosion. Road-related surface erosion in those subwatersheds typically accounts for one- to two-thirds of the total sediment in those watersheds, whereas the basinwide average for road-related erosion averages about 10% of the total sediment production.

Table 16 sorts the subwatersheds into reaches created by the GMA instream monitoring sites: above MRRTH (upper watershed above Ruth Lake), between MRRTH and MRBVR (middle watershed from Ruth Lake to Butler Valley), and between Butler Valley and the basin outlet. Review of the total unit sediment delivery by subwatershed for each of these categories shows that the upper watershed has the lowest unit sediment production rate (234 tons/mi^2/year, on average, compared with 1,398 tons/mi^2/year for the lower watershed, and 3,705 tons/mi^2/year for the middle portion of the basin, or more than twice the rate of the lower watershed, or more than 10 times the rate of the upper watershed). All of the eight subwatersheds with the highest unit sediment production, and 18 of the 20 subwatersheds with the highest unit rates, are located in the large, central portion of the watershed, where the combination of unstable geology, steep slopes, and, in many cases, high road densities, has resulted in high unit sediment yields. The rates in this subarea are as high as 11,242 tons/mi^2/year, and the seven highest subwatershed rates are all greater than 8,000 tons/mi^2/year. By contrast, the subwatersheds with the lowest unit sediment production rates (the lowest being Mud River) are found above Ruth Lake.

Table 15. Unit Sediment Delivery by Type by Subwatershed

MAD RIVER SEDIMENT SOURCE ANALYSIS
UNIT SEDIMENT DELIVERY BY TYPE BY SUB-WATERSHED

			Landslide Related Erosion (tons/mi^2/yr)					Surface Erosion (tons/mi^2/yr)		Bank Erosion (tons/mi^2/yr)	Total (tons/mi^2/yr)	Percentage of Total Unit Sediment Delivery					
BASIN ID	Watershed Name	Drainage Area (mi^2)	Background Creep from Deep-Seated Features	Background Landslides	Road Related Landslides	Timber Harvest Related Landslides	Total Landslide Related Sediment Delivery	Road Sediment Delivery	Harvest Sediment Delivery	Bank Erosion	Grand Total	Background Landslide + Creep as % of Total	Road Related Landslide as % of Total	Timber Harvest Related Landslide as % of Total	Road Surface Erosion as % of Total	Background (Landslide + Creep + Bank Erosion) as % of Total	Management Related Sources as % of Total
1001	Mud River	13.2	50	0	0	0	50	18	0.5	29	98	51.1%	0.0%	0.0%	18.7%	80.8%	19.2%
1002	Lost Creek	26.1	70	52	0	4	126	26	0.7	24	177	69.0%	0.0%	2.2%	14.8%	82.6%	17.4%
1003	South Fork Mad River	15.9	43	0	0	0	43	19	0.5	65	127	33.8%	0.0%	0.0%	14.6%	85.0%	15.0%
1004	Barry Creek	10.2	133	0	0	0	133	44	1.0	28	206	64.5%	0.0%	0.0%	21.4%	78.1%	21.9%
1005	Armstrong Creek	9.9	79	0	230	12	321	92	1.2	91	506	15.6%	45.5%	2.4%	18.3%	33.6%	66.4%
1006	Deep Hollow Creek	4.1	284	23	413	0	720	18	0.4	14	752	40.8%	54.9%	0.0%	2.4%	42.7%	57.3%
1007	Deep Hollow Creek West	4.6	69	0	0	0	69	137	1.4	120	327	21.1%	0.0%	0.0%	41.8%	57.8%	42.2%
1008	Bear Creek	8.1	461	286	2,607	0	3,354	317	2.3	48	3722	20.1%	70.1%	0.0%	8.5%	21.4%	78.6%
1009	Pilot Creek	39.7	300	1,636	0	2	1,938	74	1.0	17	2031	95.3%	0.0%	0.1%	3.7%	96.2%	3.8%
1010	Hastings Creek	11.1	634	423	354	0	1,411	106	0.5	1	1518	69.6%	23.3%	0.0%	7.0%	69.7%	30.3%
1011	Holm Creek	8	641	3,402	7,136	0	11,179	41	0.4	21	11242	36.0%	63.5%	0.0%	0.4%	36.2%	63.8%
1012	Olmstead Creek	11.3	575	61	1,093	0	1,729	250	3.7	8	1991	31.9%	54.9%	0.0%	12.6%	32.3%	67.7%
1013	Showers Creek	2.7	547	816	9,235	0	10,598	248	3.0	6	10855	12.6%	85.1%	0.0%	2.3%	12.6%	87.4%
1014	Deer Creek	6.9	653	3,010	5,813	0	9,476	190	4.5	8	9678	37.9%	60.1%	0.0%	2.0%	37.9%	62.1%
1015	Bug Creek	9.7	363	3,543	5,193	0	9,099	73	0.5	31	9204	42.4%	56.4%	0.0%	0.8%	42.8%	57.2%
1016	Morgan Creek	8.7	741	1,152	6,494	130	8,517	333	0.5	17	8867	21.3%	73.2%	1.5%	3.8%	21.5%	78.5%
1017	Wilson Creek	9.4	750	174	2,818	0	3,742	235	0.8	15	3992	23.1%	70.6%	0.0%	5.9%	23.5%	76.5%
1018	Graham Creek	13.1	711	1,191	3,378	0	5,280	278	2.7	17	5578	34.1%	60.6%	0.0%	5.0%	34.4%	65.6%
1019	Goodman Prairie Creek	10	775	951	8,297	0	10,023	266	0.5	16	10306	16.7%	80.5%	0.0%	2.6%	16.9%	83.1%
1020	Boulder Creek	19	176	1,963	1,345	142	3,626	211	0.3	20	3857	55.5%	34.9%	3.7%	5.5%	56.0%	44.0%
1021	Barry Ridge	9.1	501	777	1,771	0	3,049	266	5.2	29	3349	38.2%	52.9%	0.0%	7.9%	39.0%	61.0%
1022	Maple Creek	15.6	100	22	0	0	122	348	2.7	33	506	24.1%	0.0%	0.0%	68.8%	30.6%	69.4%
1023	Blue Slide Creek	6.1	260	0	3	0	263	157	1.1	44	465	56.0%	0.6%	0.0%	33.7%	65.4%	34.6%
1024	Devil Creek	19	188	0	1,759	149	2,096	327	4.3	37	2464	7.6%	71.4%	6.1%	13.3%	9.1%	90.9%
1025	Cannon Creek	16.4	281	1	0	0	282	683	5.0	16	986	28.6%	0.0%	0.0%	69.3%	30.2%	69.8%
1026	Dry Creek	7	246	0	4,076	500	4,822	316	4.6	28	5171	4.8%	78.8%	9.7%	6.1%	5.3%	94.7%
1027	North Fork Mad River	48.8	302	9	62	0	373	653	3.3	13	1042	29.8%	5.9%	0.0%	62.6%	31.1%	68.9%
1028	Powers Creek	20.8	397	0	0	147	544	358	5.8	45	953	41.7%	0.0%	15.4%	37.6%	46.4%	53.6%
1029	Lindsay Creek	17.7	177	0	0	0	177	440	8.6	23	648	27.3%	0.0%	0.0%	67.8%	30.9%	69.1%
1030	Deer Creek2	7.1	183	0	68	0	251	31	0.5	18	301	60.8%	22.7%	0.0%	10.3%	66.8%	33.2%
1031	Showers Creek2	5.2	289	55	0	0	344	387	9.1	19	759	45.3%	0.0%	0.0%	51.0%	47.8%	52.2%
1032	Bear Creek2	4.1	97	0	7,964	0	8,061	357	4.8	19	8442	1.1%	94.3%	0.0%	4.2%	1.4%	98.6%
1033	Tompkins Creek West	4.9	64	94	0	0	158	214	1.2	133	507	31.2%	0.0%	0.0%	42.3%	57.5%	42.5%
1034	Tompkins Creek	8.9	378	472	3,175	0	4,025	26	0.3	12	4064	20.9%	78.1%	0.0%	0.6%	21.2%	78.8%
1035	Hetten Creek West	11.9	211	0	0	0	211	156	0.7	11	379	55.7%	0.0%	0.0%	41.2%	58.6%	41.4%
1036	Hetten Creek	10.7	300	344	0	0	644	111	0.3	0	755	85.3%	0.0%	0.0%	14.6%	85.3%	14.7%
1037	Olsen Creek West	9.1	424	493	0	0	917	40	0.3	53	1011	90.7%	0.0%	0.0%	4.0%	96.0%	4.0%
1038	Olsen Creek	12.8	406	704	2,407	362	3,879	88	1.3	6	3974	27.9%	60.6%	9.1%	2.2%	28.1%	71.9%
1039	Hastings Creek West	3.2	651	615	0	0	1,266	28	0.5	48	1342	94.3%	0.0%	0.0%	2.1%	97.9%	2.1%

Source: Appendix A, Table 24

Table 16. Unit Sediment Delivery by Type by Subwatershed, Divided into Reaches Created by Monitoring Sites

MAD RIVER SEDIMENT SOURCE ANALYSIS
UNIT SEDIMENT DELIVERY BY TYPE BY SUBWATERSHED DIVIDED INTO REACHES CREATED BY MONITORING SITES

			Landslide Related Erosion					Surface Erosion		Bank Erosion	NATURAL	ROADS	HARVEST	MGMT	Total
			(tons/mi^2/year)												
BASIN ID	Watershed Name	Drainage Area (mi^2)	Background Creep (Deep-Seated Landslides)	Background	Road Related	Timber Harvest Related	Total Landslide Related	Road Sediment Delivery	Harvest Sediment Delivery	Bank Erosion	Landslide + Creep + Bank Erosion	Roads - Landslides & Surface	Harvest - Landslides &Surface	TOTAL ROADS AND HARVEST RELATED	GRAND TOTAL
BASINS ABOVE MRRTH (Upper Mad)															
1001	Mud River	13.2	50	0	0	0	50	18	0.5	29	79	18	0.5	19	98
1002	Lost Creek	26.1	70	52	0	4	126	26	0.7	24	146	26	4.6	31	177
1003	South Fork Mad River	15.9	43	0	0	0	43	19	0.5	65	108	19	0.5	19	127
1004	Barry Creek	10.2	133	0	0	0	133	44	1.0	28	161	44	1.0	45	206
1005	Armstrong Creek	9.9	79	0	230	12	321	92	1.2	91	170	323	13.2	336	506
1006	Deep Hollow Creek	4.1	284	23	413	0	720	18	0.4	14	321	431	0.4	431	752
1007	Deep Hollow Creek West	4.6	69	0	0	0	69	137	1.4	120	189	137	1.4	138	327
	Subarea Average	**84.0**	**81**	**17**	**47**	**3**	**148**	**39**	**0.7**	**46**	**144**	**86**	**3.4**	**90**	**234**
BASINS BETWEEN MRRTH AND MRBVR (Middle Mad)															
1008	Bear Creek	8.1	461	286	2,607	0	3,354	317	2.3	48	795	2,924	2.3	2,927	3,722
1009	Pilot Creek	39.7	300	1,636	0	2	1,938	74	1.0	17	1,953	74	3.1	78	2,031
1010	Hastings Creek	11.1	634	423	354	0	1,411	106	0.5	1	1,058	460	0.5	460	1,518
1011	Holm Creek	8	641	3,402	7,136	0	11,179	41	0.4	21	4,064	7,177	0.4	7,178	11,242
1012	Olmstead Creek	11.3	575	61	1,093	0	1,729	250	3.7	8	644	1,343	3.7	1,347	1,991
1013	Showers Creek	2.7	547	816	9,235	0	10,598	248	3.0	6	1,369	9,483	3.0	9,486	10,855
1014	Deer Creek	6.9	653	3,010	5,813	0	9,476	190	4.5	8	3,671	6,002	4.5	6,007	9,678
1015	Bug Creek	9.7	363	3,543	5,193	0	9,099	73	0.5	31	3,937	5,266	0.5	5,267	9,204
1016	Morgan Creek	8.7	741	1,152	6,494	130	8,517	333	0.5	17	1,910	6,827	130.4	6,957	8,867
1017	Wilson Creek	9.4	750	174	2,818	0	3,742	235	0.8	15	939	3,052	0.8	3,053	3,992
1018	Graham Creek	13.1	711	1,191	3,378	0	5,280	278	2.7	17	1,919	3,656	2.7	3,659	5,578
1019	Goodman Prairie Creek	10	775	951	8,297	0	10,023	266	0.5	16	1,742	8,564	0.5	8,564	10,306
1020	Boulder Creek	19	176	1,963	1,345	142	3,626	211	0.3	20	2,159	1,556	142.1	1,698	3,857
1021	Barry Ridge	9.1	501	777	1,771	0	3,049	266	5.2	29	1,307	2,037	5.2	2,042	3,349
1022	Maple Creek	15.6	100	22	0	0	122	348	2.7	33	155	348	2.7	351	506
1023	Blue Slide Creek	6.1	260	0	3	0	263	157	1.1	44	304	160	1.1	161	465
1030	Deer Creek2	7.1	183	0	68	0	251	31	0.5	18	201	99	0.5	100	301
1031	Showers Creek2	5.2	289	55	0	0	344	387	9.1	19	363	387	9.1	396	759
1032	Bear Creek2	4.1	97	0	7,964	0	8,061	357	4.8	19	116	8,321	4.8	8,326	8,442
1033	Tompkins Creek West	4.9	64	94	0	0	158	214	1.2	133	291	214	1.2	216	507
1034	Tompkins Creek	8.9	378	472	3,175	0	4,025	26	0.3	12	862	3,201	0.3	3,202	4,064
1035	Hetten Creek West	11.9	211	0	0	0	211	156	0.7	11	222	156	0.7	157	379
1036	Hetten Creek	10.7	300	344	0	0	644	111	0.3	0	644	111	0.3	111	755
1037	Olsen Creek West	9.1	424	493	0	0	917	40	0.3	53	970	40	0.3	41	1,011
1038	Olsen Creek	12.8	406	704	2,407	362	3,879	88	1.3	6	1,116	2,495	362.9	2,858	3,974
1039	Hastings Creek West	3.2	651	615	0	0	1,266	28	0.5	48	1,314	28	0.5	28	1,342
	Subarea Average	**266.4**	**410**	**986**	**2,080**	**32**	**3,508**	**174**	**1.6**	**21**	**1,418**	**2,254**	**34**	**2,287**	**3,705**
BASINS BETWEEN MRBVR AND MRALM (Lower/NF)															
1024	Devil Creek	19	188	0	1,759	149	2,096	327	4.3	37	225	2,085	153.7	2,239	2,464
1025	Cannon Creek	16.4	281	1	0	0	282	683	5.0	16	298	683	5.0	688	986
1026	Dry Creek	7	246	0	4,076	500	4,822	316	4.6	28	274	4,392	505.1	4,897	5,171
1027	North Fork Mad River	48.8	302	9	62	0	373	653	3.3	13	324	714	3.5	718	1,042
1028	Powers Creek	20.8	397	0	0	147	544	358	5.8	45	442	358	152.4	511	953
1029	Lindsay Creek	17.7	177	0	0	0	177	440	8.6	23	200	440	8.6	448	648
	Subarea Average	**129.7**	**278**	**4**	**501**	**72**	**855**	**514**	**4.8**	**24**	**306**	**1,015**	**77**	**1,092**	**1,398**
WATERSHED AVERAGE		**480.1**	**317**	**551**	**1,298**	**38**	**2,203**	**242**	**2.3**	**26**	**894**	**1,540**	**40**	**1,580**	**2,474**

Source: Appendix A, Table 29

When ranked by total sediment delivery in tons per year (as opposed to unit sediment delivery in tons/mi^2/year), the subwatersheds range from 1,291 and 1,504 tons/year (Mud River and Deep Hollow Creek West, in the upper watershed) to 103,062 tons/year (Goodman Prairie Creek). The subwatersheds with high landslide sediment delivery rank at the top, but larger subwatersheds with high road surface erosion also deliver large quantities of sediment. Total sediment production is 1,187,928 tons/year, with 89% from landslides, 10% from road surface erosion, 0.1% from harvest surface erosion, 12% from background creep, and 16% from bank erosion.

The upper watershed subarea, totaling 84 mi^2 (18% of the watershed area), produces just 2% of the total sediment; the middle watershed (266 mi^2, or 55% of the watershed area,) produces 83% of the sediment, and the lower watershed (130 mi^2, or 27% of the watershed area) produces 27% of the sediment%. All of the subwatersheds that produce large quantities of sediment are located in the Middle Mad or Lower/North Fork subareas.

Comparison of Upland Sediment Budget and Transport Data

By subdividing the upland sediment budget subwatersheds into monitoring subareas, (i.e., between sediment transport nodes), the volumes of sediment delivery can be compared to the average annual transport at each node from the quantities measured and computed at the GMA monitoring stations.

The nodes are as follows (Table 17): Above MRRTH is the upper watershed, between MRRTH and MRBVR is the middle watershed, and between MRBVR and MRHRB is the lower watershed, which includes NFMKB. Table 17 presents the results of this analysis. Since WY 2006 was a very wet year and WY 2007 was a very dry year, the suspended sediment loads were combined and averaged to produce a “typical” year. Loads within each reach are then compared to the average tons/year values from the sediment budget based on 31 years (1975-2006).

Table 17. Comparison of Measured SSL and Upland SSA by Monitoring Reach

COMPARISON OF MEASURED SSL AND UPLAND SSA BY MONITORING REACH

SITE	WSA	2006-2007 AVG MEASURED SSL	COMPUTED SSL FOR REACH	% OF OUTPUT	NOTES	COMPARE TO RATES FROM UPLAND SSA	
	(mi2)	(tons/yr)	(tons/yr)	(%)		(tons/yr)	(%)
MRHRB	446	1,152,000		100%	Output from System	1,187,928	100%
NFMKB	44.5	21,150		1.8%		50,847	4.3%
Gain between MRBVR and MRHRB Sites			360,850	31.3%	Subtracted NFMKB to obtain reach gain	181,317	15.3%
MRBVR	352	770,000					
Gain between MRRTH and MRBVR Sites			676,200	58.7%	Adjusted for est. 20% deposit in Ruth Lake	986,982	83.1%
MRRTH	93.6	117,250		10.2%	Input from Upper Watershed	19,628	1.7%

Source: Appendix A, Table 33.

The average measured load from the upper watershed (above MRRTH) is 117,250 tons/yr, or 10.2% of the basin output. The load for the large reach between MRRTH and MRBVR is computed as the difference between the two measured records with an adjustment (estimated at 20%) to the load passing MRRTH for sediment deposited in Ruth Lake. This computation indicates that 676,200 tons/yr or 58.7% of the basin output is contributed between the two monitoring sites. The gain between MRBVR and MRHRB is computed to be 360,850 tons/yr or 31.3% of the output. Total output at MRHRB is computed to be 1,152,000 tons/yr.

Values from the upland sediment budget are then compared to these measured values. As previously noted, the traditional sediment budget produced 1,187,928 tons/yr total, with 19,628 tons/yr or 1.7% from the upper watershed, 986,982 tons/yr or 83.1% from the middle watershed, and 181,317 tons/yr or 15.3% from the lower watershed. These values compare reasonably well to the measured values, and certainly show that the values are reasonable. When examining a specific subwatershed such as the North Fork Mad River, (the only subbasin for which a load was measured), the two approaches show some differences (21,150 tons/yr measured SSL vs. 50,847 tons/yr from the sediment budget). Upland sediment production rates from the upper Mad are low compared to the measured loads, but this reflects the fact that the December 2005 event was quite a bit more unusual (and therefore a larger sediment producer compared to an average year) in that part of the watershed.

A number of caveats, which may explain much of the difference, must be mentioned in this analysis: (1) Measured values are for suspended sediment load only and do not take into account bedload, which would be incorporated in the computations of upland sediment delivery, (2) measured values did not include the entire water year in either 2006 or 2007, though the vast majority of sediment transporting events were certainly captured in the period of record, and (3) the average of the two measured years may not be representative of the 31 year period (annual load computations by Brown (1973) and Lehre (1993) average from 1,600,000 to 2,600,000 tons/year, although the pre-1975 period was undoubtedly wetter, and produced more sediment (due to fewer regulations and more management activity),than the post-1975 period).

3.1.2.5 Synthesis

Sediment source analysis results indicate that most of the natural and management related sediment delivery is from the Franciscan mélange within the middle reach of the Mad River. The measured SSL, NetMap model, and traditional sediment budget show a substantial increase in the sediment load in the middle portion of the Mad River as the mélange terrain becomes more frequent. For chronic sediment delivery, road surface erosion appears to be the major sediment source, whereas for episodic sediment delivery earthflows and debris flows triggered naturally and by roads appear to be the major sediment sources.

It is not possible to directly compare the NetMap model and traditional sediment budget results. The main reason is the fact that the classical sediment budget does not include sediment transport and storage through the stream network where all of the upland sediment delivery is assumed to reach the watershed outlet. In contrast, the NetMap model predicts upland sediment delivery (i.e. Generic Erosion Potential) and then uses basin, valley, and stream network parameters to predict sediment transport and storage potential. The upslope sediment delivery is decayed through the stream network as a function of watershed shape, steepness, and confluence geometry. As a result, only a portion of the predicted sediment delivery is realized at the watershed outlet. The other reason is that the NetMap model uses the measured sediment load as input and proportions the load amongst lithotopo units for background and existing conditions.

For the Mad River watershed, sediment source reduction efforts should focus on chronic surface erosion from roads, and episodic erosion from areas where roads dissect landslide prone terrain within the middle reach between Highway 36 and the confluence with Boulder Creek. This reach has the highest predicted sediment load as well as habitat needed to support anadromous fish migration, spawning, and rearing.

The NetMap model identifies the relative contribution, by subbasin, of existing chronic and episodic erosion. It can also be used to predict areas prone to future erosion as land use continues within the watershed. This analysis identified a substantial data gap in road presence and absence as well as condition. Road inventories that measure road condition would greatly improve the accuracy of this analysis and could be used to identify site-specific management prescriptions aimed at reducing chronic and episodic sediment delivery.

3.1.2.6 Summary

Tables 18 and 19 summarize the results of the sediment source assessment. Landslides are the dominant sediment-producing process, and roads are the dominant management source of sediment: road-related landslides and surface erosion contribute 62% of the sediment (73% in the Lower/North Fork subarea, where the highest road densities in the entire Mad River watershed can be found in each of the subwatersheds (ranging from 4.4 to 6.3 mi/mi^2). By contrast, the Upper Mad subarea produces by far the lowest overall sediment delivery rates (234 tons/mi^2/yr), and, while 37% of that sediment is road-related, it also produces the least road-related sediment in the watershed by far: 86 tons/mi^2/yr, compared with 1,015 tons/mi^2/yr for the Lower/North Fork subarea, and 2,254 tons/mi^2/yr for the Middle subarea. The Upper subarea also contains the least dense native-surfaced road network (with native-surface road densities ranging from 1.1 to 2.5 mi/mi^2).

While the Middle Mad subarea has the highest total unit sediment delivery rates (3,705 tons/mi^2/yr), and the highest road-related sediment rates (2,254 tons/mi^2/yr), it also has the highest natural background delivery rates (1,417 tons/mi^2/yr, compared with 144 tons/mi^2/yr in the Upper Mad and 306 tons/mi^2/yr in the Lower Mad subareas). The Middle Mad subarea also contains a wide distribution of highly erodible Franciscan and mélange geologic terrains.

In the Mad River watershed, natural conditions (i.e., non-management land uses) contribute 36% of the sediment loading in the watershed. An estimated 64% of the total sediment delivered to streams was attributed to human and land management related activities (Table 18). Thus, the current sediment loading in the watershed averages 277% over the natural loading (2,474 tons/mi^2/yr total loading divided by 894 tons/mi^2/yr natural sediment loading). Management associated sediment delivery is highest in the Lower Mad/North Fork subarea, where total loading is currently nearly five times natural loading.

Table 19 shows the distribution of the suspended sediment load for the budget period. This will serve as a surrogate for the turbidity "load." This was determined by estimating the suspended sediment load as a proportion of total sediment load. Suspended sediment values are estimated at three monitoring sites: MRRTH (representing the Upper Mad subarea), MRBVR (representing the Middle Mad subarea), and MRHRB (representing the Lower Mad/North Fork subarea). Estimates of the bedload proportions of the total sediment loads are estimated as follows (Matthews, G., personal communication, 10/8/07, based on Lehre [1993], in Appendix A):

- MRRTH: 15%
- MRBVR: 10%
- MRHRB: 5%
- Basinwide: 10%

Thus, the suspended sediment load proportions for the Upper, Middle, and Lower subareas are 85%, 90%, and 95%, respectively, and 90% on a Basinwide basis (a drainage-area weighted average).

Table 18. Total Sediment Loading in the Entire Mad River Study Area (1976-2006)

Total Sediment	Upper Mad	Subarea	Middle Mad	Subarea	Lower/NF	Subarea	BASINWIDE	LOADING
Source (tons/mi^2/yr)		**% of total**		**% of total**		**% of total**		**% of total**
Current Loading								
Natural Landslides	17	7%	986	27%	4	0%	551	22%
Creep	81	35%	410	11%	278	20%	317	13%
Bank Erosion	46	20%	21	1%	24	2%	26	1%
Total Natural	**144**	**62%**	**1,417**	**38%**	**306**	**22%**	**894**	**36%**
Road-Related Landslides	47	20%	2,080	56%	501	36%	1,298	52%
Harvest-Related Landslides	3	1%	32	1%	72	5%	38	2%
Subtotal Landslides	**50**	**21%**	**2,112**	**57%**	**573**	**41%**	**1,336**	**54%**
Surface/Other Road Sources	39	17%	174	5%	514	37%	242	10%
Harvest Erosion	1	0%	2	0%	5	0%	2	0.1%
Subtotal Surface/Small Sources	**40**	**17%**	**176**	**5%**	**519**	**37%**	**244**	**10%**
Subtotal Roads	**86**	**37%**	**2,254**	**61%**	**1,015**	**73%**	**1,540**	**62%**
Subtotal Harvest	**4**	**2%**	**34**	**1%**	**77**	**6%**	**40**	**2%**
Total Management-Related	**90**	**38%**	**2,288**	**62%**	**1,092**	**78%**	**1,580**	**64%**
TOTAL	**234**	**100%**	**3,705**	**100%**	**1,398**	**100%**	**2,474**	**100%**
% natural	62%		38%		22%		36%	
% management	38%		62%		78%		64%	
Total Loading % over natural		162%		261%		457%		277%

Note: values have been rounded.

Table 19. <u>Suspended Sediment</u> Loading in the Entire Mad River Study Area (1976-2006)

Suspended Sediment	**Upper Mad**	**Subarea**	**Middle Mad**	**Subarea**	**Lower/NF**	**Subarea**	**BASINWIDE**	**LOADING**
Source (tons/mi^2/yr)		**% of total**		**% of total**		**% of total**		**% of total**
Proportion of total load:	85%		90%		95%		90%	
Current Loading								
Natural Landslides	14	7%	887	27%	4	0%	499	22%
Creep	69	35%	369	11%	264	20%	287	13%
Bank Erosion	39	20%	19	1%	23	2%	24	1%
Total Natural	**122**	**62%**	**1,275**	**38%**	**291**	**22%**	**809**	**36%**
Road-Related Landslides	40	20%	1,872	56%	476	36%	1,174	52%
Harvest-Related Landslides	3	1%	29	1%	68	5%	34	2%
Subtotal Landslides	**43**	**21%**	**1,901**	**57%**	**544**	**41%**	**1,209**	**54%**
Surface/Other Road Sources	33	17%	157	5%	488	37%	219	10%
Harvest Erosion	1	0%	2	0%	5	0%	2	0%
Subtotal Surface/Small Sources	**34**	**17%**	**158**	**5%**	**493**	**37%**	**221**	**10%**
Subtotal Roads	**73**	**37%**	**2,029**	**61%**	**964**	**73%**	**1,393**	**62%**
Subtotal Harvest	**3**	**2%**	**30**	**1%**	**73**	**6%**	**36**	**2%**
Total Management-Related	**76**	**38%**	**2,059**	**62%**	**1,037**	**78%**	**1,430**	**64%**
TOTAL	**199**	**100%**	**3,334**	**100%**	**1,328**	**100%**	**2,238**	**100%**
% natural	62%		38%		22%		36%	
% management	38%		62%		78%		64%	
Total Loading % over natural		162%		261%		457%		277%

Note: values have been rounded.

3.2. TMDLs AND ALLOCATIONS

3.2.1. Loading Capacity and TMDLs for Sediment and Turbidity

A TMDL is the total loading of a pollutant that the river can assimilate and still attain water quality standards. In these TMDLs, the pollutants are total sediment load and suspended sediment load (the pollutant that causes excess turbidity in the watershed). The pollutant loads are measured in mass per unit of time, as the average amount of sediment delivered from a unit area of the watershed (tons/mi^2/year), determined as a 15-year running average. This can also be expressed as a long-term, average daily maximum load (tons/day) by dividing the load by 365 days.

EPA is using a long-term, watershed-wide loading rate because sediment movement in streams is complex both spatially and temporally. Sediment found in some downstream locations can be the result of sediment sources far upstream. Instream sedimentation can also result from land management activities from days to decades in the past. Poor instream habitat (i.e., high percent fines, embeddedness, pool filling, and channel morphology changes) is associated with adverse affects on salmonids, and elevated sediment delivery rates are linked with the degradation of these instream factors. The approach to setting these TMDLs also assumes that salmon can be supported in streams with some fluctuations of erosion rates that have been observed in the 20th century (i.e., fluctuations that would occur with or without land management). Although sediment delivered to the streams has varied over time, salmon have adjusted to this variability by using the complex habitat created by the stream's response to these changing sediment loads.

Sediment is the pollutant for both the sediment and the turbidity TMDLs. Turbidity can be measured directly in the stream, but the pollutant causing the exceedence of the turbidity water quality standards in the Mad River watershed is fine sediment, or the suspended sediment load. The sediment and turbidity TMDLs are set equal to the loading capacity of the Mad River watershed. The TMDLs are the estimate of the total amount of sediment, from both natural and human-caused sources, that can be delivered to streams in the watershed without exceeding applicable water quality standards.

EPA is setting the TMDLs at 120 percent of natural sediment loading for this watershed. This approach to setting sediment TMDLs has been used in most of the watersheds in the North Coast of California. The approach focuses on sediment delivery, which can be influenced by direct management by landowners (e.g., roads can be appropriately designed and well-maintained). Instream indicators (e.g., pool depth, percent fines), which are broad measures of how close watershed conditions are to achieving the TMDLs (see Section 3.3), are subject to upstream management that may not be under the control of local landowners. While it would be desirable to mathematically model the relationship between salmon habitat and sediment delivery, these tools are not readily available for watersheds with landslides and road failure hazards.

EPA is using a method of setting the TMDLs and allocations similar to that employed in other basins (e.g., South Fork Eel, Noyo, Big, Albion Rivers, North Fork Eel, Middle Fork Eel, Upper Main Eel, and Middle Main Eel [USEPA, 1999a, 1999b, 2000, 2001a, 2002, 2003, 2004, and 2005]). It is based on the assumption that a certain amount of loading greater than what is natural is acceptable, and will still result in meeting water quality standards. Prior TMDL studies of the relationship between sediment loading rates and fish habitat effects found that many North Coast waters supported healthy fish habitat conditions during periods in which sediment loads were up to 125% of natural loading rates. For the Mad River TMDLs, EPA is setting the TMDLs more conservatively, at 120 percent of natural loading rates, in order to ensure that the turbidity water quality standard is met (i.e., that "turbidity shall not be increased more than 20 percent above naturally occurring background levels"). It is appropriate to set both the sediment TMDLs and the turbidity TMDLs (which are expressed as suspended sediment loading) similarly, since the relationships between fine sediment and turbidity in the watershed are very strong (see Section 3.1).

It is widely known that elevated turbidity in the Mad River basin is caused by elevated suspended sediment concentrations. In developing the source analysis, EPA found a very close correlation between turbidity and suspended sediment load. GMA (Appendix A) developed relationships at each of their monitoring stations and concluded that the Mad River's geologic character contributes to the strong relationships between suspended sediment and turbidity (R^2 averages 0.92, as shown in Table 7). Thus, if suspended sediment loads are reduced in the Mad

River, turbidity values will drop accordingly. Based on this close correlation, EPA is setting the turbidity TMDL and allocations in terms of suspended sediment loads. Suspended sediment is an appropriate surrogate for turbidity because although turbidity is related to water clarity, the pollutant causing the elevated turbidity levels in this watershed is suspended sediment.

The current suspended sediment load was estimated, and the proportion of the load that is the "naturally occurring background level" was estimated. With this information, the load that is 20 percent greater than the background suspended sediment load was determined, and the TMDLs are set to be consistent with the Regional Board's water quality objective for turbidity (i.e., that "turbidity shall not be increased more than 20 percent above naturally occurring background levels").

In developing the turbidity TMDLs, EPA estimated background values for suspended sediment loads as a surrogate for turbidity. EPA considered an alternative approach of determining the background turbidity levels based on turbidity values from reference streams (see discussion of Klein, 2003 and 2006, unpublished, in Sections 2.1 and 2.3). These values also would have been translated to suspended sediment loads. However, the data for those reference streams were based on small watersheds (less than 10 mi^2) and do not translate well to the much greater Mad River basin (480 mi^2). EPA determined that the reference stream data would be useful as an indicator for smaller subwatersheds within the Mad River basin, but that the most accurate method of determining the loading capacity and setting the TMDLs was to use the suspended sediment load. We also set TMDLs for each of the subareas in order to improve upon the accuracy and effectiveness of the TMDLs and their future implementation by the Regional Board.

Thus, EPA is using this sediment loading rate as the level that meets the water quality objectives in Table 2. The narrative objectives are set at levels that "shall not contain" sediment at levels that "adversely affect beneficial uses." Thus, the sediment loading that is not adverse to beneficial uses (i.e., the cold water uses related to salmon) and that will reduce the turbidity to no more than 20 percent above naturally occurring background levels is interpreted to be 120 percent of natural sediment loading. EPA is setting the loading capacity and TMDLs based on a calculation of 120 percent of natural loading.

While EPA is calculating the TMDLs based on the loading estimates for the entire period analyzed (representing the most accurate estimate of natural sediment loading), EPA expects progress toward the TMDLs to be evaluated in the future by estimating the total and suspended sediment loads (both natural and management-related) relative to the natural (non-management-related) loads. EPA recognizes that it is impractical for land managers to actually measure sediment loading on a daily basis. As noted in Table 18, natural sediment loading in the basin is calculated at 894 tons/mi^2/yr based on a 31-year average. Accordingly, the TMDLs are most appropriately expressed as an average annual load, and should be evaluated as a long-term (e.g., 15-year) running average, in order to account for natural fluctuations and inaccuracies in estimations of sediment loads. In order to express the TMDLs as a daily load, the average annual load can be divided by 365 days.

Lands belonging to the Blue Lake Indian Tribe are not subject to State water quality standards, so the TMDLs do not apply to them.

Basinwide

The sediment TMDL for all stream reaches is set equal to the sediment load that corresponds with 120% of natural sediment loading basinwide. The resulting sediment load is calculated as:

> **TMDL = Loading Capacity = 120% x (894 tons/mi^2/yr) = 1,073 tons/mi^2/yr, or 2.9 tons/mi^2/day, on a long-term (e.g., 15-year) running average**

Suspended sediment load, which is the portion of the sediment load that is directly responsible for the excess turbidity, comprises approximately 90% of the total sediment load basinwide (G. Matthews, personal communication, 10/8/07). The suspended sediment TMDL is similarly set at 120% of natural suspended sediment loading. The background suspended sediment load is determined by multiplying the background sediment load by the proportion of the load that is estimated to be suspended sediment. For example, in the Mad River watershed as a whole, the background sediment load is 894 tons/mi^2/yr. Background suspended sediment load is thus 90% of 894, or 809 tons/mi^2/yr.

The turbidity TMDL for all stream reaches is set equal to the suspended sediment load that corresponds with 120% of natural suspended sediment loading basinwide (note: basinwide suspended sediment is estimated as 90% of total sediment). The resulting suspended sediment load is calculated as:

> **TMDL = Loading Capacity = 120% x (809 tons/mi^2/yr) = 971 tons/mi^2/yr, or 2.7 tons/mi^2/day, on a long-term (e.g., 15-year) running average**

It is important to note that the suspended sediment loads set for the turbidity TMDLs are *subsets* of the sediment TMDL; they are *not additive*. In other words, the sediment TMDL basinwide is 1,073 tons/mi^2/yr, or 2.9 tons/mi^2/day. *Of that total sediment load*, 971 tons/mi^2/yr, or 2.7 tons/mi^2/day, is set as the suspended sediment load for the turbidity TMDL. This is true basinwide and for all subareas as well.

Subareas

Sediment loading varies greatly throughout the basin. Specifically, loading is relatively light in the Upper Mad subarea, very heavy in the Middle Mad subarea, and relatively heavy in the Lower/North Fork subarea (see Tables 18 and 19). Moreover, in the Lower/North Fork subarea, management loading as a proportion of total loading is extremely high, comprising 78% of the total load. It is apparent that achievement of water quality standards will be met most effectively by focusing sediment load reductions on the Middle Mad and Lower/North Fork subareas, and in particular, on reduction of road-related sediment in those two subareas. Because of these variations, EPA is setting TMDLs for each major subarea as well, also based on 120% of natural loading. This allows greater distinctions in setting loads by recognizing that natural loading is greater in some areas, and that management loading is greater in other areas. Obviously, natural sediment loading cannot easily be reduced, but management loading can be more readily reduced.

For the same reasons, EPA is also setting the turbidity TMDLs for each subarea (again, expressed as suspended sediment loads), also based on 120% of natural loading. Total existing suspended sediment loads by subareas are summarized in Table 19. Because the percent of total sediment that is suspended sediment varies among the three areas, different proportions are assigned to each area. Specifically, the suspended sediment load proportions for the Upper, Middle, and Lower subareas are 85%, 90%, and 95%, respectively.

Upper Mad Subarea

The sediment TMDL for all stream reaches for the Upper Mad subarea is set equal to the sediment load that corresponds with 120% of natural sediment loading in the Upper Mad subarea. The resulting sediment load is calculated as:

> **TMDL = Loading Capacity = 120% x (144 tons/mi^2/yr) = 173 tons/mi^2/yr, or 0.5 tons/mi^2/day, on a long-term (e.g., 15-year) running average**

The turbidity TMDL for the Upper Mad subarea is set equal to the suspended sediment load that corresponds with 120% of natural suspended sediment loading in the Upper Mad subarea (note: suspended sediment in the Upper Mad is estimated as 85% of total sediment). The resulting suspended sediment load is calculated as:

> **TMDL = Loading Capacity = 120% x (122 tons/mi^2/yr) = 147 tons/mi^2/yr, or 0.4 tons/mi^2/day, on a long-term (e.g., 15-year) running average**

Middle Mad Subarea

The sediment TMDL for all stream reaches for the Middle Mad subarea is set equal to the sediment load that corresponds with 120% of natural sediment loading in the Middle Mad subarea. The resulting sediment load is calculated as:

> **TMDL = Loading Capacity = 120% x (1,417 tons/mi^2/yr) = 1,700 tons/mi^2/yr, or 4.7 tons/mi^2/day, on a long-term (e.g., 15-year) running average**

The turbidity TMDL for the Middle Mad subarea is set equal to the suspended sediment load that corresponds with 120% of natural suspended sediment loading in the Middle

Mad subarea (note: suspended sediment in the Middle Mad is estimated as 90% of total sediment). The resulting suspended sediment load is calculated as:

> **TMDL = Loading Capacity = 120% x (1,275 tons/mi^2/yr) = 1,530 tons/mi^2/yr, or 4.2 tons/mi^2/day, on a long-term (e.g., 15-year) running average**

Lower/North Fork Mad Subarea

The sediment TMDL for all stream reaches for the Lower/North Fork Mad subarea is set equal to the sediment load that corresponds with 120% of natural sediment loading in the Lower/North Fork Mad subarea. The resulting sediment load is calculated as:

> **TMDL = Loading Capacity = 120% x (306 tons/mi^2/yr) = 367 tons/mi^2/yr, or 1.0 tons/mi^2/day, on a long-term (e.g., 15-year) running average**

The turbidity TMDL for the Lower/North Fork Mad subarea is set equal to the suspended sediment load that corresponds with 120% of natural suspended sediment loading in the Lower/North Fork Mad subarea (note: suspended sediment in the Lower/North Fork Mad is estimated as 95% of total sediment). The resulting suspended sediment load is calculated as:

> **TMDL = Loading Capacity = 120% x (291 tons/mi^2/yr) = 349 tons/mi^2/yr, or 1.0 tons/mi^2/day, on a long-term (e.g., 15-year) running average**

The TMDLs and allocations are discussed below and summarized in Tables 20 through 23.

3.2.2. Allocations

In accordance with EPA regulations, the loading capacity (i.e., TMDL) is allocated to the various sources of sediment in the watershed, with a margin of safety. That is, the TMDL is the sum of “load allocations” (LAs) for nonpoint and background sources, and the sum of the “wasteload allocations” (WLAs) for individual point sources. In the Mad River basin, individual point sources are negligible sources of sediment and suspended sediment. WLAs for diffuse, permitted point sources function similarly to and are represented by the nonpoint source LAs, and WLAs for permitted point sources are provided concentration-based WLAs equivalent to what is included in the permits, in order to account for incidental sediment and suspended sediment discharges, as described below.

Load Allocations

The load allocations for the Mad River sediment TMDLs are summarized in Table 20. The allocations clarify the relative emphasis and magnitude of erosion control programs that need to be developed during implementation planning. The load allocations are expressed in terms of yearly averages (tons/mi^2/yr) because sediment delivery to streams is highly variable on a daily and yearly basis. These annual averages were also divided by 365 to derive daily loading rates (tons/mi^2/day). EPA expects the load allocations to be evaluated on a 15-year rolling average, because of the natural variability in sediment delivery rates. In addition, EPA does not expect each square mile within a particular source category, or even within each subarea or subwatershed, to necessarily meet the load allocation; rather, EPA expects the watershed and subarea averages for the entire source category to meet the load allocation for that category.

The specific load allocations were based on 89 percent reductions in all management-related loading basinwide, including timber harvest and road-related sediment loadings. Because existing management-related sediment loading is so high in the watershed, dramatic cuts in sediment are necessary. Thus, the allocations are based on the assumption that the maximum possible reductions in non-natural sources of sediment will be made. Overall, the sediment load allocations reflect a total 57 percent reduction over the 1976-2006 time period, or an 89 percent reduction in human- and management-related sediment. Table 20 summarizes this.

Table 20. Total Sediment Load Allocations Summary for the Mad River Watershed

Sediment Source		**Average Annual**		**Average Daily**		**Percent Reduction over 1976-2006 Period**
		1976 – 2006 Loading (tons/mi^2/yr)	**Load Allocation (tons/mi^2/yr)**	**1976 – 2006 Loading (tons/mi^2/day)**	**Load Allocation (tons/mi^2/day)**	
Natural Load Allocation		**894**	**894**	**2.4**	**2.4**	**0%**
Road	Landslides	1,298				
	Surface	242				
Roads Subtotal		**1,540**	**174**	**4.2**	**0.5**	**89%**
Harvest	Landslides	38				
	Surface	2				
Harvest Subtotal		**40**	**5**	**0.1**	**0.01**	**89%**
Total Human-related Load		**1,580**	**179**	**4.3**	**0.5**	**89%**
Total Load: All Sources		**2,474**	**1,073**	**6.8**	**2.9**	**57%**

Note: values have been rounded.

Suspended sediment is estimated as a proportion of total sediment load, and the reductions for the suspended sediment load are shown in Table 21. The reductions reflect similar priorities as for the total sediment load.

Allocations by subareas area are shown in Tables 22 and 23 for sediment and suspended sediment loads, respectively. Although a 57% reduction basinwide is needed to achieve water quality standards as set by the TMDLs, smaller reductions are needed in the Upper Mad subarea (26%) and Middle Mad subarea (54%), and larger reductions (74%) are needed in the Lower Mad/North Fork. In the Upper Mad subarea, the reductions needed, while much smaller than in the other subareas, land management is less intense, with most of the roads on ridgetops, and relatively low densities of native-surface roads.

Table 21. Suspended Sediment Load Allocations Summary for the Mad River Watershed

Sediment Source		Average Annual		Average Daily		Percent Reduction over 1976-2006 Period
		1976 – 2006 Loading (tons/mi^2/yr)	Load Allocation (tons/mi^2/yr)	1976 – 2006 Loading (tons/mi^2/day)	Load Allocation (tons/mi^2/day)	
Natural Load Allocation		**809**	**809**	**2.2**	**2.2**	**0%**
Road	Landslides	1,174				
	Surface	219				
Roads Subtotal		**1,393**	**158**	**3.8**	**0.4**	**89%**
Harvest	Landslides	34				
	Surface	2				
Harvest Subtotal		**36**	**4**	**0.1**	**0.01**	**89%**
Total Human-related Load		**1,430**	**162**	**3.9**	**0.4**	**89%**
Total Load: All Sources		**2,238**	**971**	**6.1**	**2.7**	**57%**

Note: values have been rounded.

Basinwide, an average 89% reduction in management-related sediment delivery is necessary to achieve the TMDLs. Reductions in management-related loading that would be needed in each of the subareas to attain the TMDLs vary by subarea because the TMDLs and allocations are set at 120% of natural loading; natural loading varies by subarea. Thus, in the Upper Mad subarea, where the proportion of *management-related* total sediment and suspended sediment loading comprise a smaller proportion of *total* loading (38%) than in the other subareas (64% basinwide), total management-related reduction is 68%. By contrast, in the Lower Mad/North Fork subarea, the proportion of management-related loading is 78% of total loading, and natural loading comprises only 22%. Thus, a 94% reduction in management-related sediment is necessary in the Lower Mad/North Fork subarea to achieve the TMDL and allocations. Most of the load reductions would be needed from road-related sediment.

The Regional Board may wish to refine these TMDLs and allocations further in the future. Data are available in Appendix A for 39 subwatersheds, and other organizations may develop additional data in the future to refine or improve upon the current data. For example, the Regional Board may want to focus initial efforts at data refinement on the larger subwatersheds, such as the North Fork Mad River (49 mi^2), Pilot Creek (40 mi^2), Lost Creek (26 mi^2), and Powers Creek (21 mi^2). These and some other subwatersheds are large enough that the combination of historical sediment delivery to the streams, land use, geology, slope and microclimate may be unique in these areas, and setting individual TMDLs, or simply developing focused implementation efforts, may be the most effective method of achieving water quality standards, both within individual subwatersheds and in the basin as a whole.

Table 22. Total Sediment Load Allocations Summary by Subareas

SUMMARY OF CURRENT TOTAL SEDIMENT LOADING AND TMDL/ALLOCATIONS (tons/mi^2/year, tons/mi^2/day)									
							Annual Load	Daily Load	
Source (tons/mi^2/yr)	Upper	% of total	Middle	% of total	Lower/NF	% of total	BASINWIDE	BASINWIDE	% of total
							t/mi^2/year	t/mi^2/day	
Current Loading									
Natural Landslides	17	7%	986	27%	4	0%	551	1.5	22%
Creep	81	35%	410	11%	278	20%	317	0.9	13%
Bank Erosion	46	20%	21	1%	24	2%	26	0.1	1%
Total Natural	**144**	**62%**	**1,417**	**38%**	**306**	**22%**	**894**	**2.4**	**36%**
Road-Related Landslides	47	20%	2,080	56%	501	36%	1,298	3.6	52%
Harvest-Related Landslides	3	1%	32	1%	72	5%	38	0.1	2%
Subtotal Landslides	**50**	**21%**	**2,112**	**57%**	**573**	**41%**	**1,336**	**3.7**	**54%**
Surface/Other Road Sources	39	17%	174	5%	514	37%	242	0.7	10%
Harvest Erosion	1	0%	2	0%	5	0%	2	0.0	0.1%
Subtotal Surface/Small Sources	**40**	**17%**	**176**	**5%**	**519**	**37%**	**244**	**0.7**	**10%**
Subtotal Roads	**86**	**37%**	**2,254**	**61%**	**1,015**	**73%**	**1,540**	**4.2**	**62%**
Subtotal Harvest	**4**	**2%**	**34**	**1%**	**77**	**6%**	**40**	**0.1**	**2%**
Total Management-Related	**90**	**38%**	**2,288**	**62%**	**1,092**	**78%**	**1,580**	**4.3**	**64%**
TOTAL	**234**	**100%**	**3,705**	**100%**	**1,398**	**100%**	**2,474**	**6.8**	**100%**
% natural	62%		38%		22%		36%		
% management	38%		62%		78%		64%		
TMDL/ Allocations =120% of natural	**Annual Load**	**Daily Load**	**Annual Load**	**Daily Load**	**Annual Load**	**Daily Load**	**Annual Load**	**Daily Load**	**Reduction**
TMDL	**173**	**0.5**	**1,700**	**4.7**	**367**	**1.0**	**1,073**	**2.9**	57%
Total Natural	144	0.4	1,417	3.9	306	0.8	894	2.4	0%
Total Management	**29**	**0.1**	**283**	**0.8**	**61**	**0.2**	**179**	**0.5**	89%
Landslides	16	0.04	262	0.7	32	0.09	151	0.4	89%
Roads/Harvest Surface	13	0.0	22	0.1	29	0.1	28	0.1	89%
Management-Roads	**28**	**0.1**	**279**	**0.8**	**57**	**0.2**	**174**	**0.5**	89%
Management-Harvest	**1**	**0.00**	**4**	**0.01**	**4**	**0.01**	**5**	**0.01**	89%
% natural	83%		83%		83%		83%		
% management	17%		17%		17%		17%		
Total Reduction	26%		54%		74%		57%		
Management Reduction	68%		88%		94%		89%		
Roads Reduction	68%		88%		94%		89%		
Harvest Reduction	68%		88%		94%		89%		
area (sq mi)	84		266		130		480		
total TMDL (tons/yr)	14,515		452,306		47,736		514,944		

Note: figures have been rounded.

Table 23. Suspended Sediment Load Allocations Summary by Subareas

SUMMARY OF CURRENT TOTAL SUSPENDED SEDIMENT LOADING AND TMDL/ALLOCATIONS (tons/mi^2/year, tons/mi^2/day)									
							Annual Load	Daily Load	
Source (tons/mi^2/yr)	**Upper**	**% of total**	**Middle**	**% of total**	**Lower/NF**	**% of total**	**BASINWIDE**	**BASINWIDE**	**% of total**
							t/mi^2/year	**t/mi^2/day**	
Suspended Load Portion:	85%		90%		95%		90%		
Current Loading									
Natural Landslides	14	7%	887	27%	4	0%	499	1.4	22%
Creep	69	35%	369	11%	264	20%	287	0.8	13%
Bank Erosion	39	20%	19	1%	23	2%	24	0.1	1%
Total Natural	**122**	**62%**	**1,275**	**38%**	**291**	**22%**	**809**	**2.2**	**36%**
Road-Related Landslides	40	20%	1,872	56%	476	36%	1,174	3.2	52%
Harvest-Related Landslides	3	1%	29	1%	68	5%	34	0.1	2%
Subtotal Landslides	**43**	**21%**	**1,901**	**57%**	**544**	**41%**	**1,209**	**3.3**	**54%**
Surface/Other Road Sources	33	17%	157	5%	488	37%	219	0.6	10%
Harvest Erosion	1	0%	2	0%	5	0%	2	0.0	0%
Subtotal Surface/Small Sources	**34**	**17%**	**158**	**5%**	**493**	**37%**	**221**	**0.6**	**10%**
Subtotal Roads	**73**	**37%**	**2,029**	**61%**	**964**	**73%**	**1,393**	**3.8**	**62%**
Subtotal Harvest	**3**	**2%**	**30**	**1%**	**73**	**6%**	**36**	**0.1**	**2%**
Total Management-Related	**76**	**38%**	**2,059**	**62%**	**1,037**	**78%**	**1,430**	**3.9**	**64%**
TOTAL	**199**	**100%**	**3,334**	**100%**	**1,328**	**100%**	**2,238**	**6.1**	**100%**
% natural	62%		38%		22%		36%		
% management	38%		62%		78%		64%		
TMDL/ Allocations =120% of natural	**Annual Load**	**Daily Load**	**Annual Load**	**Daily Load**	**Annual Load**	**Daily Load**	**Annual Load**	**Daily Load**	**Reduction**
TMDL	**147**	**0.4**	**1,530**	**4.2**	**349**	**1.0**	**971**	**2.7**	**57%**
Total Natural	122	0.3	1,275	3.5	291	0.8	809	2.2	0%
Total Management	**24**	**0.1**	**255**	**0.7**	**58**	**0.2**	**162**	**0.4**	**89%**
Landslides	14	0.04	235	0.6	31	0.08	137	0.4	89%
Roads/Harvest Surface	11	0.0	20	0.1	28	0.1	25	0.1	89%
Management-Roads	**23**	**0.1**	**251**	**0.7**	**54**	**0.1**	**158**	**0.4**	89%
Management-Harvest	**1**	**0.00**	**4**	**0.01**	**4**	**0.01**	**4**	**0.01**	89%
% natural	83%		83%		83%		83%		
% management	17%		17%		17%		17%		
Total Reduction	26%		54%		74%		57%		
Management Reduction	68%		88%		94%		89%		
Roads Reduction	68%		88%		94%		89%		
Harvest Reduction	68%		88%		94%		89%		
area (sq mi)	84		266		130		480		
total TMDL (tons/yr)	12,338		407,076		45,349		465,916		

Note: figures have been rounded

Wasteload Allocations

Although nonpoint sources are responsible for nearly all sediment loading in the watershed, point sources may also discharge some sediment in the watershed. Current and potential future point sources subject to National Pollutant Discharge Elimination System (NPDES) permitting that may discharge sediment in the watershed and are therefore at issue in these TMDLs include both stormwater (e.g., municipal and construction sites) and non-stormwater discharges:

Diffuse discharges subject to General National Pollutant Discharge Elimination System (NPDES) permits:

- California Department of Transportation (CalTrans) facilities that discharge pursuant to the CalTrans statewide NPDES permit issued by the State Water Resources Control Board,
- Construction sites larger than 1 acre that discharge pursuant to California's NPDES general permit for construction site runoff,
- Facilities permitted under the NPDES Industrial stormwater program,
- The Korbel Sawmill Complex, and
- The City of McKinleyville Municipal Storm Water Permit.

Wastewater Treatment Plants (WWTPs) and other pipe-end point sources subject to an individual NPDES permit:

- McKinleyville WWTP
- Blue Lake WWTP
- Mad River Fish Hatchery

To ensure protection of the cold water beneficial use, EPA has determined that it is appropriate to consider the rates set forth in these TMDLs as load allocations to also represent wasteload allocations for the *diffuse* discharges in the watershed that are subject to NPDES permits, as discussed below.

These TMDLs identify wasteload allocations for diffuse point sources and load allocations for nonpoint sources as pollutant loading rates (tons/mi^2/yr) for the Mad River basin Table 22 and Table 23). The source analysis supporting these allocations evaluated sediment loading at a subwatershed scale, and did not attempt to distinguish sediment loading at the scale of specific land ownerships. Nor did the source analysis specifically distinguish between land areas subject to NPDES regulation and land areas not subject to NPDES regulation. Therefore, **the TMDLs include separate but identical load allocations (LAs) for nonpoint sources and wasteload allocations (WLAs) for the diffuse point sources for each subarea.** These WLAs are equivalent to and represented by the LAs, and the LAs are expressed on a unit loading basis (tons/mi2/year); therefore, they are *not added to the LAs* in the TMDL equation. (See USEPA 2001b for additional information concerning the WLAs.)

For the diffuse permitted sources identified above, the waste load allocation (WLA) is expressed as equivalent to the load allocation (LA) for roads.

For the McKinleyville WWTP and the Mad River Fish Hatchery, discharges generally should not include sediment. The NPDES permits for these facilities include concentration-based limits for TSS (total suspended solids) and SeS (settleable solids), which address, in addition to organic discharges, any incidental colloidal discharges. The Blue Lake WWTP NPDES permit does not allow discharges to surface waters.

For the current and future WWTPs and other individual point sources, the WLAs are expressed as follows:

McKinleyville:	**TSS 95 mg/l; SeS 0.1 mg/l**
Mad River Fish Hatchery:	**TSS 8 mg/l; SeS 0.1 mg/l**

The WLAs for turbidity for these permitted, pipe-end discharges is expressed as: "no net increases in turbidity in receiving water greater than 20 percent over naturally occurring background level."

In these TMDLs, while some sediment sources are currently considered to be nonpoint sources, future investigations may result in one or more of these nonpoint sources being identified as point sources, subject to NPDES permitting requirements; therefore, the corresponding load allocations would later become waste load allocations.

3.3. WATER QUALITY INDICATORS AND TARGETS

Indicators and targets can be used to represent attainment of water quality standards. This section identifies numeric water quality indicators and targets specific to the Mad River watershed. For each indicator, a numeric or qualitative target value is identified to define the desired condition for that indicator.

Attainment of the targets is intended to be evaluated using a weight-of-evidence approach, because no single indicator applies at all points in the stream system, and stream channel conditions are inherently variable. In other words, when considered together, the indicators are expected to provide good evidence of the condition of the stream and attainment of water quality standards.

Instream indicators reflect sediment conditions that support healthy salmonid habitat. They relate to instream sediment supply and deposition, and are important because they are direct measures of stream "health." In addition to instream indicators, previous TMDLs included watershed indicators such as targets for stream crossing failures. However, EPA is not setting watershed indicators in these TMDLs because the Regional Board's more recent review of habitat targets does not include watershed indicators (NCRWQCB 2006). In addition, the Mad River watershed is making progress toward the overall TMDL goal and instream indicators are more readily measured, so continued progress can be evaluated more regularly.

3.3.1. Summary of Indicators and Targets

Table 24 sets forth the indicators along with their target, description, and purpose. The background on these indicators is contained in the Regional Board's "Desired Salmonid Freshwater Habitat Conditions for Sediment-related Indices" (NCRWQCB 2006) that has been developed as part of the basin planning process. EPA notes that the Regional Board's guidance document is intended to be updated as scientific information becomes available. Details on the applicability to different sizes and types of streams, along with monitoring notes, sampling notes, and background literature, are available in that document. EPA expects that future monitoring of these indicators will provide additional information to assess whether the water quality standards are being attained and whether the TMDLs are effective in meeting water quality standards.

Table 24. Sediment and Turbidity Indicators and Targets

INDICATOR	TARGET	PURPOSE
Instream		
Substrate Composition - Percent fines	<14% < 0.85 mm ≤30% < 6.4 mm	Indirect measure of fine sediment content relative to incubation and fry emergence from the redd. Indirect measure of ability of salmonids to construct redds
Turbidity and Suspended Sediment	Turbidity ≤ 20% above naturally occurring background (also included in Basin Plan)	Indirect measure of fish feeding/growth ability related to sediment, and impacts from management activities
Riffle Embeddedness	≤25% or improving (decreasing) trend toward 25%	Indirect measure of spawning support; improved quality & size distribution of spawning gravel
V*	≤0.21	Estimate of sediment filling of pools from disturbance
Macroinvertebrate community composition	Improving trends	Estimate of salmonid food availability, indirect estimate of sediment quality.
Thalweg profile	Increasing variation from the mean	Estimate of improving habitat complexity & availability
Pools	Increasing trend in the number of backwater, lateral scour pools. Increasing trend in the number of stream reaches where the length of the reach is composed of ≥40% in primary pools	Estimates improving habitat availability

3.3.2. Turbidity Indicators for Basins Less than 10 mi^2

GMA (Appendix A) compared turbidity at undisturbed reference sites with data from Klein (2006, unpublished, in Appendix A) with data from Mad River study sites, and developed exceedence probability curves for both the reference watersheds and the Mad River sites (Table 11). GMA determined that the 1% exceedence probability (the turbidity, associated with flow, that is exceeded only 1% of the time), which represents acute conditions (i.e., large floods), is 22

FNU; the 10% exceedence probability, representing chronic (long-term) conditions, is 5 FNU. Thus, an indicator of 20 percent over background is 26 FNU for the 1% exceedence probability and 6 FNU for the 10% exceedence probability. Because the reference watersheds are very small (2-8 mi^2), it is difficult to apply these indicators throughout the watershed, but they are appropriate indicators for the smaller subwatersheds. Thus, these indicators are suggested for subwatersheds that are less than 10 mi^2 in size.

3.4. MARGIN OF SAFETY

The margin of safety is included in a TMDL to account for uncertainties concerning the relationship between pollutant loads and instream water quality and other uncertainties in the analysis. The margin of safety can be incorporated into conservative assumptions used to develop the TMDL, or added as an explicit, separate component of the TMDL. These TMDLs incorporate a margin of safety through use of conservative assumptions.

EPA is setting the TMDLs at 120% of natural sediment loading for this watershed. A similar approach to setting sediment TMDLs has been used in most of the watersheds in the North Coast of California. EPA is using a method of setting the TMDLs and allocations similar to that employed in other basins (e.g., South Fork Eel, Noyo, Big, Albion Rivers, North Fork Eel, Middle Fork Eel, Upper Main Eel, and Middle Main Eel [USEPA, 1999a, 1999b, 2000, 2001a, 2002, 2003, 2004, and 2005]). It is based on the assumption that a certain amount of loading greater than what is natural is acceptable, and will still result in meeting water quality standards. Prior TMDL studies of the relationship between sediment loading rates and fish habitat effects found that many North Coast waters supported healthy fish habitat conditions during periods in which sediment loads were up to 125% of natural loading rates. These TMDLs are set more conservatively, at 120% of natural sediment loading. It is likely that setting the TMDLs at 125% of natural loading rates would adequately achieve water quality standards, but EPA is setting these TMDLs more conservatively in order to ensure that the turbidity standard (i.e., that turbidity should not be increased greater than 20% over naturally occurring background rates) is met. The difference between setting the TMDLs at 125% and setting the TMDLs at 120% can also be considered a Margin of Safety for the sediment TMDLs. Basinwide, this can be calculated as the difference between 125% of background loading (1,099 tons/mi^2/yr basinwide) and 120% of background loading (1,055 tons/mi^2/year), or 44 tons/mi^2/year total sediment loading, including 40 tons/mi^2/year suspended sediment loading, that is explicitly reserved as a Margin of Safety.

There is also uncertainty concerning the interpretation of the amount of sediment delivery associated with management activities versus natural background sources, as discussed in the various sections. Conservative assumptions were used throughout the sediment source analysis. These are discussed in each of the sections. For example, although the road-related surface erosion estimates were revised downward for the Final TMDLs (from their values in the Draft TMDLs), it is possible that the models used to develop them still slightly overestimate the road-related sediment estimate. By overestimating this value, the TMDLs are calculated as needing a slightly greater reduction than they would if the values were underestimated. In addition, the reductions of 89% over current management loading are substantial: these are the greatest reductions in sediment loading that have been calculated to date. While it is clear that sediment loading in the Mad River basin needs to be reduced, it is possible that these reductions are greater than would actually be required. These conservative assumptions are considered collectively to represent an implicit Margin of Safety.

Because the sediment TMDLs are calculated based on the amount of natural loading, these assumptions result in a more conservative TMDL calculation.

3.5. SEASONAL VARIATION AND CRITICAL CONDITIONS

The TMDLs must describe how seasonal variations were considered. Sediment delivery in the Mad River watershed has considerable annual and seasonal variability. The magnitudes, timing, duration, and frequencies of sediment delivery fluctuate naturally depending on intra- and inter-annual storm patterns. The analysis accounted for this seasonal and yearly variability by calculating the sediment delivery over the recent long term (1976 - 2006). This accounts for both the seasonal variation (winter producing the most sediment) and the critical conditions (large storms producing a large percentage of sediment). Adverse effects on instream conditions and salmonid habitat are the result of the accumulation of sediment, including the impacts from infrequent and large storms. Thus, EPA recommends that these TMDLs be evaluated on a 15-year rolling average or longer-term average that accounts for the influence of large storms.

CHAPTER 4: IMPLEMENTATION AND MONITORING RECOMMENDATIONS

The main responsibility for water quality management and monitoring resides with the State. EPA fully expects the State to develop implementation measures as part of revisions to the State water quality management plan, as provided by EPA regulations at 40 C.F.R. Sec. 130.6. The State implementation measures should contain provisions for ensuring that the allocations in the TMDLs will in fact be achieved. These provisions may be non-regulatory, regulatory, or incentive-based, consistent with applicable laws and programs, including the State's recently upgraded nonpoint source control program.

Protection of Anadromous Salmonids, Western Snowy Plover, or other Threatened or Endangered Species

The Regional Board may wish to focus on the fish-producing tributaries to the Mad River: Lindsay Creek, North Fork Mad River, Canon Creek, Maple Creek, and Pilot Creek (Trinity Associates and HBMWD 2004). In fact, given the fragile status of some salmonid species, it may be prudent to prioritize subwatersheds on that basis. NMFS assigns a recovery priority number to each listed species. This number is based on the magnitude of threat, recovery potential, and the presence of conflict between the species and development or economic activities. There are twelve recovery priority numbers, with one being the highest priority and 12 being the lowest (50CFR 17: Vol. 71 FR pp 24296-24298, June 15, 1990). NMFS has assigned Recovery Priority Numbers to the salmonid populations found in this watershed: the highest priority (1) to coho, based on a high magnitude threat and high potential recovery; recovery priority number of 3 to Chinook, based on a high magnitude threat and low-moderate recovery potential, and a recovery priority number of 5 to steelhead, based on a moderate degree of threat and high recovery potential (NMFS, 2007). Recovery outlines for steelhead and Chinook were recently published. NMFS has identified a number of priority recovery actions, including:

- working toward improvements to California's Forest Practice Rules;
- improving freshwater habitat;
- improving agricultural and forestry practices, city and county planning, particularly for riparian protections, grading ordinances, road construction and maintenance;
- appropriate screening of water diversions;
- identification and improvements to wastewater treatment programs, including septic systems;
- removing artificial barriers; and
- improvements in hatchery programs; and additional research on distribution, status, and trends.

Some of the specific programs that are underway include: working with the Five Counties Roads Program and State Board of Forestry; implementing the Fish Friendly Farming program; and coordination on programs such as gravel management plans, General Plan updates, grading ordinances, and riparian ordinances (NMFS, 2007).

EPA strongly urges that the habitat needs of the species listed under the Endangered Species Act (ESA) found in the watershed (Chinook, coho and steelhead, listed by NMFS, and the western snowy plover, listed by USFWS) be considered when developing implementation plans—including restoration plans, even if undertaken parallel to, but not a direct result of, TMDL implementation.

EPA expects that these TMDLs are likely to benefit the listed salmonid species, and we likewise anticipate that implementation of the TMDLs will do no harm to either the listed salmonids or the FWS-listed western snowy plover. The TMDLs' "Fish Population and Endangered Species Concerns" analysis (Chapter 1), allocations, and targets (Chapter 3) are based on habitat requirements for salmonids, and they do not address the habitat requirements of the FWS-listed species. In its comments on the draft TMDLs, FWS stated that attainment of the TMDL targets will not affect, or may also be beneficial, for the habitat requirements the western snowy plover. EPA agrees with that statement. However, as noted by FWS in its comments, some activities, like gravel bar removal, tide gate replacements, tributary channel and estuarine habitat modification undertaken independently of TMDL implementation or to achieve watershed restoration or TMDL goals, could impact them (Long, M., U.S. Fish and Wildlife Service, 2007). Therefore, EPA recommends that any potential impact on this species be considered in any future restoration or implementation activities.

Existing Data Collection or Watershed Planning Efforts

An existing, active watershed management group has begun to undertake the tasks of watershed management in the Mad River Basin. They are currently operating through the Redwood Community Action Agency (RCAA), and are funded, in part, by a grant from the State Water Resources Control Board. This presents an excellent opportunity to make use of the information collected for these TMDLs. Moreover, many seasoned watershed management professionals as well as dedicated and knowledgeable non-professionals live in or near the Mad River watershed. The information for these TMDLs can be put to good use by these groups; the data can be refined or expanded, and additional questions that are not addressed by these TMDLs (for example, temperature conditions, which are influenced in part by sediment conditions) can be addressed in the future. Ongoing data collection efforts by HBMWD and Blue Lake Rancheria should be utilized and coordinated with the watershed management group in order to maximize utility of the data and minimize effort. EPA would like to encourage any future efforts to implement the requirements of these TMDLs, to coordinate with other resource restoration efforts of NMFS and USFWS, and to improve upon the information contained within TMDLs and implementation programs.

Some subwatersheds—Pilot Creek, for example—have the advantage of broader data collection and analysis from the Forest Service through their watershed analysis process (USDA Forest Service 1994). The Forest Service has also expressed a desire that TMDLs reflect the management programs that have been implemented by that agency as well as the more detailed data that has been collected on Forest Service lands. For example, Forest Service ownership accounts for most of the Pilot Creek subwatershed, and management in that subwatershed is much less intensive than on similar lands in private timber-production ownership (T. Kelley, 2007). While investigations at the subwatershed level are left to the initiative of the Regional Water Board and the Forest Service, EPA encourages the agencies to work together to improve upon the information provided here, in order to implement the most effective strategy to attain water quality standards.

Gravel Mining

Gravel mining can adversely affect both FWS and NMFS-listed species, and should be addressed in implementation plans. The County of Humboldt Extraction Review Team (CHERT) has conducted extensive analyses focused on historic and current channel conditions in the Mad River. Humboldt County Planning Department is currently developing a Supplemental Program Environmental Impact Report (PEIR) to address an adaptive management strategy based on mean annual gravel recruitment.

Development of Additional Information, Prioritization of Implementation Efforts

For the sediment and turbidity TMDLs, EPA specifically recommends that more instream sediment information be gathered throughout the basin. EPA also suggests that the State consider additional review and revision, if necessary, of the sediment source analysis, and consider using the information developed from it in setting priorities for any new sediment reduction programs in the watershed. Given the large sediment reductions needed to attain the allocations in the TMDLs, EPA recommends that the Regional Board supplement the information on turbidity and the relationships between turbidity and fine sediment collected and analyzed for these TMDLs.

It is possible that the Regional Board may wish to refine these TMDLs and allocations further. Data are available in Appendix A for 39 subwatersheds, and additional data may be developed in the future to refine or improve upon the data. For example, the Regional Board may wish to focus initial efforts at data refinement on the larger subwatersheds, such as the North Fork Mad River (49 mi^2), Pilot Creek (40 mi^2), Lost Creek (26 mi^2), and Powers Creek (21 mi^2). These and some other subwatersheds are large enough that the combination of historical sediment delivery to the streams, land use, geology, slope and microclimate may be unique in these areas, and setting individual TMDLs, or simply developing focused implementation efforts, may be the most effective method of achieving water quality standards, both within individual subwatersheds and in the basin as a whole. In addition, Pilot Creek is an example of a watershed that is largely managed by the USFS, which may provide unique opportunities for effective implementation.

The Regional Water Board may adopt and implement these TMDLs as they are, or may choose to revise and improve the TMDLs if additional information becomes available, subject to EPA approval. Moreover, the Regional Water Board may choose to develop and implement TMDLs on a subwatershed basis if appropriate, also subject to EPA approval.

EPA also encourages the Regional Board to use the information developed from the sediment source analysis in setting priorities for any new sediment reduction programs. The Regional Board is currently investigating how to set priorities in addressing sediment waste discharges on a watershed scale, and recently released a Public Review Draft “Work Plan To Control Excess Sediment In Sediment-Impaired Watersheds” (NCRWQCB, 2007b). EPA recommends that the Regional Board consider the relative progress and threats of different watersheds when setting priorities. Landslides are the dominant process that produces sediment, and reducing this risk may be the most cost-effective approach.

EPA recommends that the Regional Board consider the relative progress and threats of different watersheds when setting priorities. For example, given the extremely small population size of the endangered coho salmon and NMFS' priority status for the species, the Regional Board should consider assigning a high priority to sediment-reduction schemes in those watersheds with viable coho populations. In addition, because roads are the dominant source of sediment in the watershed, improving road conditions and maintenance may be the most cost-effective approach. EPA recommends that the Regional Board continue with their practice of taking into account site-specific conditions during implementation. This is consistent with the Regional Board's action plans for the Scott and Salmon River temperature TMDLs.

Subwatershed Information

These TMDLs and the appendix contain information on a subwatershed basis, much of it aggregated into four major subareas: the Upper Mad (Ruth HSA), the Middle Mad (Butler Valley HSA), Lower Mad (Blue Lake HSA), and the North Fork (North Fork HSA). Much of the information can facilitate a focused geographical approach to sediment reduction, in order to make the most effective improvements with limited resources. For example, the Upper Mad River subarea, in general, does not produce much sediment relative to the other areas, whereas the Middle Mad River subarea produces, by far, the greatest sediment relative to the rest of the watershed. This has been true for decades, and is a result of active geology combined with active management in the area. The Middle Mad River subarea is also where much of the commercial timber harvesting activities can be found. The Lower Mad/North Fork subarea produces the greatest proportion of management-related sediment.

Improvements to Roads Data

Given that roads are responsible for the vast majority of the sediment in the watershed (directly, from surface erosion, and, indirectly, by triggering landslides) a good first step can be made by focusing on reducing sediment from roads in the middle and lower portions of the watershed. Road densities, which are usually associated with sediment production, are highest in the Lower/North Fork subarea. Reducing road-related sediment in that subarea should be made a high priority.

Improving information on the roads may be a good first step toward reducing sediment. In verifying the roads information, it may be possible to identify more specifically where more sediment is being delivered and road segments or road-associated landslides may be more readily corrected. The WEPP model used to predict road and timber harvest surface erosion has a wide range of error, and, while the final TMDLs include improved estimates, refining the information further in the future can also improve the effectiveness of sediment reduction efforts.

Refined Sediment Source Analysis

It may also be helpful, when developing revised or improved data for WEPP, that NetMap might be further developed and utilized to provide a refined sediment budget that may also more clearly identify priority areas for watershed improvement efforts. NetMap can be used to model sediment budgets based on design flows: for example, one with 2-year recurrence interval, which would be expected to occur at least once in many average years, versus a larger flood with a 25-year recurrence interval. This would be a fairly large flood. NetMap can identify sediment storage areas, and the GIS tools can overlay the data with information on the range of various salmonids, for example. The Regional Water Board, US Forest Service, or a watershed group may be interested in pursuing the use of this tool.

Timber Harvest Planning

The State may also consider revisiting the timber harvest review process. Harvest-related landslides are most prevalent in the Middle Mad subarea, and it may be that these are related to landslides triggered on unstable geology, including inner gorge areas. For example, in the Middle Mad subarea, which currently produces the greatest quantity of sediment in the Mad River watershed, there may be areas of greater risk of catastrophic failure from timber harvest or other management activities along inner gorge areas in unstable geology (P. Higgins, personal communication, 2007).

CHAPTER 5: PUBLIC PARTICIPATION

EPA initiated public participation in the summer of 2006, contacting major landowners and professionals who have an interest in or knowledge of the watershed, as well as a list of persons identified by the Regional Board with an interest in North Coast sediment issues. A mailing list was maintained during the period of the TMDL development. An initial, introductory meeting was held on July 11, 2006.

EPA provided public notice of the draft Mad River Turbidity and Sediment TMDLs by placing a notice in the Eureka Times-Standard, papers of general circulation in Humboldt and Trinity Counties. The public notice regarding availability of the draft Mad River TMDLs was posted on EPA's web site, along with the document and associated appendices. The public notice was also mailed or emailed to additional parties.

A public meeting on the draft TMDLs was held from 7-8:30 pm October 22, 2007 at the Six Rivers National Forest conference room in Eureka, California. EPA considered all written comments that were received during the public comment period, which ran from October 17-November 16, 2007. EPA revised the TMDLs as appropriate, and prepared a responsiveness summary that addresses the comments received.

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