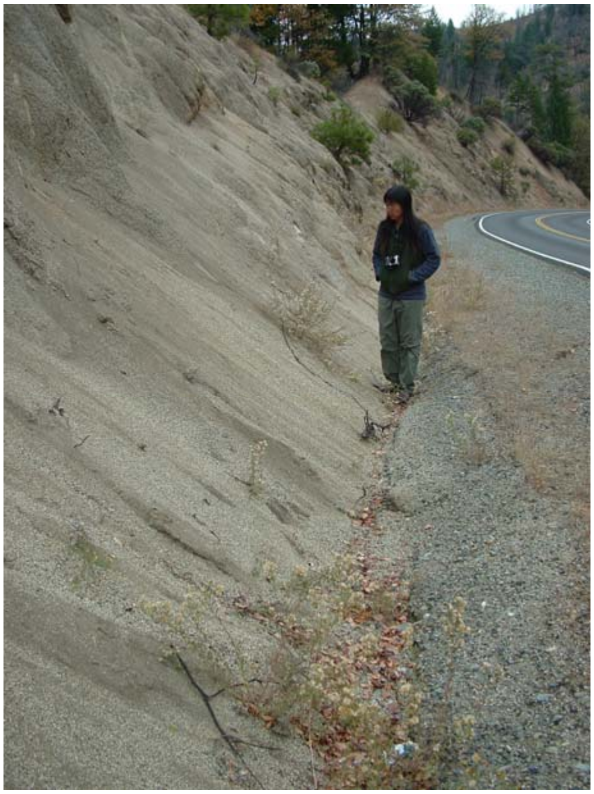
A Report in fulfillment of the Trinity River Restoration Project Agreement # 04AA202062.

A Strategy to Reduce Fine Sediment from Tributaries in the Trinity River Basin

By Mary Ann Madej



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Contents

Figures

Tables

Part 1. A Strategy to Reduce Fine Sediment from Tributaries in the Trinity River Basin

By Mary Ann Madej

Executive Summary

This strategy outlines steps to identify the major sources of fine bedload sediment (0.5 to 8 mm in diameter) originating from tributary basins in the Upper Middle Trinity River watershed. The strategy is based upon a sediment budget approach with the incorporation of soil particle size data and slope stability modeling. The strategy builds upon previous studies on geology, hydrology, soils and roads analyses in the project area. Possible restoration techniques are presented and protocols for monitoring effectiveness of restoration actions are suggested. A bibliography of pertinent literature on watershed assessment, restoration and monitoring is included. The production of fine sediment from tributaries is assessed on a subwatershed scale, using Rush Creek as an example, as well as from the perspective of the Upper Middle Trinity River watershed.

Introduction

The purpose of developing a Fine Sediment Control Strategy is to identify and suggest remediation for sources of fine sediment to the mainstem Trinity River from tributary basins located between Lewiston Dam and the North Fork Trinity River (Figure 1). Major tributaries in this reach are: Deadwood Creek, Hoadley Gulch, Grass Valley, Reading, Indian, Rush, Weaver and Browns Creeks. This strategy outlines a plan for the Trinity River Restoration Program (TRRP) to “address the problems of excessive sediment input from many tributaries of the Trinity River resulting from land use practices” as stated in the Record of Decision (ROD) within a science-based, adaptive management framework. The overall sediment management goals of the Trinity River Restoration Program are to: 1) reduce delivery of fine bedload sediment (0.5 to 8 mm in size) and oversized sediment (> 153 mm in size); and 2) to encourage continued delivery of coarse sediment (8 mm to 153 mm in size). An additional goal is to comply with the sediment Total Maximum Daily Load (TMDL) objective of reducing sediment delivery to 125% above background.

The Trinity River is the largest tributary to the Klamath River, draining an area of about 3000 square miles. The terrain is mostly steep, mountainous and forested. Major land use activities have been mining and timber harvest, with associated ground disturbance and road construction. Small towns have clusters of residential development, and recreation involves water activities on the reservoirs and in the rivers, hiking, fishing, and hunting. In the early 1960's the Trinity and Lewiston dams were constructed, which have had major influences on the hydrologic and sediment transport regimes of the Trinity River. In 2001 the Environmental Protection Agency established a Trinity River Total Maximum Daily Load (TMDL) for Sediment in accordance with Section 303(d) of the Clean Water Act. The TMDL lists several subwatersheds in the Upper Middle Assessment Area, including the major tributaries listed above, which will be the initial focus of the sediment reduction work.

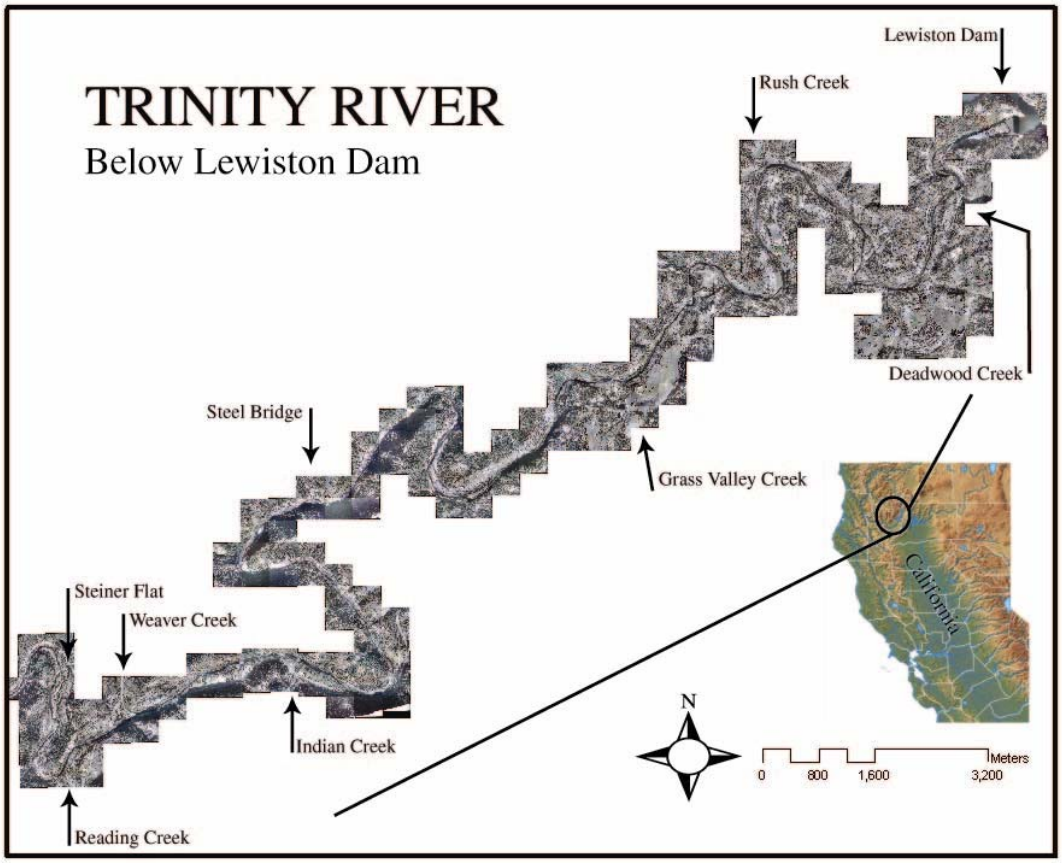


Figure 1. Location map of the Upper Middle Trinity River.

Many studies have already been conducted on the Trinity River (see Bibliography). The present report builds upon past efforts but contains several new approaches. Most hydrologic and sediment transport studies to date have focused on the mainstem Trinity River (see Bibliography Part 2), whereas this report focuses on sediment sources and routing in tributaries. Past sediment source analyses have not differentiated sources by particle size, but efforts to control fine sediment input need to recognize that different soils and different erosional processes contribute different amounts of fine sediment to the stream channel. Newer techniques, such as slope stability modeling, were not incorporated into earlier reports but now provide a basis to identify potentially unstable areas within a subwatershed. Recent aerial photographs, from 2003, can be used to update landslide maps previously created in 1997.

Some previous reports focused only on a specific land ownership. The U. S. Forest Service (USFS) has completed several watershed analyses, which emphasize forest management issues, ranging from fuel reduction strategies to impacts of timber harvest on fishery resources. Watershed analyses usually are structured around a series of questions in which the answers "provide a model of ecosystem processes and elements, disturbance history, and current and potential future conditions" (Montgomery and others 1995), but do not necessarily include sediment budgets.

The present strategy is <u>not</u> intended to be a design for a watershed analysis, although data generated through this strategy could be incorporated into watershed analyses. The scope of a watershed analysis is much broader, and covers issues such as recreation, transportation networks, socioeconomic concerns, timber harvest planning, vegetation management, terrestrial wildlife, fisheries and water temperature. This strategy simply targets sources, routing and delivery of sediment from tributary basins to the mainstem Trinity River. Elements of the strategy include information on the geology, geomorphology, soils, hydrology, dominant erosional processes, climate, land use and sediment transport regimes of the watersheds of concern.

Basic Concepts:

Several basic concepts form the underpinning of this report, and are summarized as follows. The rate of sediment supply and size of particles delivered to a stream channel depend on several watershed characteristics: bedrock, soil, topography, climate, vegetative cover, runoff characteristics and land disturbances. These differ by watershed and over time. The capability of a stream to transport sediment depends on channel gradient, watershed area, and runoff regime, which influence flow velocity and depth. Transport capability can be lessened by channel features that increase hydraulic roughness and dissipate energy (such as large wood in the channel, bank irregularities, and bed forms such as gravel bars).

The timescale of a sediment source study is important to specify. Much of the analysis of sediment sources depends on comparisons of sequential aerial photographs. In this case, the time period between successive air photo flights defines the period during which erosion rates are computed. These time periods will differ among watersheds, depending on the availability of photographs. Erosion rates between different time periods will differ depending on the climate and flood history occurring during a given time period.

Although the air photo analysis will provide a time-averaged erosion rate (for example, tons of sediment per square mile of watershed per year) it is important to recognize that sediment input and transport is actually highly episodic. In the Klamath Mountain province, major erosional processes such as shallow landslides and debris torrents are active in large storms, but may not produce much sediment during years of mild weather patterns.

Because this strategy for sediment reduction focuses on fine sediment (< 8mm in diameter), results may differ from studies of total sediment production. For example, even though a landslide may contribute more sediment to a creek based on total volume of material, much of that material may be coarse, and within the 'preferred range' of 8 to 153 mm in diameter. In contrast, an eroding cutbank in granitic soils may deliver less material in total to a channel, but if most of this material is in the 'non-preferred' range of < 8mm, the cutbank may pose a greater problem than the landslide in a particular subbasin. An individual small erosion problem may not pose a risk to the stream system, but the cumulative effect of many small problems can result in damage.

Another consideration is the use of past erosion rates as an indication of future erosion threats. A study of past erosion is, of course, essential in determining sediment source areas, but the past cannot always be used as a predictor of what will happen in the future. For example, if road construction and maintenance techniques have improved during the last decade, erosion rates based on studies of older roads may not be relevant. In contrast, as roads age they can become even more susceptible to erosion due to rusting of culverts, the decay of organic material incorporated in road fill, etc. In this case past erosion rates would underestimate the future threat of erosion from these roads. Again, site-specific studies are necessary to tease out the various factors influencing erosion rates.

There is a limit to the effectiveness of erosion control techniques, and it is usually more cost-effective to prevent a problem than to treat it (Kelsey and others, 1981). Prevention of sediment input can include the establishment and enforcement of sediment and pollution control measures, as well as active measures such as road upgrades, maintenance and decommissioning (Pacific Rivers Council, 1995). The Grass Valley sediment basins are a good example of the need for expensive treatments after severe erosion and sediment delivery became a large problem in Grass Valley Creek.

Procedures for Sediment Source Analyses

Much of the following is taken from "Rapid Evaluation of Sediment Budgets" (Reid and Dunne, 1996). That reference covers sediment source analysis in much more detail than presented here. Since that book was published, many more approaches to watershed assessment have been advanced, such as the California Watershed Assessment Model (Shilling and others, 2005). Bibliography Part 1 provides a list of various watershed analysis and assessment report. In addition, modeling of watershed processes has been streamlined so that analytical tools are easily accessible, such as in the Desktop Watershed Model (*http://www.nced.umn.edu/Desktop_Watersheds_IP.html*). The following is a description of the general steps involved in formulating a fine sediment control strategy. Next, in Part 2, specific examples from the Rush Creek watershed are used to illustrate these steps.

Step 1 – Define the problem and critical questions to be answered

The general problem is to define sources of material 0.5 to 8mm in diameter in tributary basins of the Upper Middle Trinity River. Rates of erosion and sediment delivery to the mainstem of the Trinity River need to be determined for this size class. Specific subwatersheds may have other concerns, such as delta growth and dynamics, that need to be addressed.

The following are examples of critical questions that can be addressed.

1) What are the significant sources of fine sediment from tributary basins?
Example hypothesis: Significant sediment sources include landslides, road-related erosion and bank erosion. Tributaries contribute significant sediment loads to the mainstem Trinity, and proportionally, tributaries near Lewiston Dam (Deadwood, Rush, Grass Valley and Indian Creeks) are more significant sediment contributors in terms of total mainstem sediment loading than tributaries farther downstream.

2) Can sediment reduction techniques applied in tributary basins significantly reduce chronic and episodic inputs of fine sediment to the mainstem Trinity River in a cost-effective and timely manner?
Example hypothesis: If a tributary contributes more than 20% of the fine load to the associated mainstem reach, and more than 50% of the total sediment yield from the sub-basin is human-induced, sediment reduction techniques can significantly reduce fine sediment input to the mainstem Trinity River.

Uncertainties: Because no long-term monitoring of sediment production in tributaries has been conducted, there is considerable uncertainty in defining rates of sediment inputs from various erosion processes. Extrapolation from monitoring results from similar basins will help reduce the uncertainty. Comparisons of past sediment budget efforts with actual sediment yield measurements suggest that results can agree to within a factor of 2, and usually to within 30% (Reid and Dunne, 1996).

Step 2 – Acquire Background Information

A literature review assesses existing regional information. Many sources of information on the physical and aquatic resources of the tributary basins exist, but much of the information is in the grey literature (agency and consultant reports). Fortunately, the Klamath Resource Information System (KRIS) has scanned many of these reports, which can be downloaded from the internet. Maps of topography are available from the U.S. Geological Survey (USGS). Maps of historical and current land use, timber harvest history, vegetation age types and age classes all help reconstruct the history of disturbance in an area. KRIS pulled together maps, data tables, charts, photographs and bibliographic resources concerning the Trinity River into a PC-based computer program, and the bibliography is available at:

http://www.krisweb.com/biblio/biblio_trinity.htm

Other sources of information include universities (theses and dissertations) and historical societies. Irwin (2003) has compiled an extensive bibliography on the geology and physiography of the Klamath Mountains, which includes many citations relevant to the Trinity River basin. It is available online at:

http://geopubs.wr.usgs.gov/open-file/of03-306.

A list of relevant references on the Trinity River are included in Bibliography Part 2, but specific information on individual sub-basins still needs to be compiled while conducting a sediment source study. Commonly local residents, road maintenance crews, anglers, and other users of the watershed will be able to describe erosion events, changes in stream channels, and other information relevant to sediment sources and routing.

In response to the 1997 listing of the coho salmon as threatened, five counties in northwestern California (Del Norte, Humboldt, Mendocino, Trinity and Siskiyou) formed the Five Counties Salmonid Conservation Program. One of the objectives of this program is to identify and correct erosion problems on county roads, and to assist in this effort a 5C Roads Maintenance Manual was prepared. It is available at:

http://www.5counties.org/Projects/FinalGeneralProjectPages/RoadsManual800.htm

In 2000, the State Water Resources Control Board awarded Trinity County a Proposition 204 contract to conduct a road sediment source and mitigation barrier inventory and to implement several restoration projects on county roads within the Trinity River watershed. Road inventories followed the methodology of Pacific Watershed Associates (PWA), with some modifications to account for differences between private and public roads. The final county roads inventory is called DIRT (Direct Inventory of Roads and Treatments). Data from the inventory are stored in a Microsoft Access database. The inventory accounts for surface erosion, cutbank and fill failures, and potential stream crossing failures. A summary of the report is available at:

http://www.5counties.org/PDF_Files/TrinityDIRTFinal%20Report.pdf

Other sources of information on erosion problems include the U.S. Forest Service (USFS), California Department of Transportation (Caltrans), and studies conducted in similar terrain, such as the Klamath Nation Forest and parts of the Sierra Nevada.

Repeat photography is a powerful tool to assess geomorphic and vegetative changes through time. Sequential aerial photographs can be obtained to map erosion features, such as debris slides, debris torrents and gullies, and to characterize land use changes, such as road construction, timber harvest, and residential development. Air photos can be examined at offices of the U.S. Forest Service, Trinity County Resource Conservation District, and other agencies. The National Center for Earth Resources Observation and Science of the USGS also has an index of available imagery:

http://edc.usgs.gov/

Other forms of remote sensing, such as satellite imagery, are available, and can be useful in supplementing information garnered from aerial photographs. In regions of diverse land ownership, remote sensing allows an investigator to study the landscape in a uniform manner without requiring on-the-ground access to all points. Historical on-the-ground photographs can also be useful in documenting such changes as river bank erosion or delta growth. Humboldt State University and historical societies have archival photographs for specific areas in the Trinity River basin.

Climate is an important control on erosion rates, and the temporal and spatial patterns of rain and snow affect flow regimes. The California Data Exchange Center (CDEC) installs, maintains, and operates an extensive hydrologic data collection network including precipitation and river stage sensors for flood forecasting. CDEC collects, stores, disseminates, and exchanges hydrometeorological data and related information and provides a centralized location to store and process real-time data. The CDEC cooperative database contains information collected by the National Weather Service (NWS) (weather forecasts, river bulletins, full weather data), the U.S. Bureau of Reclamation (USBR) (reservoir operations, reservoir summary reports), and the U.S. Geological Survey (USGS) (river gage data, river flow rating tables and shifts, sediment data).

http://cdec.water.ca.gov

The National Water Information System is another source of hydrological and sediment data. It provides access to water-resources data collected at U.S. Geological Survey gaging stations. Online access to this data is organized by categories of site information, real time data, surface water and water quality.

http://nwis.waterdata.usgs.gov/nwis

Stream gaging has also been conducted by Graham Matthews and Associates (GMA) and the Hoopa Tribe, and the USGS reviews the GMA gaging for adherence to USGS standards. Where gaging station data exist, useful information on channel changes can be gleaned from discharge records and rating curves. Streambed elevation, shifts in discharge or sediment rating curves, hydraulic geometry and cross-sectional areas can be determined from gaging station records. Smelser and Schmidt (1998) provide a detailed description of how to assess historical changes in mountain streams. Most of the tributary basins in the Trinity River are ungaged or have short records, however, so will not have this level of information available.

The timber harvest history for privately owned lands in Trinity County has been compiled by the Klamath Watershed Team of the Natural Resources Conservation Service in Yreka, California, based on timber harvest plans that have been filed. Records of timber harvest on USFS lands are available from the Shasta-Trinity National Forest office.

Step 3: Subdivide the area into terrain units

Because the tributary basins will be underlain by a variety of bedrock types, and have a mix of vegetation and land uses, each acre of the watershed can be considered unique in some fashion. Nevertheless, for a sediment source strategy, some generalizations need to be made. Usually basins are classified into several strata, and each stratum is then evaluated separately. Reid and Dunne (1996) suggest using one to 25 strata defined on the basis of topography and geology, with land use considered a treatment variable within a stratum. The number of strata selected is a compromise between having few enough strata to allow adequate estimates of erosion and having enough to adequately characterize the range of conditions in the project area. Stratification may also be based upon land ownership, where the sources of information and level of data acquisition vary widely.

To assist in terrain identification, a basic geology map of the Trinity River area has been produced by Fraticelli and others (1987). This map can be supplemented by soil mapping by the Natural Resources Conservation Service (Howell and others, 1998) and the USFS. Because the size distribution of sediment input is relevant to the Trinity River Restoration Program, it is critical to obtain particle size data for the soil units in the watersheds. The NRCS has compiled soil property data for most of the soil units on privately owned lands in the Weaverville area.

The Trinity River and its tributaries drain the Klamath Mountains. This block of rugged mountains is extremely complex and geologists are still unraveling its history. Mapping the lithology and faults is especially challenging due to the steep slopes and heavy vegetation that obscures bedrock outcrops. Past glacial activity shapes processes and landforms in high elevation sites. There is a complex mix of old ocean floor, volcanic rocks, granitic batholiths, and sedimentary and metamorphic rocks. The mountains can be generally divided into four belts: Eastern Klamath, Central Metamorphic, western Paleozoic and Triassic, and the Western Jurassic belts. Even within a single belt, however, there is a wide variety of rock types. The underlying geology forms the template upon which the soils develop, vegetation patterns form, and river channels evolve, and the rate, magnitude and type of erosion processes active differ by bedrock type. Consequently, it is important in a sediment source study to understand the specific geology of an area. Although all the Klamath Mountains exhibit high erosion rates compared to national averages, certain rock types, such as serpentinite, and decomposed granite, are especially susceptible to erosion. Bedrock types are commonly used as the basis for stratification of the watershed to estimate erosion rates, and sediment source analyses should use the best available geologic mapping for a specific area (sources of information are listed in Bibliography Part 2).

Step 4: Evaluate sediment production

Sediment source analysis involves the identification of the locations and timing of hillslope sediment sources (such as debris slides, road fill failures, road crossing failures, cutbank erosion, and gullies) and channel sources and sinks (bank erosion, channel incision, or storage of sediment in bars or floodplains). Landslide occurrence can be documented through analysis of sequential air photos, and landslide-prone areas can be identified through slope stability modeling. Results from existing road inventories of erosion problems from the U.S. Forest Service and Trinity County can be extrapolated to estimate problems on inaccessible lands, although road management standards may vary by ownership. Soil types and particle size distributions of sediment source areas are available from Natural Resource Conservation Service's mapping. Pebble counts and subsurface sampling of the channel bed provide channel substrate size in tributaries. Sediment source areas can be categorized as 'natural' (no sediment reduction needed) and 'human-induced' (sediment reduction techniques can be applied).

As a general guideline, if fine sediment contribution from a tributary is greater than 20% of the fine load in the associated mainstem reach, and if human-induced sediment contributions are greater than 50% of the total sediment yield from a subwatershed, sediment reduction techniques may be useful in making detectable improvements in fine sediment loading. Techniques for landslide-prone areas include drainage improvement, excavation of sidecast fill along landings and roads, buttressing and revegetation. Road-related erosion can be addressed through road upgrades and decommissioning. Techniques for reducing surface erosion include mulching and revegetation. Bank erosion, if significant, can be addressed by localized bank stabilization.

The main types of erosion processes are mass movement (landslides), channel erosion, gullying, and surface erosion (sheetwash and ravel). Erosion processes can be further divided into natural and human-induced (primarily associated with road construction, timber harvest or development). Several references describe methodologies to measure and estimate volumes of material generated from these processes (Bibliography Part 1) and to monitor rates of erosion (Bibliography Part 3).

Landslides:

Documenting the history of past mass movement activity provides an estimate of the volume of material that has been delivered to streams from landslides and is an indication of locations of unstable areas. An analysis of repeat aerial photography forms the basis of landslide quantification. Shallow debris slides, debris flows and earthflows are common types of mass movement found in the study area. Sequential air photos can be used to calculate landslide areas and landslide frequency (number of landslides per year for the time period covered by the air photos). The amount of material delivered to a channel from landslides (sediment delivery) can also be estimated from air photos. Field observations of landslide depth are used in conjunction with landslide areas mapped from air photos to calculate volume. Representative depths for a range of landslide types and size are measured in the field. Field work is also necessary to determine the minimum size of landslide scar that is visible on air photos, which will vary in areas by topography, vegetation cover, and other factors. Locally, land management agencies may have on-the-ground surveys of landslides, especially as they affect the road transportation network. Information on the size of landslides in these inventories can be compared to air photo inventories to determine which slides were or were not visible on the air photos.

In order to predict where landslides will occur in the future, which is important in guiding future land use activities, slope stability models can be used to characterize the terrain. Dietrich and Montgomery (1998) built a digital terrain model for mapping the pattern of potential shallow slope instability, called SHALSTAB. This model uses digital elevation data to define surface topography, which influences the location and frequency of shallow landsliding. For example, large storms are more likely to generate slope instability in steep convergent areas rather than on ridges with divergent topography. SHALSTAB is based on an infinite slope form of the Mohr-Coulomb failure law. A further simplification in SHALSTAB is to set the soil cohesion to zero. Slope stability fields can range from 'unconditionally stable when saturated' to 'unconditionally unstable when unsaturated,' based on a ratio of q (the effective precipitation (rainfall minus evapotranspiration) times the upslope drainage area) and shallow subsurface flow at saturation, expressed as T, transmissivity (the vertical integral of the saturated conductivity times the head gradient). Landscapes for which the model is not expected to perform well include areas that have been glaciated (or may still be adjusting to post-glacial climatic conditions), terrain dominated by deep-seated landslides, areas dominated by rocky outcrops or cliffs, and areas with deep groundwater flow and locally emergent springs.

There are at least four prescriptive uses to be made of the SHALSTAB model: 1) hazard mapping for public safety, 2) guiding forest practices to minimize potential for shallow landsliding and debris flows, 3) redesign of road networks to reduce road failures, and 4) coarse screen ranking of watersheds to prioritize them for watershed analysis (Dietrich and Montgomery, 1998). Work is currently in progress to expand SHALSTAB's capability to predict the size of landslides, in addition to their location.

Another slope stability model based on digital elevation data is SINMAP (Stability INdex MAPping). The following description is taken from Pack, Tarboton and Goodwin (1998). SINMAP is an ArcView extension that implements the computation and mapping of a slope stability index based upon geographic information, primarily digital elevation data. SINMAP has its theoretical basis in the infinite plane slope stability model with wetness (pore pressures) obtained from a topographically based steady state model of hydrology. Digital elevation model (DEM) methods are used to obtain the necessary input information (slope and specific catchment area). Parameters are allowed to be uncertain following uniform distributions between specified limits. These may be adjusted (and calibrated) for geographic "calibration regions" based upon soil, vegetation or geologic data. The methodology includes an interactive visual calibration that adjusts parameters while referring to observed landslides. The calibration involves adjustment of parameters so that the stability map "captures" a high proportion of observed landslides in regions with low stability index. This calibration is done while simultaneously referring to the stability index map, a specific catchment area and slope plot (of landslide and non-landslide points) where lines distinguish the zones categorized into the different stability classes and a table giving summary statistics. Results are given in terms of factors of safety (SI), ranging from SI > 1.5 (stable slope zone) to SI < 0 (defended slope zone).

Both models have been used successfully to define landslide-prone areas. Nevertheless, it is important that these tools be used in combination with air photo analyses and field mapping techniques to validate landslide occurrence or potential, and define specific site conditions.

Mining Ditches

The Trinity River basin has a legacy of impacts from past mining. Abandoned tailings piles and mining ditches are common. Many of the ditches still carry water, and when flow breaches the ditch wall, the ensuing runoff can cause gullies or landslides. Figure 2 shows the locations of the largest ditches in the Weaverville area, but many smaller ones also dot the landscape. Ditch erosion is another erosion process that may need to be part of the evaluation of sediment sources in the tributary watersheds.

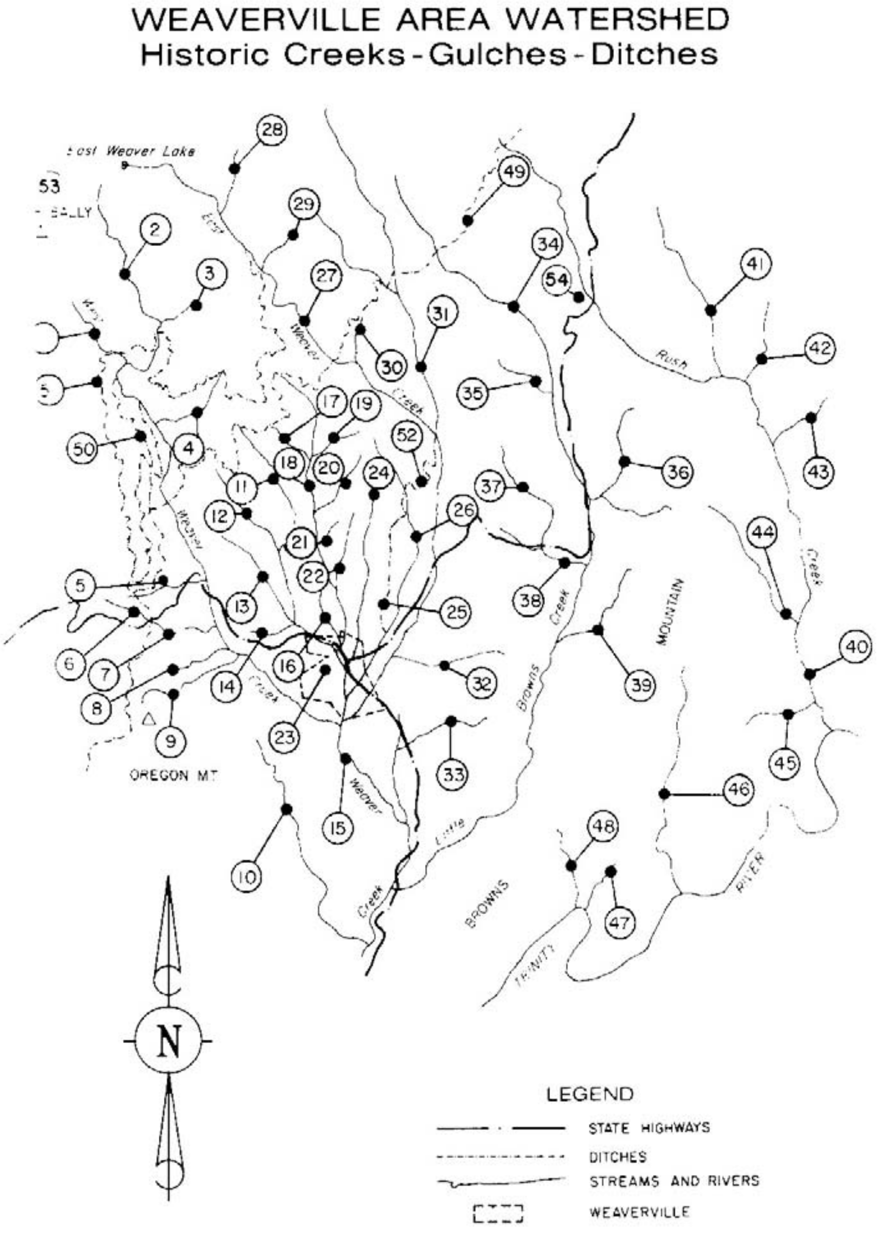


Figure 2. Major mining ditches in the Weaverville area (from Jones and others, 1981).

Stream bank erosion:

Stream bank erosion is common on lowland rivers with wide floodplains, as indicated by abandoned meander scars and oxbow lakes, and can be measured through the use of sequential air photos. However, bank erosion is more difficult to evaluate under field conditions common to Trinity River tributaries, which are generally steep, narrow and covered by forest canopy. Field measurements are needed to determine bank height, bank material, and evidence of recession, such as root exposure. Discrete bank failures due to landslides or windthrow can also be mapped in the field. Bank erosion can also occur through continuous spalling or raveling. Estimated soil creep rates are often used to check estimates of bank erosion rates in colluvium. Average creep-supply rates to channel banks can be approximated by measuring colluvial soil depths on channel banks at randomly selected points, applying the estimated creep velocity to the soil depth at each point, averaging the results, and applying the average to the length of colluvial bank (Reid and Dunne, 1996). In a report on the South Fork Trinity River and Hayfork Creek, the EPA (1998) used creep rates of 0.4 mm/yr in flat-lying valley fill to 2 mm/yr on slopes greater than 30 percent, based on creep rates measured in Redwood Creek (Swanston and other, 1983).

Surface Erosion

Several types of soil erosion processes are active in the mountainous terrain in Trinity County. Laurent (2006) describes soil erosion processes and rates in the Klamath National Forest. Sheet erosion consists of raindrop splash displacement of soil particles and subsequent downslope transport of this dislodged material. Rill erosion occurs when runoff becomes concentrated and forms rills that are less than 1 ft^2 in cross-sectional area. Gullies (>1 ft^2 in cross-sectional area) can form where flow is diverted from its natural channel onto formerly unchanneled hillslopes, such as downslope of a culvert, and rills can develop into gullies if runoff continues to enlarge the rills. Gullies are commonly associated with roads and road drainage structures. Gullies may also form on earthflows, as the ground shifts and changes the channel network. Large gullies or gullies on grasslands are visible on air photos. Smaller gullies or gullies under a forest canopy need to be examined in the field.

Dry surface ravel is common on soils with coarse textures, especially on soils formed from granitic rock types. Laurent (2006) summarizes surface erosion rates following fires and clearcut logging. GMA (2001, Table 43) used 4 tons/acre as a surface erosion rate on areas harvested from 1980 to the present, and 12 tons/acre for the period of 1940 to 1970.

The Klamath National Forest used two models, the Universal Soil Loss Equation (USLE) and the Water Erosion Prediction Project (WEPP) models to estimate surface soil erosion. The USLE model is an empirical approach which computes soil loss based on the following factors: rainfall-runoff, soil erodibility, slope-length, slope steepness and cover. The WEPP model, distributed by the National Soil Erosion Research Laboratory (Tysdal and others, 1999), is a process-based, distributed parameter, continuous simulation, erosion prediction model and is applicable to sheet and rill erosion. The hillslope model in WEPP is a direct replacement for the Universal Soil Loss Equation (USLE) approach. With the addition of being applicable to nonuniform slopes, soils, and management, the hillslope model can predict both soil loss and deposition on a slope -- something the USLE is not capable of doing. The hillslope model also computes distributions of soil loss and deposition. The WEPP model is process based and computes erosion by storm events. Comparing the overall averages for Klamath Mountain soil erosion data, Laurent (2006) found both models performed equally well.

Sediment Production from Roads

Surface erosion

Surface erosion processes represent a chronic rather than episodic source of sediment. Because other studies in the region have suggested that roads are a major sediment source, sediment production from roads is evaluated as a separate component in this strategy. Common areas subject to surface erosion are road cutbanks, treads and fills. These mostly unvegetated sites are subject to sheetwash, rilling, frost heave, and ravel. Several erosion models are available to estimate sediment production from roads (USLE, WEPP (discussed above), SEDMODL, WARSEM and R1-R14). SEDMODL is a GIS-based model developed by Boise Cascade and the National Council for Air and Stream Improvement. Washington State's Department of Natural Resources updated this approach to develop the Washington Road Surface Erosion Model (WARSEM). The R1-R4 model was developed by the US Forest Service specialists in the Rocky Mountain region. Other models that have been used to evaluate road surface erosions rates are ROSED (Simons and others, 1980) and KINEROS (Woolhiser and others, 1990). The advantages and disadvantages of erosion models are discussed in more detail by the U.S. Environmental Protection Agency (1999).

These models are useful in identifying the areas most susceptible to erosion, but precise estimate of erosion volumes requires field work, as well as information on traffic use, road surfacing, road widths, gradients and hydrologic connectivity. Field measurements of exposed roots, rill dimensions, rainsplash pedestals and debris fans can help verify such estimates (Reid and Dunne, 1996). Because the fine-scale evidence of surface erosion is easily obliterated by road grading, revegetation, traffic, etc., it is important to measure these features soon after the erosion event occurs. The date of road construction (needed for cutbank retreat calculations) can usually be obtained from county or USFS records, or from air photo inventories.

Road erosion rates are highly variable among sites and across years because of differences in variables such as road surfacing, maintenance, soil type, rainfall erosivity, level of traffic, and recency of grading. Because erosion rates vary seasonally, and are dependent on factors such as vegetation cover, slope steepness, freeze-thaw cycles and wetting and drying frequency, short-term measurements may over- or under-estimate the long-term erosion rates. Estimates of erosion rates can also be compared to those in the literature for which longer term measurements are available. Because previous studies have been conducted with different approaches and results are not reported in consistent units, comparisons among studies must be done with care.

Previously, road surface erosion rates have been estimated for the Trinity River area and other watersheds in the region using measurements reported in the literature or models. There is a wide range of estimated erosion rates (Table 1). For example, in the South Fork Trinity River, sediment delivery to streams from road surface erosion was estimated using SEDMODL (Raines, 1998). The model uses information from an elevation grid along with road and stream layers to estimate which segments of the road system are likely to drain to streams. The relative amount of sediment produced from these road segments was then calculated based on erosion factors drawn from the Washington Department of Natural Resources Standard Methodology for Conducting Watershed Analysis, surface erosion module (WDNR 1995, in Raines 1998), with modifications based on additional empirical road erosion research conducted in the Pacific Northwest. Other data layers employed included geology and precipitation. Field surveys were conducted in the South Fork basin to calibrate the model to the six generalized geologic units and road sediment delivery attributes in the South Fork basin. All roads were attributed with construction year, surfacing, and 1998 traffic levels.

In the Sediment Source Analysis for the Mainstem Trinity River, Trinity County, California, Graham Matthews & Associates used a combination of field inventories, GIS and air photo work to estimate erosion rates on roads for seven geologic units, three road surface types and three road slope positions (riparian, mid-slope and ridge-top). Road surface erosion was greatest on native roads (average of 31.5 tons/mi/yr), whereas rocked roads and paved roads had an average of 19.8 tons/mi/yr and 2.1 tons/mi/yr, respectively. When cutbank erosion and other erosion processes were added, average road erosion was 46 tons/mi/yr on native roads, 52 t tons/mi/yr on rocked roads, and 36 tons/mi/yr on paved roads (GMA, 2001, Table 36). For comparison with other studies, these rates have been converted to Mg/km of road/yr in Table 1.

Measurements of erosion on granitic terrain have been made in the Sierra Nevada and Idaho batholiths, and can be used to bracket the estimates for the Trinity River (Table 1), although erosion rates vary from snow-dominated to mixed rain-and-snow regimes. Burroughs and others (1984) found that in the Idaho batholith sediment yield was reduced by a factor of 4.3 for gravel surfacing, 3.2 for dust oil, and 28.2 for bituminous surfacing relative to an unsurfaced road. Gravel spread in the ditch reduced sediment yield by a factor of 2.3. Unprotected cutslopes and ditches produced 6.3 to 12 times more sediment per unit area than the native road surface, due to rills, small slumps and ravel. Grassed cutslopes in granitic materials yielded less than 5 percent of the sediment than measured on a road with bare cutslopes. In the Sierra Nevada, Coe (2006) found that sediment production rates from native surface roads (0.22 kg/m^2) were 12 to 25 times greater than from rocked roads, and recently graded roads produced twice as much sediment per unit of storm erosivity as roads that had not been recently graded. The major long-term source of sediment from road construction on granitic lands in Idaho over a 45-year period was cutbank erosion, with an average rate of about 1.1 cm/year (Megahan and others, 1983). Trinity County's DIRT road inventory uses three erosion rates for cutbanks: 0.3 cm/yr (low), 0.9 cm/yr (medium) and 1.5 cm/yr (high). Erosion pins installed along various types of cutbanks in the Trinity River basin can validate these estimated erosion rates.

Table 1. Erosion rates from roads in various terrains.

Study site	Lithology	Rate	Author
Sierra Nevada, CA	Granitics, andesitic lahar	Native: 0.22kg/m^2 (1.1 Mg/km/yr*) Rocked: 0.02 kg/m^2 (0.1 Mg/km/yr*)	Coe, 2006
Olympic Mountains, WA	Metasedimentary	41 Mg/km/yr	Reid and Dunne, 1984
Redwood Creek, Marin County, CA	Greenstone, greywacke, chert	Paved: 1.5 Mg/km/yr Rocked: 0.9 Mg/km/yr Native: 0.9 Mg/km/yr	Stillwater Sciences, 2004
Trinity River, CA	Granitic, metamorphic, metasediments	Paved: 20 Mg/km/yr Rocked: 29 Mg/km/yr Native: 26 Mg/km/yr	GMA, 2001
Idaho Batholith**	Granitic	0.48 kg/m^2	Megahan, 1974
Idaho batholith**	Granitic	0.01-0.21 kg/m^2/yr	Burroughs and King, 1989
Oregon Coast Range**	Sedimentary, metasedimentary	0.02 kg/m^2/yr	Luce and Black, 2001.

*Coe assumed average road width of 5 m.

** Road widths were not listed, so can not convert to Mg/km/yr

Stream crossings and landslides

Past landslides from roads can be detected through sequential air photo analysis, as described above. Potential future erosion and sediment delivery from stream crossings and road-related landslides have been estimated on roads managed by Trinity County through field-based road inventories (DIRT). The volume of fill at crossings and the relative stability of the crossing are recorded as part of the inventory. This volume is not equivalent to the volume of fill likely to erode in a short-term period, such as the next 10 years, however. Not all culverts will fail, and when a culvert does fail, the amount of fill eroded is commonly less than the total fill volume at the stream crossing, unless a debris torrent is generated. Estimations of potential sediment savings from crossing upgrade or crossing removal work need to clarify whether the entire fill volume is used, or an estimate of what would actually fail in the time period of concern. A GIS approach can be used to provide information on road density, stream crossings and distribution of roads on different slope steepness and slope stability classes. Stream crossings can also be classified by diversion potential, land ownership and geologic terrains to assist in erosion control planning.

Post-Fire Erosion

Fire is a frequent disturbance mechanism in this region, and both rates of surface erosion and mass movement can increase following fires. The level of erosion depends on fire severity as well as soil type, slope steepness, timing of storms, and rates of revegetation. Randi Paris (NRCS, personal communication) has compiled an annotated review of the literature on post-fire erosion, which is available upon request. Additional resources are listed in the Bibliography Part 4.

Laurent (2006) summarizes several post-fire erosion studies. He cites McNabb and Froehlich (1988) who found that three years following a fire, the bulk density of fine soil in burned plots was 0.50 g/cm^3 compared to 0.28 g/cm^3 in unburned plots. This may be the result of raindrop-induced surface crusts, pores filled with clay and silt, and rain-induced surface compaction. Laurent observed rill erosion was about 2.8 to 4.3 yd^3/acre, after a fire in 1987 on granitic terrane. He also reported that dry ravel on slopes in granitic terrane produced 2.1 yd^3/acre over a period of two months after a wildfire. Helvey and others (1985) concluded that dry ravel along stream channels is an important erosional process after wildfires. Water repellency in soils can form after fires. Laurent report that in the Klamath Mountains water-repellent-related erosion occurs predominantly on coarse-textured soils (sandy load or loamy sands) formed from granitic rocks.

One concern in this region related to post-fire erosion is salvage logging of burned trees. Harvest of burned trees which have commercial value can possibly fund the treatment of dead trees and fuels which do not have commercial value. On the other hand, salvage logging and associated road-building activities can accelerate erosion as well as have other ecological effects. When a tree is killed by fire, the roots slowly decay during the next few years, and root strength in the soil decreases unless there is vigorous revegetation of the area. Figure 3 shows a landslide that occurred in the Trinity River basin downstream of Lewiston Dam several years after a fire which occurred in 1999. More research is needed on the mechanisms and causes of mass movement following fires in this region. In addition, fuel reduction management activities (Figure 4) are becoming more common, which includes ground fuels management and mastication, prescribed fire, and construction of fuel breaks. The effects of such activities on soil erosion are presently unknown.

Figure 3. Example of a landslide that occurred several years after the 1999 Lowden Fire in the Trinity River basin near Lewiston. Survey rod is 25 ft. high.

Figure 4. Fuel reduction activities leave the ground surface covered with an organic mulch. The erosional impact of such work on steeper slopes is unknown.

Erosion rates determined through cosmogenic techniques

In granitic terrain in the Sierra Nevada and Idaho, researchers have used cosmogenic ^{26}Al and ^{10}Be in stream sediment to measure long term erosion rates (Riebe and others, 2000; Kirchner and others, 2001). Although it would be interesting to compare erosion rates over the 10^3 year time scale with contemporary erosion rates, the technique cannot easily be transferred to the Trinity River basin because several of the underlying assumptions are not met in this area. The cosmogenic approach assumes that the concentrations of cosmogenic nuclides in the source material (soil and colluvium) are in equilibrium with the long-term average denudation rates for those sites (Reid and others, in press) and that channel storage plus transport time is small relative to the erosion time scale and to isotope meanlife (Granger and others, 1996). In the case of the Trinity River basin, channel storage has been extensively manipulated through hydraulic mining activities. Gold-bearing gravels were stripped from the hillsides and large tailings deposits mantle many of the floodplains. Modern land use has changed the rates and proportions of various erosional processes. For example, during the last few decades in Grass Valley Creek widespread ground disturbance caused extensive surface erosion of decomposed granitics. Under these watershed conditions of extensive historical alterations, it is unlikely that the cosmogenic approach using a sample of contemporary stream sediment could yield accurate estimates of long-term erosion.

Step 5: Assess sediment delivery, storage and transport

Sediment Delivery

In order to assess how much sediment actually reaches the mainstem Trinity River from tributary streams, it is not only necessary to account for sediment production, but also sediment delivery to streams, sediment transport, and sediment storage within the stream channels. For example, if a landslide occurs on a hillslope, but the landslide material is deposited downslope or on a terrace and not in a stream, it is not a direct concern to this project. Or, if water flowing down an inboard ditch of a road carries sediment through a ditch relief culvert and disperses the runoff and sediment on the fillslope, that portion of the sediment load is not a concern to this project. Hydrologic connectivity refers to how well integrated the road drainage network is with the stream network. High hydrologic connectivity means that most road runoff (and its associated sediment load) reaches a stream. The closer an erosion source is to a stream channel, the more likely it is that sediment will be delivered to running water.

Road ditches commonly act as an extension to the stream network in a basin (Wemple and others, 1996). Drainage ditches, if connected to a stream network, convey water and sediment from the road prisms and cutbanks to watercourses. An assessment of hydrologic connectivity is included in some road inventories, and upland erosion control efforts commonly focus on disconnecting road drainage from direct entry into streams. Harris (2005) explains the methodology of quantifying hydrologic connectivity and suggests techniques to reduce connectivity. Basically the methodology consists of measuring the length of road or ditch which is delivering runoff and fine sediment to a stream channel. In many northern California watersheds, 25 to 40% of the road length drains directly into streams. An inventory of 410 miles of roads in the Redwood Creek basin, Humboldt County, for example, shows that more than one-fourth of the road length drains directly to stream (Bundros, Redwood National Park, personal communication). Coe (2006) found that 25% of road length in his Sierra Nevada study site was connected to the channel network. A common restoration goal is to reduce connectivity by 80 to 90 percent. Techniques used may include installation of rolling dips and ditch relief culverts, and outsloping the road tread. Such methods aim at dispersing runoff and sediment onto vegetated slopes. Harris (2005) shows examples of lower connectivity following road restoration work.

Sediment transport

Once sediment reaches a channel, the potential for the sediment to be stored or transported downstream is dependent on the shear stress generated in a particular channel reach during high flows. In many alluvial rivers it is the bankfull flow that mobilizes the median particle size, D_{50}, on a stream bed (Leopold and others, 1964). The following analysis helps elucidate the general sediment regime of a given stream reach. Shear stress is a function of water depth and channel slope (and fluid density). Thus, it is important to quantify both bankfull water depths and channel slopes in the stream reaches of concern. Stream gradient is defined as "rise over run," or a change in elevation over a given distance, and is commonly expressed as a percent or a drop in feet per mile. For example, a drop in the streambed elevation of 8 ft. over a distance of 500 ft. results in a local gradient of 8/500 or 1.6%. For general use, stream gradients for each stream segment can be easily generated from USGS 7.5' topographic maps, using the blue-line stream distance between 40 ft. contour lines as the denominator and the change in elevation (usually 40 ft.) as the numerator. Digital elevation models (DEM's) have also been used to calculate stream gradients, but caution is needed to ascertain that adjacent hillslopes and streambanks are not included in the DEM calculation of stream gradient. For more detailed analysis, field surveys using a clinometer (for slopes > 3%) or a self-leveling level for gentler streams is recommended to determine channel gradient more accurately.

In mountain regions, bankfull depth is commonly not as obvious as in lowland systems where banks and floodplains are clearly defined. Nevertheless, bankfull depth can be determined by field surveys of channel gradient, tops of gravel bars, especially point bars, breaks-in-slope on the bank from a nearly horizontal surface down to a more vertical surface, evidence of fine-grained deposition on horizontal surfaces, the lower limit of perennial vegetation, and examination of stream gaging records. The USDA Stream Systems Technology Center has produced a helpful DVD called "Identifying bankfull stage in the eastern and western United States." Bankfull discharge occurs about every 1.5 to 2 years, so gaging station records (for example, USGS 9-207 forms) can be used to approximate bankfull records. Regional curves provide average values of bankfull channel dimensions as functions of drainage area (See Dunne and Leopold, 1978, p. 615) but to date a regional curve for the Trinity-Klamath system has not been published. It is important to use a combination of methods at several sites in areas where floodplains are not easily identified.

Once the reach-averaged bankfull water depth, h, and channel gradient, S, are known, the expected median streambed particle size, D_{50}, can be calculated as:

$$D_{50} = \rho\, h\, S / (\rho_s - \rho)\, 0.03$$

Where ρ_s and ρ are sediment and fluid densities, respectively, and 0.03 is assumed to be the critical Shields stress for movement of D_{50}. D_{50} is dependent on sediment supply as well as channel hydraulics. If the actual D_{50} in the stream is less than the predicted D_{50}, it may be that the channel has a greater hydraulic roughness due to bedforms or large wood (Buffington and others, 2004), or it may indicate a high sediment supply (Dietrich and others, 1989). A smaller grain size (textural fining of the stream bed) implies increased bed mobility at stages lower than bankfull and thus more frequent scour (Montgomery and others, 1996). Conversely, D_{50} commonly is greater than predicted in reaches downstream of dams or at sites of coarse sediment input.

Because particle size is critical to the determination of sediment transport, the size distribution of sediment in the stream channel needs to be quantified. A pebble count (Wolman, 1954) is a simple procedure to quantify particle sizes of the channel bed surface. These counts consist of measuring the intermediate B-axis of substrate particles chosen on a grid across the channel bed. Subsurface sediment is the sediment under the streambed surface, and these sediment are usually finer than the surface layer, or armor layer, of the stream bed. Subsurface sediment is usually sampled by first removing the armor layer and then sieving a sample of the underlying material. Bunte and Abt (2001) present a comprehensive methodology to sample both surface and subsurface sediments, and to calculate particle size distributions for such samples. Reid and Dunne (1996) present guidelines on choosing a channel reach for substrate analysis. They recommend that alluvial sediments should be present in bars on the channel bed, grain sizes should be homogeneously distributed through the reach, and the reach should be straight and single thread if possible.

Suspended sediment and bedload transport are measured at several gaging stations in the Trinity River basin. Annual sediment flux is typically calculated through the use of sediment rating curves, for example by relating suspended sediment concentrations at a given discharge and applying that relationship to time periods without sediment measurements. Sediment computations must be integrated over a flow duration curve or applied to the flow hydrograph, so continuous water discharge measurements at the gaging stations are needed. Sediment rating curves can shift due to many causes, such as seasonal changes in sediment supply or the occurrence of a large landslide. Consequently the estimation of annual sediment flux is not strictly a ‘cookbook’ procedure and necessitates some interpretation. There are manuals that describe how to predict and monitor suspended sediment transport, for example, Vanoni (1975). Bedload samples are also sieved to determine particle size distributions. Flow and sediment data from gaged stations can be used to estimate sediment flux at ungaged stations, taking into account drainage area, geology and land use.

Formulas do exist for predicting sediment transport capacity, but they are poorly developed for the field situations common to Trinity River tributaries, which are generally steep and coarse grained, with a mixed grain size and large in-channel wood. Reviews of sediment transport equations, their limitations and their applicability are provided by Gomez and Church (1989) and Reid and Dunne (1996).

Sediment Storage in Tributaries

Areas of channel stored sediment can be delineated at several scales. Using air photos and topographic maps, one can discern floodplains, terraces, valley widths, and coarse estimates of channel gradient. Narrow, steep stream reaches are not likely to store significant amounts of sediment, whereas reaches with broad valley floors can trap large volumes of sediment. Another mode of sediment storage common in the Trinity River basin is the tailings left by placer mining. Whether or not these coarse particles can be transported by a given stream depends on the shear stresses generated in that reach and the channel pattern. Field surveys may be needed to define sediment storage areas obscured on air photos by forest canopy or to more accurately measure channel gradient, height of gravel bars and floodplains, and determine the character of the streambanks. Production of fine sediment in tributaries upstream of a sediment storage area, where it may be trapped or slowed, is of less concern than sediment that can be easily routed to the mainstem Trinity River.

Sediment Storage in Mainstem Trinity River

To put the contribution of fine sediment from tributary basins into a broader perspective, it is useful to compare annual sediment yields from tributaries to the volume of fine sediment stored in the mainstem Trinity River. Fine sediment can be stored in various ‘reservoirs’ which have different levels of accessibility by the river to entrain the sediment. As an example, we considered several types of storage in the mainstem Trinity:

1) Mainstem Trinity River pools (McBain and Trush, 1997 p. 158)
2) Riparian Berms
3) Low flow channel (‘river bed’)
4) Several types of gravel bars
5) Floodplain

McBain and Trush (2004) mapped the areas of channel units in the mainstem Trinity and classified them into 71 categories (Table 2). Table 3 is a simplified classification using nine categories and the associated planimetric area for each category in several reaches of the Trinity River. The mass of fines in the mobile layer of river bed sediment was estimated by multiplying the planimetric area of the river bed by a depth equal to two times the dominant particle size (D_{84}) (in this case, 90 mm) times the fraction of bed material that is less than 8 mm:

Volume of fines = [river bed area * (2 * 90 mm) * (fraction of fines)]

The assumption is that the fraction of fines in the bed material is represented by the fraction of fines determined from bulk samples collected at several sites that combined surface and subsurface gravel (GMA, 2001) (Table 4). Figure 5a shows the air photo imagery used in this analysis, and Figure 5b shows the reach boundaries used to compute channel areas. A finer scale view of the polygons of various channel units is shown in Figure 6. This procedure can be refined to include other sediment storage units or different mainstem sediment cell boundaries as needed.

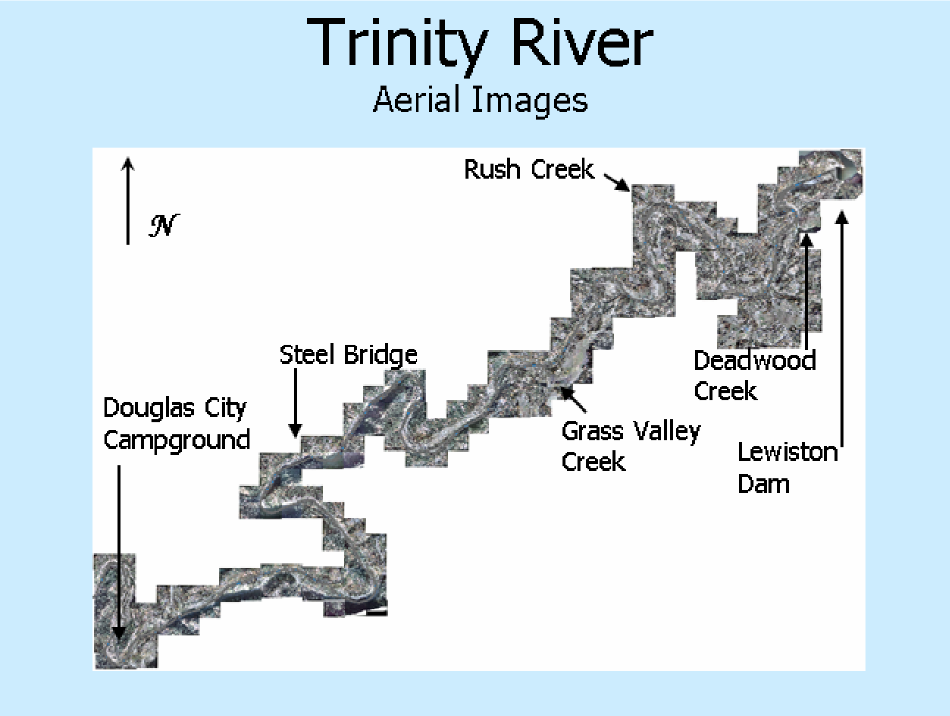
Table 2. Description of sediment storage units in the mainstem Trinity River (from McBain and Trush, 2004).

geo	
GEO	**description**
Apb(gc)	alluvial point bar gravel cobble
Apb(gc-b)	alluvial point bar gravel cobble to boulder
Apb(s)	alluvial point bar sand
Amb(s)	alluvial medial bar sand
Amb(s/gc)	alluvial medial bar sand over gravel cobble
Amb(gc)	alluvial medial bar gravel cobble
Amb(s-gc)	alluvial medial bar sand to gravel cobble
Fmb(s)	anthropogenic medial bar sand
Fmb(gc)	anthropogenic medial bar gravel cobble
Arb(s-gc)	alluvial riparian berm sand to gravel cobble
Arb(s)	alluvial riparian berm sand
Frb(s)	anthropogenic riparian berm sand
Afp(s)	alluvial flood plain sand
Afp(s/gc)	alluvial flood plain sand over gravel cobble
Afp(gc)	alluvial flood plain gravel cobble
Afp(s-gc)	alluvial flood plain sand to gravel cobble
Ffp(gc)	anthropogenic flood plain gravel cobble
Ate1(s)	alluvial fluvial terrace active sand
Ate1(gc)	alluvial fluvial terrace active gravel cobble
Ate1(s/gc)	alluvial fluvial terrace active sand over gravel cobble
Ate1(s-gc)	alluvial fluvial terrace active sand to gravel cobble
Fte1(gc)	anthropogenic fluvial terrace active gravel cobble
Fte1(s/gc)	anthropogenic fluvial terrace active sand over gravel cobble
Fte1(s-gc)	anthropogenic fluvial terrace active sand to gravel cobble
Fte1(gc-b)	anthropogenic fluvial terrace active gravel cobble to boulder
Ate2(s)	alluvial fluvial terrace possibly inundated sand
Ate2(s/gc)	alluvial fluvial terrace possibly inundated sand over gravel cobble
Ate2(s-gc)	alluvial fluvial terrace possibly inundated sand to gravel cobble
Ate2(gc)	alluvial fluvial terrace possibly inundated gravel cobble
Ate3(s/gc)	alluvial fluvial terrace inactive sand over gravel coble
Ate3(s-gc)	alluvial fluvial terrace inactive sand to gravel cobble
Fte2(s/gc)	anthropogenic fluvial terrace possibly inundated sand over gravel cobble
Fte2(s-gc)	anthropogenic fluvial terrace possibly inundated sand to gravel cobble
Fte2(gc)	anthropogenic fluvial terrace possibly inundated gravel cobble
Ate3(gc)	alluvial fluvial terrace inactive gravel cobble
Fte3(s)	anthropogenic fluvial terrace inactive sand
Fte3(s/gc)	anthropogenic fluvial terrace inactive sand over gravel cobble
Fte3(s-gc)	anthropogenic fluvial terrace inactive sand to gravel cobble

geo	
GEO	**description**
Fte3(paved)	anthropogenic fluvial terrace inactive paved
Fdts(gc)	anthropogenic fluvial terrace inactive gravel cobble
Fdts(s-gc-b)	anthropogenic fluvial terrace sand to inactive gravel cobble to boulder
XXu	soil mantled bedrock
XX	bedrock
Ff(gc)	anthropogenic fill gravel cobble
Ff(gc-b)	anthropogenic fill gravel cobble to boulder
Ff(b)	anthropogenic fill boulder
Fl(gc-b)	anthropogenic levee gravel cobble to boulder
Adf(gc)	alluvial debris fan gravel cobble
Ad(gc-b)	alluvial delta gravel cobble to boulder
Ad(gc)	alluvial delta gravel cobble
WATER	water
UNK	off aerial photo extent
Amb(gc-b)	alluvial medial bar gravel cobble to boulder
Ate2(s-XX)	alluvial fluvial terrace possibly inundated sand to bedrock
Ate3(s)	alluvial fluvial terrace sand
Ate3(gc-b)	alluvial fluvial terrace gravel cobble to boulder
Fas	anthropogenic aggregate stockpile
Ff	anthropogenic fill unspecified
Fdts(s-gc)	anthropogenic fluvial terrace sand to gravel cobble
Fte2(s)	anthropogenic fluvial terrace possibly inundated sand
XX-Fdts	bedrock to anthropogenic fluvial terrace
XXdf(gc-b)	
Ad(s-gc)	alluvial delta sand to gravel cobble
Afp(s-b)	alluvial flood plain sand to boulder
Afp(s-XX)	alluvial flood plain sand to bedrock
Afp(s/XX)	alluvial flood plain sand over bedrock
Fdts(gc-b)	anthropogenic fluvial terrace gravel cobble to boulder
Fte3(s-gc-b)	anthropogenic fluvial terrace inactive sand to gravel cobble to boulder
Fte3(gc)	anthropogenic fluvial terrace inactive gravel cobble
Afp(gc-s)	alluvial flood plain gravel cobble to sand
Afp(b)	alluvial flood plain to boulder

Table 3. Area of mainstem Trinity River channel units in hectares, based on mapping by McBain and Trush (2004).

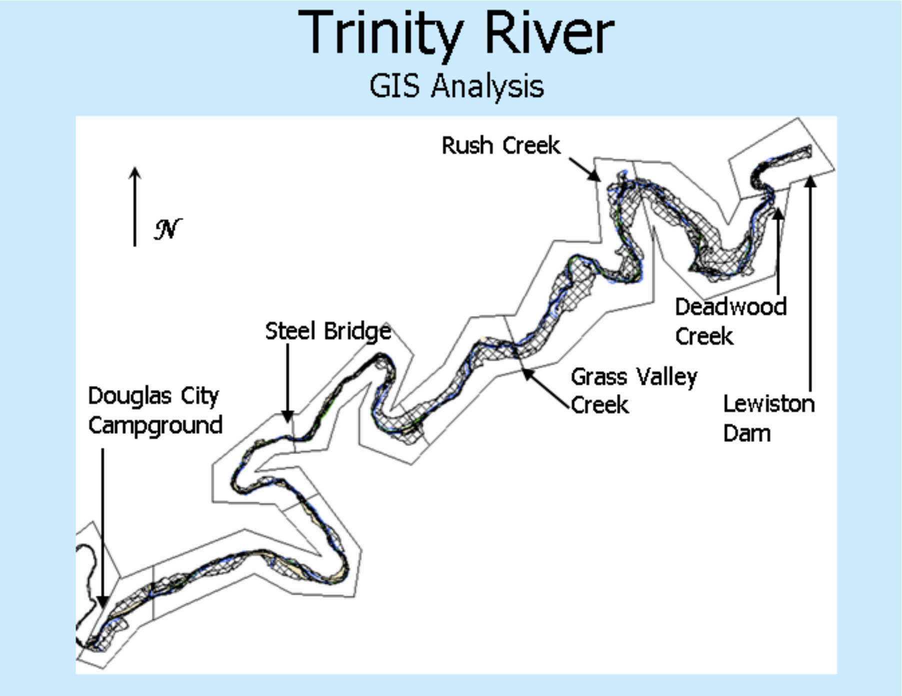
GeoClassifications	**Lewiston Dam to Deadwood Creek (ha)**	**Deadwood Cr - Rush Creek (ha)**	**Rush Cr - Grass Valley Creek (ha)**	**Grass Valley Cr - Steel Bridge (ha)**	**Steel Bridge - Douglas City Campground (ha)**	**Total (ha)**
Anthropogenic/Anthropomorphic	15.2	133.7	138.2	94.2	86.4	467.7
Alluvial Terrace	0.4	1.1	1.5	7.8	34.5	45.3
Alluvial Riparian Berm	0.0	2.0	3.0	4.2	4.8	14.0
Alluvial Point Bar	0.1	0.2	0.6	0.7	0.8	2.3
Alluvial Medial Bar	0.4	0.5	2.4	1.1	1.1	5.4
Alluvial Floodplain	1.5	8.2	17.4	11.4	23.1	61.6
Alluvial Debris Fan	0.0	0.0	0.0	0.0	0.0	0.0
Alluvial Delta	0.0	0.0	0.3	0.4	0.3	1.0
River	7.0	14.7	15.2	21.3	23.9	82.0
Total	*24.6*	*160.4*	*178.5*	*140.9*	*174.9*	



Trinity River

Aerial Images

A.



Trinity River

GIS Analysis

B.

Figure 5A and B. Mainstem Trinity River with channel unit polygons and storage cell boundaries shown.

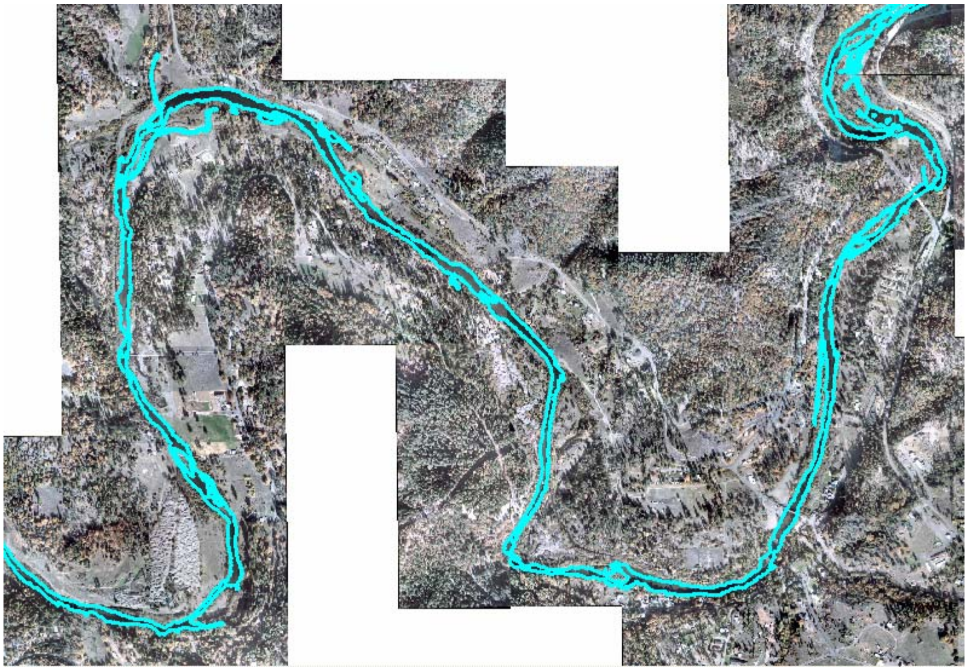


Figure 6. Close-up of mainstem Trinity River near Rush Creek confluence with channel unit polygons (McBain and Trush, 2004) shown.

Table 4. Fraction of bed material samples between 0.85 and 8 mm in diameter measured in the mainstem Trinity River (from GMA, 2001, Table 1).

Site	Mean % fines between 0.85 and 8 mm
Lewiston	5
Rush	27
Poker	58
Steelbridge	26
Indian	22
Steiner	24

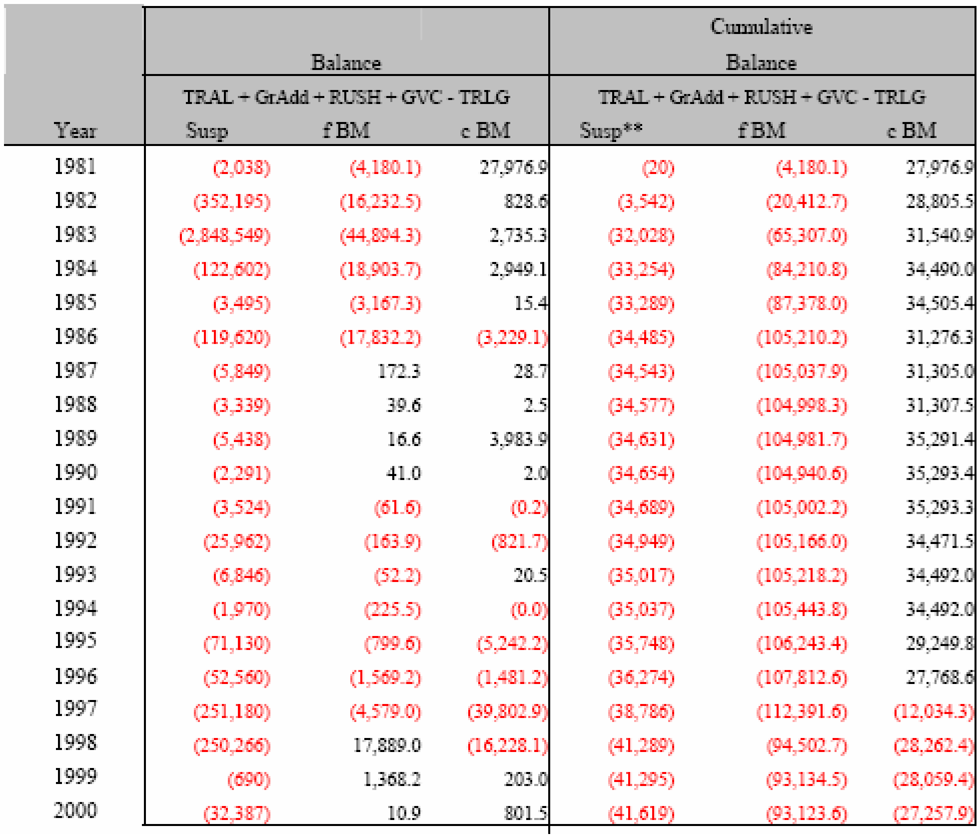
Table 5. Estimated volume and mass of fine sediment in mobile layer of Trinity River bed

	Lewiston Dam to Deadwood Creek	Deadwood Cr - Rush Cr	Rush Cr - Grass Valley Creek	Grass Valley Cr - Steel Bridge	Steel Bridge - Douglas City Campground	Total
Volume of active sediment [River bed area * 2(D84 of .09m)] (m^3)	12659	26412	27369	38264	42944	
Fraction of fines in bed	0.05	0.27	0.58	0.26	0.22	
Volume of fines (m^3)	633	7131	15874	9949	9448	
Mass of fines (Mg)*	1200	13600	30200	18900	18000	**81,900**

*assumed bulk density of 1.9 Mg/m^3

Wilcock (2004) estimated input and output of suspended load and fine and coarse bed material from the Trinity River at Lewiston (TRAL) to Trinity River below Limekiln (TRLG)gages, based on estimated sediment yields from Deadwood, Rush and Grass Valley Creeks (GVC) (Table 6). From these data he was able to compute a cumulative change in storage (sediment balance) over the period of 1981 to 2000. Wilcock's estimates of sediment yields vary from GMA's 2001 estimates because of differences in interpreting sediment rating curves. Depending on which set of sediment rating curves are used, the cumulative loss of fine sediment storage in the mainstem Trinity from 1981 to 2000 varied from about 0 to 93,000 tons (84,400 Mg). Additional monitoring at the gaging stations will help refine the sediment rating curves better in the future. Wilcock's method evaluates the change in storage but not the total volume of fine sediment in storage, which was estimated by the methods outlined in Table 5.

Besides storage of fine bedload in the interstices of a gravel-bedded channel, fines can be stored on the surface of the channel bed if the underlying pore spaces are filled. Fines on the bed of the Trinity River have been observed by many researchers, but to date the volume of fines on the mainstem streambed has not been quantified. Gaeuman (2007) proposed a method to estimate this fine sediment storage component by using the D50 and D90 particle sizes plus visual estimates of sand cover.



Year	Balance			Cumulative Balance		
	TRAL + GrAdd + RUSH + GVC - TRLG			TRAL + GrAdd + RUSH + GVC - TRLG		
	Susp	f BM	c BM	Susp**	f BM	c BM
1981	(2,038)	(4,180.1)	27,976.9	(20)	(4,180.1)	27,976.9
1982	(352,195)	(16,232.5)	828.6	(3,542)	(20,412.7)	28,805.5
1983	(2,848,549)	(44,894.3)	2,735.3	(32,028)	(65,307.0)	31,540.9
1984	(122,602)	(18,903.7)	2,949.1	(33,254)	(84,210.8)	34,490.0
1985	(3,495)	(3,167.3)	15.4	(33,289)	(87,378.0)	34,505.4
1986	(119,620)	(17,832.2)	(3,229.1)	(34,485)	(105,210.2)	31,276.3
1987	(5,849)	172.3	28.7	(34,543)	(105,037.9)	31,305.0
1988	(3,339)	39.6	2.5	(34,577)	(104,998.3)	31,307.5
1989	(5,438)	16.6	3,983.9	(34,631)	(104,981.7)	35,291.4
1990	(2,291)	41.0	2.0	(34,654)	(104,940.6)	35,293.4
1991	(3,524)	(61.6)	(0.2)	(34,689)	(105,002.2)	35,293.3
1992	(25,962)	(163.9)	(821.7)	(34,949)	(105,166.0)	34,471.5
1993	(6,846)	(52.2)	20.5	(35,017)	(105,218.2)	34,492.0
1994	(1,970)	(225.5)	(0.0)	(35,037)	(105,443.8)	34,492.0
1995	(71,130)	(799.6)	(5,242.2)	(35,748)	(106,243.4)	29,249.8
1996	(52,560)	(1,569.2)	(1,481.2)	(36,274)	(107,812.6)	27,768.6
1997	(251,180)	(4,579.0)	(39,802.9)	(38,786)	(112,391.6)	(12,034.3)
1998	(250,266)	17,889.0	(16,228.1)	(41,289)	(94,502.7)	(28,262.4)
1999	(690)	1,368.2	203.0	(41,295)	(93,134.5)	(28,059.4)
2000	(32,387)	10.9	801.5	(41,619)	(93,123.6)	(27,257.9)

Table 6. Sediment balance for fine (fBM) and coarse (cBM) bed material load and suspended load, Trinity River at Lewiston (TRAL) to Trinity River below Limekiln (TRLG) gages, in tons (from Wilcock, 2004, Table 7b).

Riparian Berms

Following the completion of the Trinity River Division there has been an increase in riparian vegetation along formerly unvegetated floodplains of the Trinity River. Species of willow, alder and cottonwood are common. As the vegetation encroaches on the channel it traps fine sediment. This deposition has created levee-like features along the low water's edge, and are termed 'riparian berms" (McBain and Trush, 1997). Riparian berms are typically about 3 ft. high and 20 ft. wide, and for the 80 miles of bank from Lewiston Dam downstream to the North Fork Trinity River, riparian berms are estimated to store almost 1 million yd^3 of sand (McBain and Trush, 1997, p. 294). This implies that the 19.8 mile reach between Lewiston Dam Creek and Douglas City Campground (39.6 miles of river bank) stores more than 450,000 yd^3 in riparian berms. Some of this material will be removed during bank and channel rehabilitation projects. Sand trapped in riparian berms is not mobilized every year, and the amount of sand from berms contributing to fine sediment loading of spawning gravels in the main channel bed depends on local bank erosion rates. The rate that berms will continue to trap sediment depends on flow magnitude, the supply of fine sediment and the growth of vegetation.

Pool Surveys

Fine sediment is also stored in pools in the mainstem Trinity River. Pools have the potential to store large volumes of fine sediment. In 1993, staff from Johns Hopkins University and the University of California at Berkeley surveyed pool topography in five pools in a five-mile reach of river downstream from Grass Valley Creek. McBain and Trush (1997, p. 164) resurveyed these pools following the January 1997 flood, which deposited both fine and coarse sediment in the pools. Because the water was too turbid to allow visual observations of the bed, it was difficult to determine the relative volumes of sand and coarse sediment in these pools. They determined net fill in pools as follows:

Ponderosa Pool (RM 103.6)	4050 yd^3
Tom Lang Pool (RM 102.8)	3270 yd^3
Reo Stott Pool (RM 102.0)	670 yd^3
Society Pool (RM 101.3)	615 yd^3
Upper Steelbridge Pool (RM 99.0)	670 yd^3

The pool upstream of the Rush Creek delta was surveyed in April 2004 and June 2004. There was a net fill of 2260 yd^3 or 3615 tons of sediment (assuming a bulk density of 1.6 tons/ yd^3). (GMA, 2006, Table 8). The bedload of Rush Creek was 2850 tons in WY 2004, and 1975 tons in WY 2006 (GMA, 2006, Table 7). The gaging records suggest that the pool upstream of the confluence of Rush Creek is currently trapping more sediment than is being supplied by Rush Creek.

Sediment Basins

Sediment loads can be estimated by measuring deposition in sediment basins, as well as through direct measurements at gaging stations. Upper and Lower Hamilton Ponds are located in the lower reach of Grass Valley Creek and sediment (Figure 7), mostly decomposed granite, is trapped in the ponds during winter flows. The ponds do not fill completely every year; however, in the winter of 1998, both ponds completely filled with sediment. The 1998 sediment accumulation was about 42,000 yd^3 (Trinity County Resource Conservation District, 1998). When the ponds are filled or mostly filled, they no longer trap 100% of the bedload, so the estimate of 42,000 yd^3 for 1998 is a minimum amount. As the ponds are dredged in the future, a more complete record of deposition will become available.

Figure 7. View of Hamilton Ponds on lower Grass Valley Creek. The ponds trap fine sediment, mostly sand and fine gravels derived from decomposed granite. Photo courtesy of the U.S. Bureau of Reclamation.

Step 6: Prioritize, prescribe and implement restoration projects

There have been many previous efforts at watershed restoration in the western United States, some focused on in-stream restoration and others on upslope or riparian restoration. Based on a review of past projects and hands-on experience with restoration, a scientific panel developed a framework to prioritize restoration activities in salmon-bearing river basins (Bradbury and others, 1995). This framework provides a basis for restoration in tributary basins of the Trinity River, but specific goals of the Trinity River Restoration Program (TRRP) need to be incorporated into prioritization in this region. The following first summarizes the restoration framework set out by the Pacific Rivers Council (Bradbury and others, 1995), and then adds special concerns relevant to the TRRP.

1. Identify the geographic units to be prioritized, based on resources to be protected and risks to those resources.
2. Understand the pre-development condition of the watershed, historical changes in watershed conditions, current conditions, probable trends, and desired future conditions.
3. Remove or stop the human-caused perturbations that are degrading aquatic habitats and biological conditions in priority areas.
4. Then, allow the watershed time to recover naturally.
5. If the watershed cannot recover or recover quickly enough naturally, identify restoration activities that will help return it to conditions characterized by rates and patterns of erosion processes that deliver sediment at desired levels. Restoration projects are generally aimed at

moving the rates and patterns of erosion processes toward background conditions.

However, when there is lack of specific information about a watershed, the strategy most likely to be effective is to treat and reduce physical hazards in upslope areas that threaten the future health of the watershed (such as potential landslides), and to allow the riparian ecosystem to recover by stopping the damaging effects of activities such as grazing, timber harvest, road building and intense recreational use. At a minimum, following this strategy will reduce the likelihood that major disturbances, such as floods and fires, will exacerbate human impacts in a watershed and promote further ecosystem degradation. It will do no harm, and likely will be effective in helping a watershed return to conditions characterized by ecosystem processes and elements that sustain native fishes. The Bradbury report states that in the face of limited information it may make sense to redouble protection efforts rather than pursuing restoration. At the same time, efforts should be made to gain an understanding of ecosystem processes and elements so that a more targeted restoration strategy can be developed. If watershed-specific information is not detailed enough to construct a basin plan, the following steps can be followed (from Bradbury and others, 1995):

1) Treat and reduce upslope hazards.

Upslope efforts are primarily focused on treating road conditions that potentially lead to mass land failures, excessive gully erosion and chronic sedimentation (Table 7). In steep forested lands managed for timber, there are a few basic sources of human-caused erosion and sediment yield that have been identified as common and potentially important to anadromous fish. A sediment source assessment can identify if anthropogenic sources are dominant contributors of sediment in a given basin. There are only a limited number of these sediment sources that can be treated cost-effectively. Soil movement originating from roads is the most easily treated sediment source.

Cost-effective treatments are available to prevent and control these sources:

1. Stream crossing failures
2. Stream diversions at stream crossings
3. Road fill slope failures
4. Debris torrents from roads built across steep slopes or swales
5. Landing fill failures
6. Erosion of fine sediment from road surfaces, cutbanks and ditches.

Appendix 1 lists sources and uses of various erosion control products. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

In contrast to road-related sediment sources, sediment which originates from landslides, harvested hillslopes or steep streamside slopes and bank erosion is usually difficult or impossible to effectively control. The most effective technique is to prevent these human-caused sediment sources by avoiding timber harvest and road construction on potentially unstable slopes and avoiding disruptive land uses that trigger soil movement. Regardless of source of sediment, prevention is almost always the cheapest treatment for human-caused erosion and sediment yield, and in many cases it may be the only cost-effective solution.

Although some erosion occurs naturally, many watersheds now experience rates of soil erosion that are greatly increased over those of undisturbed landscapes. Of this increased erosion, only that sediment which reaches a stream channel, and is then transported downstream to fish-bearing reaches, will adversely impact aquatic habitat. Thus, the amount of this sediment actually delivered to a stream channel becomes more important than the total amount which may have eroded or failed. This delivered volume is called sediment yield. For this reason, recommended erosion prevention treatments are generally prescribed only for sites with a potential for future sediment yield. These are the only sites deemed capable of delivering sediment to downstream fish-bearing stream channels. Different erosional processes have different rates of sediment delivery or yield to the stream system. Some eroded sediment never reaches stream channels, and these sites become low priority for treatment. Many road cutbank failures and fill slope failures, where soil is deposited on the road bench or a naturally low gradient slope without entering a stream, fall into this category. Other processes deliver only a small portion of the failed or eroded sediment to a channel. Many hillslope landslides and slope failures along roads and landings fall into this category. Finally, some processes deliver a large proportion (up to 100%) of the eroded sediment directly to streams. These include eroded stream crossings (for example, where a culvert plugs and the stream gullies through the road fill), as well as gullies that develop when a stream is diverted out of its channel and down the adjacent road or hillslope.

A variety of treatments can be applied to prevent erosion and sediment yield to stream channels from roads. These include erosion-proofing roads and landings (Weaver and Hagans, 1994), road upgrading, and full road decommissioning. Roads in highly productive watersheds and sub-basins can be considered for either decommissioning or upgrading, depending upon the risk of their impacting the aquatic system. General techniques for decommissioning are well documented and tested, and costs and procedures are well established (Weaver and Hagans, 1994).

In priority watersheds, roads which pose high risk of accelerated or chronic sediment production and delivery or high long term maintenance costs, and which might be excellent candidates for decommissioning (proper “hydrologic closure”) can be delineated. Based on potential threats to the aquatic system, a variety of roads qualify as best candidates for decommissioning. These include roads built in riparian zones, roads with a high potential risk of sediment production (such as those built on steep inner gorge slopes and those built across unstable or highly erodible soils), roads built in tributary canyons where stream crossings and steep slopes are common, roads which have high maintenance costs and requirements, and abandoned roads. Not all roads are high risk roads and those that pose a low risk of impacting aquatic habitat in the basin may not need immediate attention. Roads which are of low relative priority for decommissioning include those which follow low gradient ridges, roads traversing large benches or low gradient upland slopes, and roads with few or no stream crossings.

2) Riparian ecosystem recovery

The first step in restoring riparian vegetation is to remove the human impacts that cause degradation, such as logging in riparian zones, development or agricultural activities at the streambank edge, and road construction. The objective of riparian ecosystem recovery is to re-establish functional and structural attributes of riparian vegetation. This means that riparian vegetation serves as a filter or buffer to reduce sediment input into streams, promotes bank stability, and is a source of large woody debris (important in trapping sediment and providing habitat). This objective of riparian restoration in tributary basins is different from the riparian restoration efforts on the mainstem Trinity River, where flow regulation has led to riparian encroachment on the floodplain.

3) Focus on prevention and protection efforts.

Where information on specific erosion rates is lacking, it may make more sense to put available resources into additional or broader protection and prevention of problems than to pursue restoration. Given limited financial and human resources, the incremental success is usually greatest when a given expenditure is applied to preventing potential problems, rather than to fixing existing problems (Ziemer, 1997). Involvement with public review processes, forming public-private partnerships, and exploration of alternative protection strategies such as conservation easements have all been used successfully in different areas. The public review process allows for specific land management concerns to be considered. For example, the California State Board of Forestry and Fire Protection is proposing changes to the Forest Practice Rules in several pertinent areas. One is for the development of a Road Management Plan (RMP) as a supplement to the Timber Harvest Plan process. The objective of the RMP is to specify measures to be applied to a forest transportation system to protect, maintain, and enhance the beneficial uses of water and other environmental resources. Another issue is that interim California State Forest Practice Rules for protection of listed anadromous salmondis will expire on Decmber 31, 2007. The California Board of Forestry and Fire Protection has appointed a Technical Advisory Committee to review scientific literature on forest management effects on riparian functions in anadromous fisheries. Land managers can submit literature for consideration for review and participate in the public review process to assure that relevant issues will be addressed by the State.

4) Other types of activities

There may be reasons to implement other types of activities in a watershed restoration program. For example, they may be legitimate experiments based on an analysis of reference conditions, including monitoring based on using a reference stream as a control; or funds or volunteer resources may only be available for specific activities other than those described above. Where ecosystem processes and elements are poorly understood, there is great potential for doing more harm than good, and a conservative approach to restoration may be considered.

Table 7. Examples of possible treatments for upslope, riparian and instream problems

Problem	Restoration Technique
Upslope	Rock native roads
Upslope	Construct sediment basins
Upslope	Outslope roads
Upslope	Upgrade culverts
Upslope	Excavate unneeded stream crossings
Upslope	Excavate unstable road fill
Upslope	Clean inboard ditches
Upslope	Install wattles on cutbanks
Upslope	Install silt fences below ravel/sheetwash areas
Upslope	Seed and mulch
Upslope	Install waterbars, critical dips or rolling dips
Upslope	Construct inboard ditch groins
Upslope	Fortify bridge abutments
Upslope	Drain or de-water wet areas to prevent erosion
Upslope	Maintain roads and patrol during storms
Upslope	Reduce concentrated discharge of water
Upslope	Remove skid roads and logging landings
Instream	Streambank replanting
Instream	Construct side channels
Instream	Dredge catchment ponds
Instream	Reset stream channel to natural path
Instream	Install streambank revetment
Instream	Remove aggraded sediment
Instream	Gravel ripping
Instream	Riparian planting
Instream	Riparian fencing
Riparian	Revegetation

5) Evaluate Treatment Cost-Effectiveness

Requiring proposed restoration projects to meet pre-established cost-effectiveness criteria is critical to developing a defensible and objective watershed protection and restoration plan. For sediment control, the cost-effectiveness of treating a work site can be defined as the average amount of money spent to prevent one cubic yard of sediment from entering or being delivered to the stream system ($/yd3). By using this evaluation methodology a variety of different techniques and proposed projects can be compared against each other using the same criteria: reducing the greatest amount of accelerated sediment yield for the least expenditure possible. The most cost-effective projects are those which prevent erosion and sediment yield, rather than those which try to control erosion once it has begun. Perhaps the most cost-effective tool for minimizing future erosion and sediment delivery to fish-bearing streams is the use of preventive land use practices that limit the amount and location of watershed disturbances. Next, projects that prevent erosion from existing disturbed areas (such as roads) through physical excavation, removal or upgrading are often relatively cost-effective. Projects which are least cost-effective are generally those which require relatively large amounts of hand labor, those that attempt to control ongoing erosion, and those that are designed to treat relatively small sediment sources.

Cost-effectiveness can be used as a tool to prioritize potential treatment sites throughout a sub-basin. It assures that the greatest benefit is received for the limited funding that is typically available for protection and restoration projects. The sites selected for eventual treatment are the ones that are expected to generate the most cost-effective reduction in sediment delivery to the drainage network and the mainstem channel. Estimating the cost-effectiveness of such projects will also help identify which roads in the basin are truly the best targets for decommissioning.

6) Trinity River Restoration Program -specific concerns:

In addition to the above generalized criteria, fine sediment reduction in Trinity River subbasins requires consideration of several other factors:

1) What is the fine sediment component of the sediment source?
2) What is the fine sediment component of the sediment delivered to the mainstem Trinity?
3) What is the timeframe of sediment delivery to the mainstem Trinity?
4) How does the probable fine sediment contribution from the tributary basin compare with the magnitude of fine sediment presently stored in stream channels?
5) Are proposed restoration activities consistent with other mandates, such as the TRRP Record of Decision or the Trinity River TMDL?

Comparison with Other Efforts:

Total Maximum Daily Loads (TMDL's)

In 1992, the Trinity River and the watersheds draining the Browns Project area were listed as water-quality impaired due to excessive sediment under the Clean Water Act Section 303(d) (NCRWQCB, 2001). The EPA (2001) concluded that the limiting factor to beneficial uses is excess sediment transported or deposited in the Trinity River. Fine and coarse sediment are considered negative to the designated beneficial uses including spawning gravel quality and permeability, pool depth and frequency, and other geomorphic indicators (e.g., channel stability). A water quality management plan or Total Maximum Daily Load (TMDL) was developed and approved by the EPA (2001) to reduce the amount of sediment in the Trinity River. The TMDL used existing data and reports to determine which subwatersheds nested within the Trinity River watershed are producing excess sediment. These reports included one by De la Fuente and others (2000), who conducted a region-wide assessment on USFS lands, and by GMA (2001) who conducted a sediment source study on the mainstem Trinity River. The TMDL sets sediment load allocations, by subwatershed, that specify the amount of sediment reduction needed to meet the water quality objectives (Fitzgerald, 2005).

The TMDL sediment source analysis shows that the majority of the management-related sediment sources result from roads, legacy mining, and timber harvest (GMA, 2001). The Weaver-Rush watersheds were analyzed as a subset of the TMDL analysis area. According to the TMDL, fine and coarse sediment originating from these watersheds needs to be reduced 42 percent to meet water quality objectives (EPA, 2001). The TMDL targets eliminating controllable sediment discharge sources which are sites or locations, both existing and those created by proposed land use activities, within the project area that meet the all of the following conditions (NCRWQCB, 2001):

--is discharging or has the potential to discharge sediment to waters of the state in violation of water quality requirements;

--was caused or affected by human activity; and

--may feasibly and reasonably respond to prevention and minimization management measures (i.e., Best Management Practices).

Sediment targets were set for both the mainstem and the watersheds draining to the Upper Middle Trinity River (USEPA, 2001). The watershed targets include:

> Less than 1% of the stream crossings will have diversion potential or stream crossing failure potential in a 100 year storm,
>
> The length of hydrologically connected roads will decrease.
>
> The length of roads inspected and corrected annually will increase.
>
> Road density next to streams will decrease.
>
> The percentage of outsloped and hard surfaced roads will increase.
>
> Activities in unstable areas will be avoided or eliminated.
>
> Areas disturbed by roads, landings, skid trails, and agriculture will decrease in impaired subareas.

Northwest Forest Plan

In 1993 President Clinton convened an interagency and interdisciplinary team to study management strategies in the range of the northern spotted owl. The outcome, a Forest Plan for a Sustainable Economy and a Sustainable Environment, outlined strategies for forest management, economic development and agency coordination. In the Record of Decision (ROD) of April, 1994, Alternative 9 of the Final Supplemental Environmental Impact Statement was adopted. Several guidelines in the ROD are applicable to restoration activities in the Trinity River basin:
P. 10: “Watershed restoration is designed to restore currently degraded habitat conditions. The most important components are control and restoration of road-related runoff and sediment production, restoration of riparian vegetation, and restoration of in-stream habitat complexity. Restoration programs will initially focus on arresting road-

related erosion and silvicultural treatments in riparian reserves to restore large conifer canopies. In-stream restoration is inherently short-term and will be accompanied by upslope and riparian restoration to achieve long-term watershed restoration. "

P. 73: "Watershed restoration is designed to address past disturbances by treating roads (decommissioning, upgrading, modifying drainage, etc.), restoring riparian vegetation and restoring instream habitat structure. "

B-31: "The most important components of a watershed restoration program are control and prevention of road-related runoff and sediment production, restoration of the condition of riparian vegetation, and restoration of in-stream habitat complexity." (This section emphasizes prevention as well as active restoration).

C-32: This section outlines road management guidelines, which include minimizing disruption of natural hydrologic flow paths, and minimizing sediment delivery to streams from roads.

The proposed strategy for fine sediment reduction in the Trinity River basin is consistent with the Aquatic Conservation Strategy outlined in the 1994 Record of Decision.

When Does It Make Sense to Move to Another Watershed?

Bradbury and others (1995) discuss the sequencing of restoration activities as follows: Watershed assessments and erosion inventories describe and document the expected magnitude of future, preventable erosion and sediment yield, especially from roads and other treatable sediment sources. Not all these future threats are of the same magnitude or importance, and not all have to be treated at once to provide adequate protection from short-term, catastrophic loss. In basins that are to be managed primarily for fisheries recovery and protection, a discrete list of prioritized erosion prevention and restoration projects can be implemented to limit the threat of future human-caused erosion and sediment yield. High priority, cost-effective erosion prevention sites need to be treated quickly in each high priority basin to protect valuable habitat from preventable storm damage or loss. As a general rule-of-thumb erosion prevention treatments which can be performed for less than \$10/yd^3 of material moved are considered relatively cost-effective. In most sub-watersheds, there will often be projects that are not considered cost-effective, compared to needed restoration and protection work that could have been done in other priority watersheds. Once initial, cost-effective measures have been undertaken to protect these basins from the threat of catastrophic habitat loss, the remaining prevention, protection and restoration measures that are needed to encourage long term recovery can then be implemented. Restoration and protection work in a priority watershed may never be completed if that watershed is also to be subjected to continued disturbances associated with land management. High risk roads can be decommissioned and "storm-proofed" to provide for immediate protection against loss, but proposed land management necessitates continual review and analysis to assure that the aquatic system is adequately restored and protected from the effects of past and future land use activities.

Common recommendations for roads that will not be decommissioned are to: reduce wet season traffic, water native-surface roads during dry season use, disconnect the road hydrologically by outsloping the road or installing ditch relief culverts, frequent cross road drains or waterbars with armored outlets, and rocking hydrologically connected areas. Rolling dips can be constructed at all culvert locations, or inverted water bars can be used where rolling dips are unfeasible. Other actions include installing trash racks at culverts and wattles at critical stream crossings, and placing rock weirs or gravel in inboard ditches to trap fine sediment. Coe (2006) states that road sediment production is best mitigated by rocking native surface roads, decreasing sediment transport capacity by improving and maintaining drainage, and avoiding sites with soil characteristics that increase road surface and ditch runoff. He suggests that grading road surfaces and ditches be kept to a minimum as this increases sediment production rates.

Step 7: Monitor effectiveness of erosion control efforts

A critical step in adaptive management is to learn from one's mistakes into order to prescribe more effective management actions. An evaluation of restoration effectiveness is necessary to adapt restoration techniques and to apply resources in the most cost-effective manner. Bibliography Part 3 lists suggested reading for monitoring protocols and designing monitoring studies.

Several examples of monitoring road upgrades and road decommissioning projects in northwestern California are available. Pacific Watershed Associates (2005) assessed 51 miles of decommissioned roads in northwestern California. This assessment included 275 stream crossings and 111 landslides. Stream crossings accounted for 85 % of the documented sediment delivery, and 57 % of the treated stream crossings that were inventoried did not meet standards. The average delivery volume for a stream crossing that met all of California Department of Fish and Game (CDFG) protocols was 23 yd^3/site and the average delivery volume for a stream crossing that did not meet CDFG protocols was 42 yd^3 /site. Channel incision, surface erosion, slumping and debris slides were the most common post-treatment erosion features. These results are consistent with those of Madej (2001) who examined 24 miles of roads with 207 stream crossings. In this case the treated crossings were 'tested' by a large flood in 1997, and average erosion at the crossings was about 65 yd^3 /site. However, post-treatment erosion is variable, and 20 percent of the excavated stream crossings accounted for 73 percent of the post-treatment erosion. In the Mattole River basin, Klein measured an average post-treatment erosion rate of 15.5 yd^3 /site at 18 stream crossings.

http://www.bof.fire.ca.gov/pdfs/RKleinSanctSept2003.pdf

The effects of stream crossing upgrading (not removal) on channel erosion are reported by Harris and others at:

http://www.bof.fire.ca.gov/pdfs/Harris_Sept_2006_MSG_crossing_upgrade_DANR.pdf

In their study, average erosion was only 1.75 yd^3 /site, probably because the streambed was protected by a culvert rather than having a native bottom as in stream crossing excavations. Seventeen percent of the crossings accounted for 76 percent of the erosion.

In channel measurements following road upgrade work in the Scott River basins showed a decrease of fine sediment in pools:

http://www.bof.fire.ca.gov/pdfs/FrenchCreekWAG_04SariS.pdf

It is expected that monitoring the effectiveness of sediment reduction activities in the Trinity River basin will be conducted primarily by the agency or organization that implements the restoration action. CDFG has established protocols to monitor the effectiveness of road upgrades, road decommissioning, bank stabilization, and in-stream substrate restoration. Details of these protocols with sample field forms are listed in Harris (2005). Depending on the type of restoration work conducted, monitoring of restoration sites is likely to include the following:

A) Road upgrades and decommissioning:

Before and after photography on site
Measurement of erosion voids after storms
Measurement of soil pedestals after winter.
Erosion pins to measure surface erosion
Limited use of soil erosion troughs and sediment traps on experimental sites
Grab samples for turbidity or suspended sediment concentration in inboard ditches and at culverts and stream crossings

B) Bank stabilization

Before and after photographs
Cross-sectional surveys
Vegetation transects

C) Landslide prevention

The general procedures for treating road-related landslides are to permanently remove unstable fill from the potential landslide feature and to dewater the site if possible. Landslide frequency can be monitored through air photo analysis every five years, or as air photo flights are obtained. Possible sources of air photos are the US Forest Service, Trinity County and timber companies. Field-based road inventories are needed to assess small features that are not visible on air photos. PWA (2005) provides examples of monitoring landslide treatments.

D) In-channel monitoring of fine sediment storage and transport

1. Stream gaging with turbidity sampling and limited suspended sediment sampling. Such sampling is on-going in Rush and Indian Creeks. Shifts in turbidity or suspended sediment rating curves following treatment can be detected by testing for significant differences in slopes or intercepts, using multiple slopes model of the rating curve regressions.
2. Shifts in bedload rating curves in gaged tributaries.
3. Facies mapping in low gradient, depositional index reaches of tributary channels.
4. Average surface particle size can be determined with pebble counts in index reaches

5. Average subsurface particle size can be determined through bulk sampling and sieving in index reaches
6. Measurement of fines in pools (V_*). Pools are the most vulnerable locations for fine deposition. The fraction of residual pool volume filled with fine sediment, known as V_*, may be used as an index of fine sediment supply (Lisle and Hilton 1992; Lisle and Hilton 1999). Decreases in fine sediment supply may be reflected in lower V_* numbers and higher residual pool volumes.
7. Delta surveys at the mouths of tributaries. Rush and Indian Creeks have prominent deltas, but not all tributaries exhibit this geomorphic feature.

Within the larger framework of the Trinity River Restoration Program, the Integrated Assessment Plan covers other restoration techniques. Monitoring the effectiveness of watershed restoration in tributary basins will be incorporated into this assessment plan as well, and the interaction of various restoration activities will be assessed.

Part 2: Rush Creek Example

Purpose

The purpose of this section is to apply the guidelines proposed in Part 1 to a pilot watershed, the Rush Creek watershed, which is located downstream of Lewiston Dam at about River Mile108. Rush Creek drains an area of 22.7 mi^2 (22.3 mi^2 at the gaging station). Factors contributing to sediment production in this basin are explored. Sources of fine sediment from Rush Creek are identified broadly in this section, and more details of contributions from landslides, roads and harvest units will be discussed by Fiori (in preparation).

Previous studies

Extensive studies have been conducted in the Trinity River basin (2ee Bibliography 2). In Rush Creek specifically, there have been several efforts to document channel and watershed conditions in portions of the watershed by various agencies. The "Sediment Source Analysis for the Mainstem Trinity River, Trinity County, CA (Graham Matthews and Associates, 2001) (GMA, 2001) reports turbidity measured at several sites in February, 2000, ranging from 6 to 743 NTU's. McBain and Trush (M&T) surveyed three cross sections on Rush Creek in 1997 at the gaging station. Three other cross sections on lower Rush Creek were surveyed in 1995 and resurveyed in 1997 (reported in GMA, 2001, p. 12). McBain and Trush also have mapped the delta at the mouth of Rush Creek and the pool upstream of the Rush Creek delta, which will be discussed in more detail below. The U. S. Forest Service (USFS) has measured channel and substrate characteristics in Rush Creek on USFS lands. The study reach is about 4200 ft. long on middle Rush Creek, downstream of Baxter Gulch and upstream of the Rush Creek Road bridge.

The USFS also completed a watershed analysis for the Weaverville area (USDA Shasta Trinity National Forest, 2004). In this, slope stability hazards were determined through air photo interpretation and field reconnaissance. The Weaver-Rush Creek subwatershed area had the highest road hazard indicator as compiled by de la Fuente (2000). In his analysis he found 13 road miles on slopes greater than 45 percent gradient, a road density in the stream buffer zone of 1.65 mi/mi^2, and the density of road-stream intersects to by 3.6 $intersects/mi^2$. These data were used in constructing the TMDL targets described in Part 1.

Climate

Average precipitation at Weaverville is 37.6 inches per year, based on records from 1870 to 2006 (Figure 8). Annual precipitation is greater at higher elevations, where snowfall becomes more important. 2005 was the ninth wettest year on record, with 54.87

inches. This amount corresponds to about a 25-year recurrence interval (California Department of Water Resources:

(*http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=WVR*)

There is a wide range of monthly precipitation values, and December and January are usually the wettest months (Figure 9). A plot of the cumulative departure from the mean (Figure 10) shows periods that are wetter than usual (rising limb) or drier than usual (falling limb). Since 1994 the Weaverville area has experienced a wetter-than-usual trend, which probably increases short-term erosion rates. The influence of storms on landslide occurrence will be discussed by Fiori (in preparation).

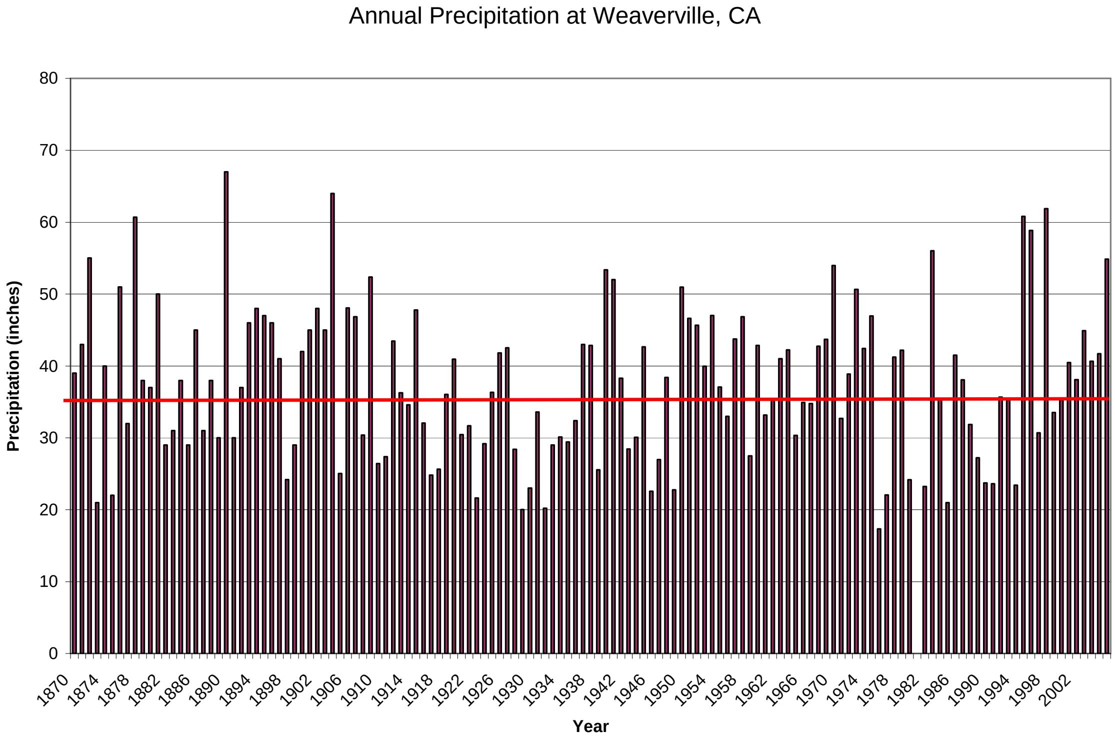


Figure 8. Annual precipitation at Weaverville, California, 1870-2006.

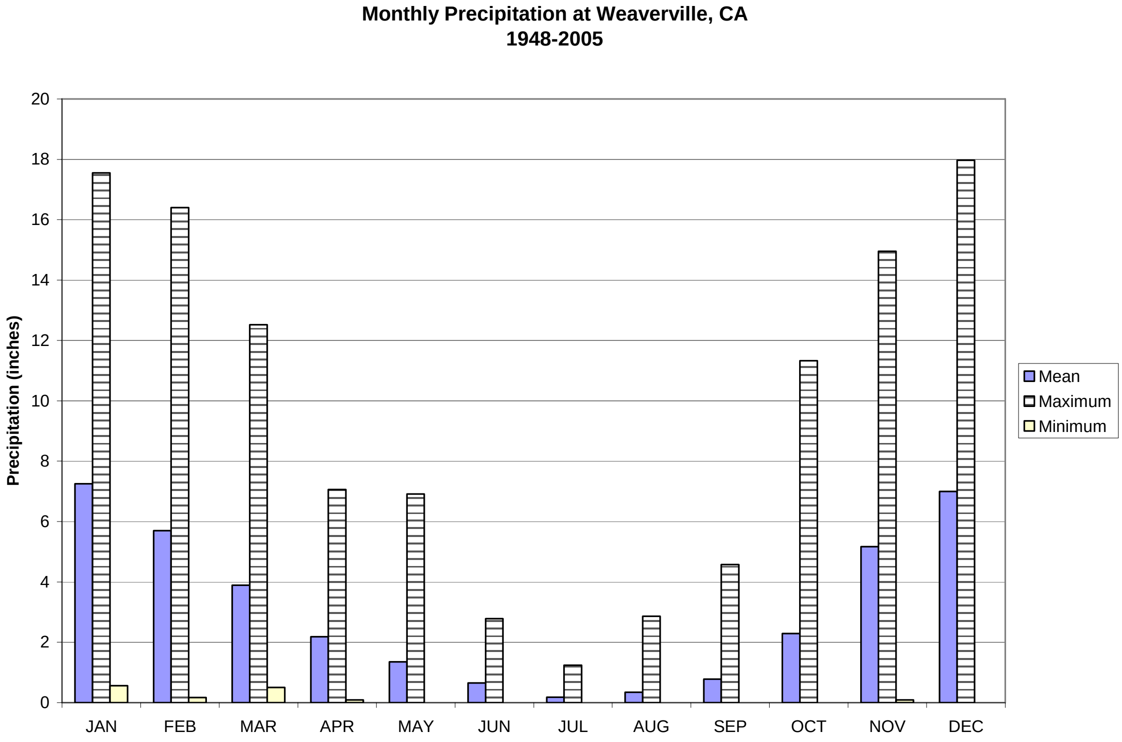


Figure 9. Maximum, minimum and mean monthly precipitation at Weaverville, California, 1948 - 2005.

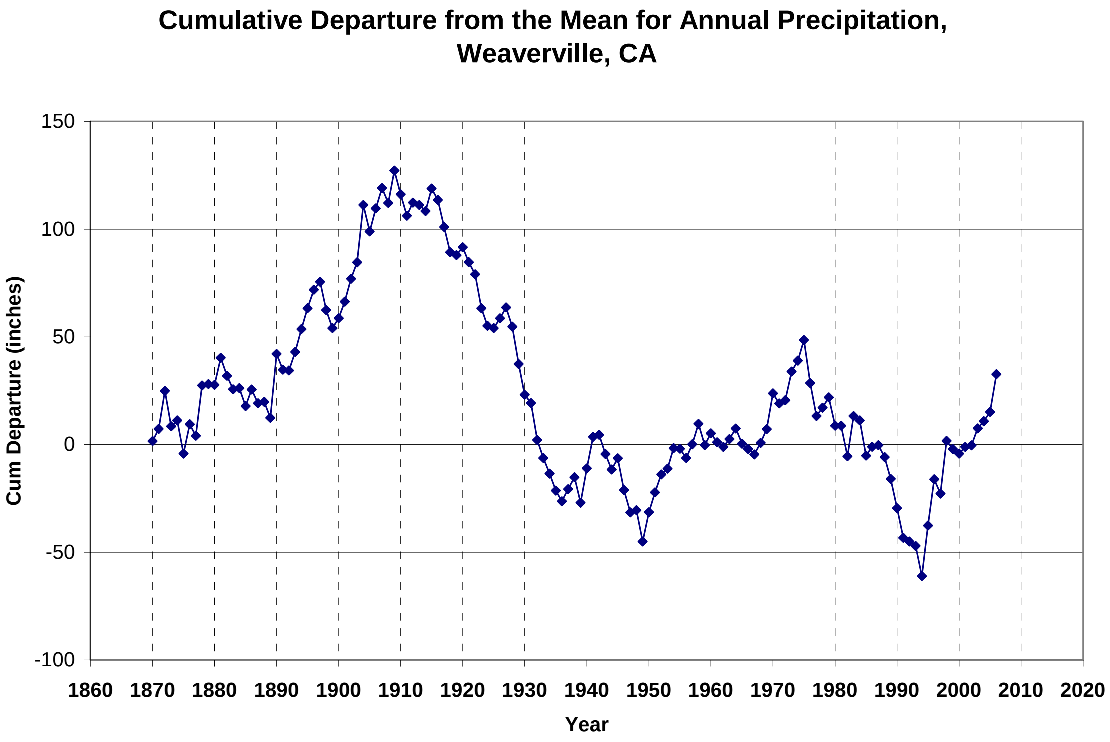


Figure 10. Cumulative departure from the mean for annual precipitation, Weaverville, California.

Geology and Geomorphology

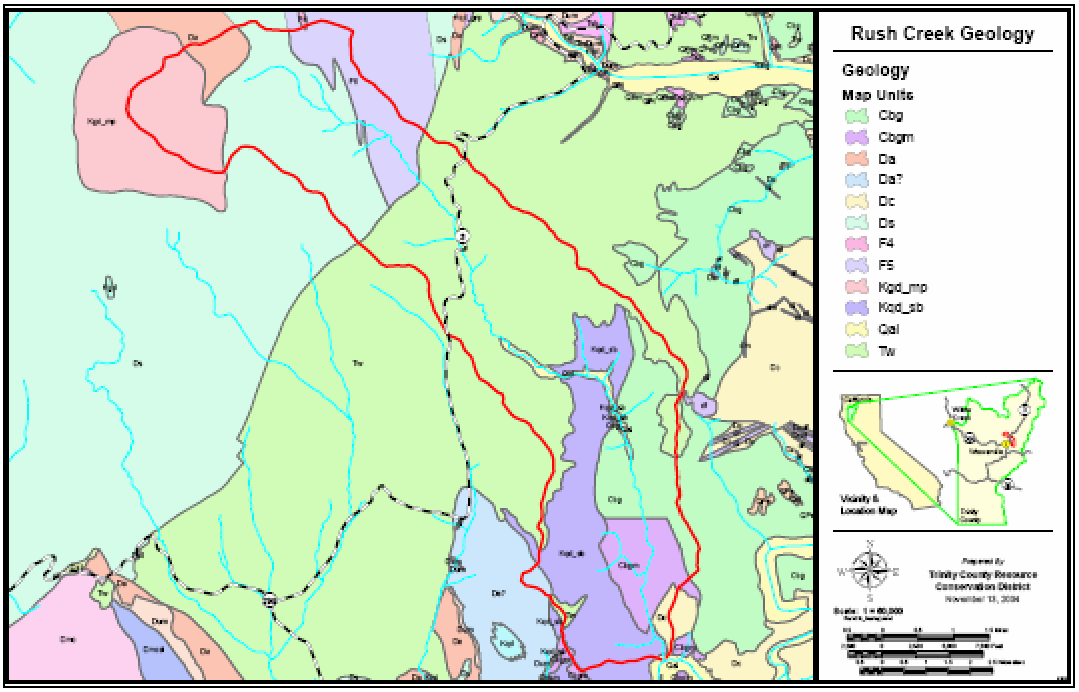


Figure 11. Geology of the Rush Creek watershed.

Figure 11 shows the geologic units of the Rush Creek basin. The watershed boundary is outlined in red. Descriptions of the units (below) are based on Fraticelli and others (1987) and Phillips (1989). The predominant bedrock types underlying managed lands in the Rush Creek basin are the Weaverville Formation, the Shasta Bally batholith, and the Bragdon Formation. All of these produce abundant fine material upon weathering. For example, average grain sizes of the Weaverville Formation sandstones vary from 0.5 to 3 mm (Phillips, 1989), which is within the size range of concern for sediment input into the Trinity River. Soils (discussed in detail in a later section) reflect the characteristics of the underlying bedrock in terms of particle size.

Cbg: Bragdon Formation (Eastern Klamath Terrane): Dark-gray to black shale, mudstone, and siltstone in lower part; siliceous sandstone, grits, and chert conglomerate prominently interlayered with dark pelitic rocks in middle and upper parts. The abundant chert in the conglomerate is of unknown source.
Cbgm: Bragdon Formation, within contact aureole of Shasta Bally batholith.
Da: Abrams Mica Schist (Central Metamorphic Group): Schistose metasedimentary rocks; generally micaceous and quartzitic; discontinuous lenses of micaceous marble near base.
Da?: Abrams Mica Schist in contact aureole of Shasta Bally batholith, with gneiss and amphibolite.

Dc: Copley Greenstone (Eastern Klamath Group) (Pillow lavas and volcanic breccias; includes some metaandesite and metabasalt.
Ds: Salmon Hornblende Schist (Central Metamorphic Group): Amphibolite-grade hornblende schist and gneiss; locally includes lenses of micaceous schist. Lower part of unit in the Weaver Bally area may be metagabbro;
F4: Stuart Fork Formation (North Fork Terrane): Metasedimentary rocks; includes phyllitic quartzites and dark quartz-mica phyllites, commonly graphitic.
F5: Stuart Fork Formation (North Fork Terrane): Metavolcanic rocks; fine-grained greenstones and associated schistose metavolcanic rocks interfingering with siliceous Stuart Fork rocks in upper part of formation.
Kgd_mp: Monument Peak Pluton –granodiorite.
Kqd_sb: Shasta Bally Batholith: Quartz diorite and granodiorite of Shasta Bally
Qal: Alluvium: Unconsolidated silt, sand, and gravel in modern stream channels and on associated low terraces.
Tw: Weaverville Formation: Lacustrine facies occur at the base of the Weaverville sequence and are overlain by alluvial floodplain sediments which include coarse channel fill deposits and bar conglomerates. Floodplain sediments and fluvial conglomerates are intercalated with debris flow deposits. The diverse assortment of clasts consists primarily of hornblende schist, mica schist, greenstone, serpentized periodotite, gabbro, sandstones and siltstones, with smaller percentages of granodiorites.

The USFS prepared a map of geomorphic features for the Weaverville area (Figure 12) that was incorporated into the Weaverville Watershed Analysis (2004). The headwaters of Rush Creek are dominated by steep slopes and many slope failures or areas prone to failure (A), but a sediment storage area at B probably traps much of the sediment originating from the headwaters. A stream reach at ‘C’ is mapped as a scoured channel or transport zone and has little stored sediment in the channel. Several deep-seated slides are identified, especially in the middle basin. Many slides are considered dormant, but have the potential for re-initiation if the land is managed intensely in the future. Valley inner gorges are defined as those slopes adjacent to channel margins having gradients greater than 65%, and these areas are considered to be a high hazard zone.

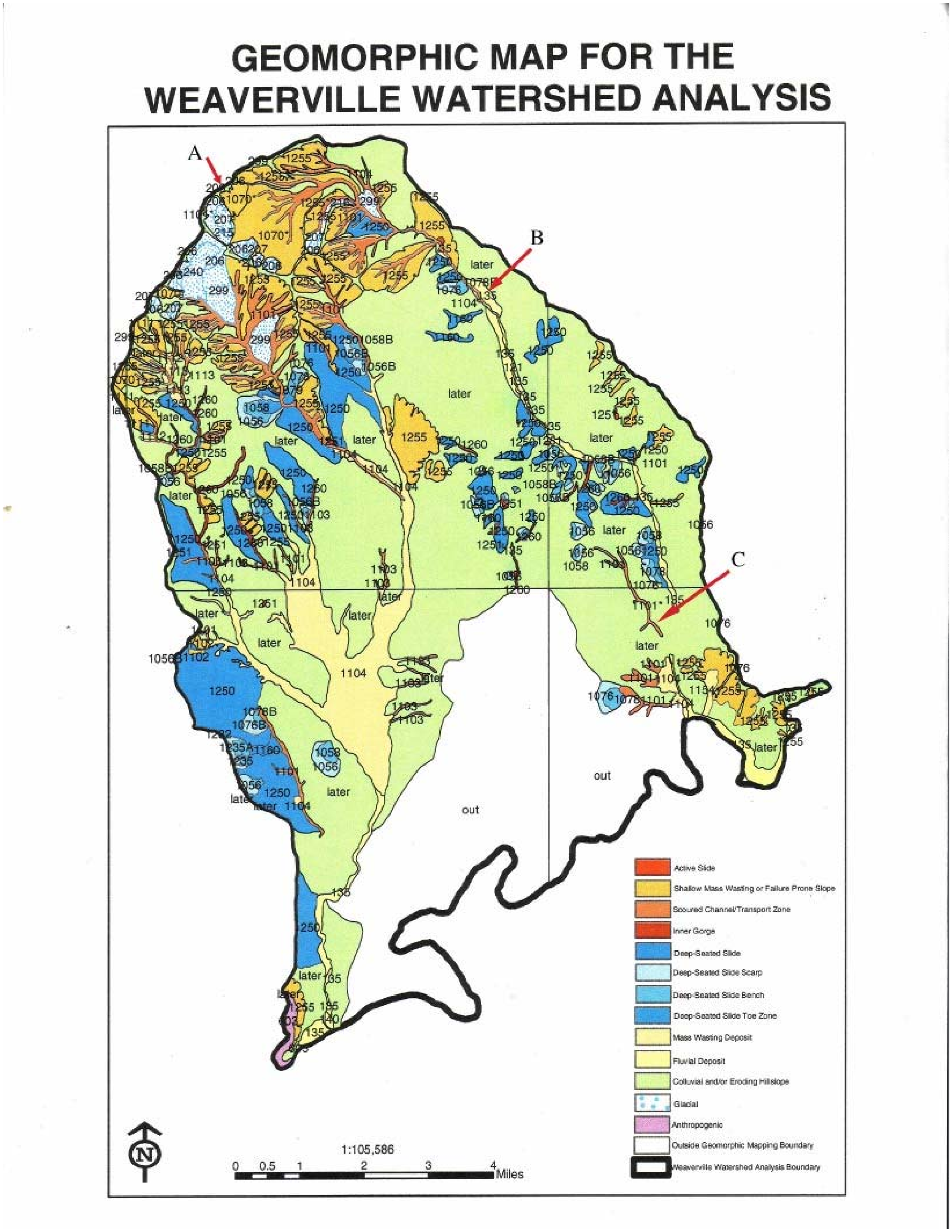


Figure 12. Geomorphic map (from USFS).

Soils

Soils in the Rush Creek basin have been mapped by two different methodologies, one by the U.S. Forest Service on federal lands and one by the Natural Resources Conservation Service (Figure 13), which covers most of the privately owned lands. Soils have formed primarily as weathering products of metavolcanic and metasedimentary bedrock units. Soils are generally shallow to moderately deep loams to gravelly loams. Erosion susceptibility of the soils is a function of many factors, including soil texture, depth, fraction of clay and of coarse fragments, hillslope gradient, and surface cover. The relative contribution of a given soil to the fine sediment loading of a stream depends greatly on the particle size distribution of the soil column. Detailed soil characteristics and particle size information are listed in Appendix 2, and Appendix 3 shows a map of the relative coarseness of the soil units in the Rush Creek watershed.

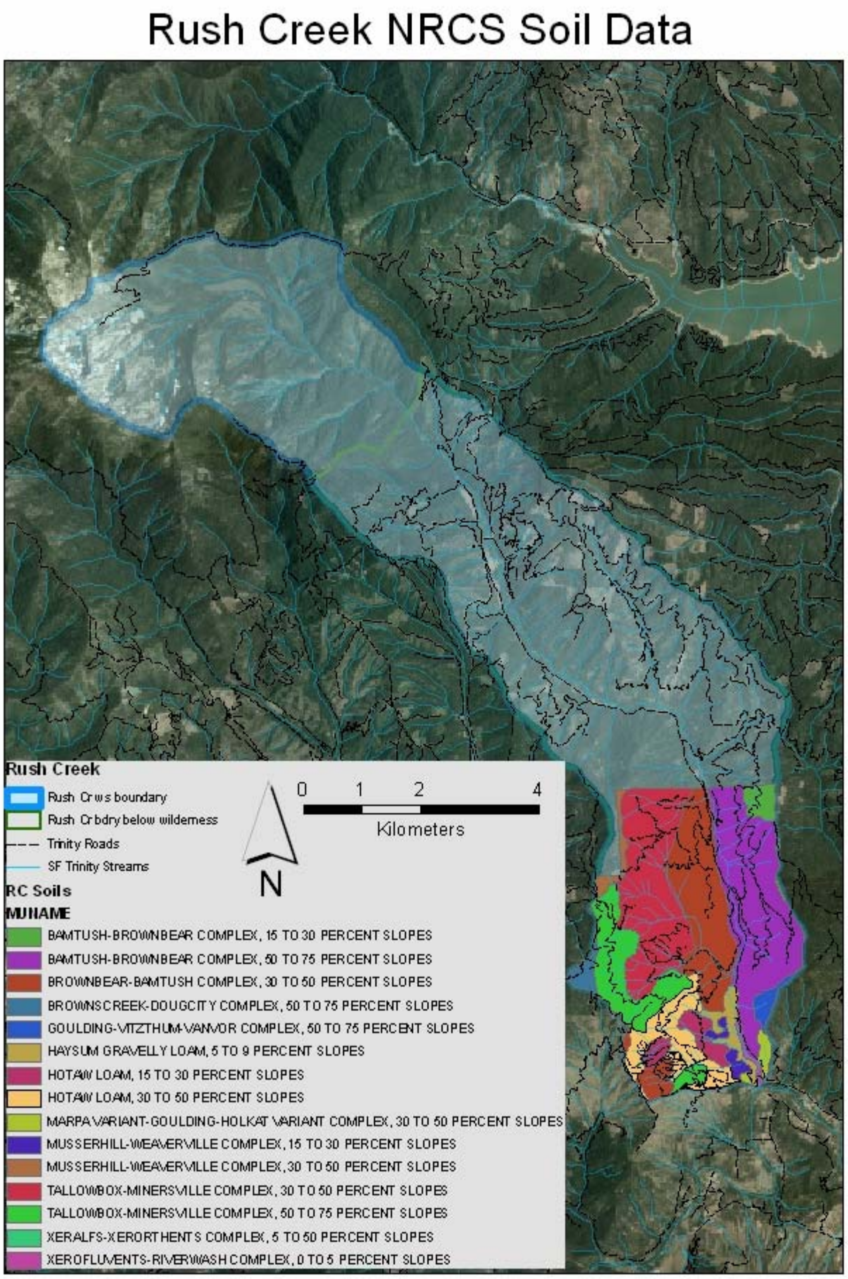


Figure 13. Rush Creek soil map (Natural Resources Conservation Service).

Table 8. U.S. Forest Service Soil Survey and NRCS equivalent soils

STNF Soil Name	STNF Taxonomic Name	NRCS Soil Equivalent	NRCS Taxonomic Equivalent
Soulajule Family	clayey-skeletal, mixed, mesic, Ultic Haploxeralfs	Marpa Variant	clayey-skeletal, mixed, mesic Ultic Haploxeralfs
Ishi Pishi Family	clayey-skeletal, serpentinitic, mesic, Ultic Haploxeralfs	Dubakella Series	clayey-skeletal, serpentinitic, mesic, Mollic Haploxeralfs
Holland Family, deep	fine-loamy, mixed, mesic, Ultic Haploxeralfs	Hotaw Series	loamy-skeletal, mixed, mesic Ultic Haploxeralfs
Marpa Family	loamy-skeletal, mixed, mesic, Ultic Haploxeralfs	Marpa Series	loamy-skeletal, mixed, mesic Ultic Haploxeralfs
Forbes Family	fine, oxidic, mesic, Ultic Palexeralfs	Weaverville Series	fine-loamy, oxidic, mesic Ultic Palexeralfs
Chaix Family	coarse-loamy, mixed, mesic, Dystric Xerochrepts	Minersville Series	coarse-loamy, mixed, mesic Typic Xerochrepts
Neuns Family	loamy-skeletal, mixed, mesic, Dystric Xerochrepts	Barpeak Series	loamy-skeletal, mixed, mesic, Dystric Xerochrepts
Neuns Family	loamy-skeletal, mixed, mesic, Dystric Xerochrepts	Sheetiron Series	loamy-skeletal, mixed, mesic, Dystric Xerochrepts
Deadwood Family	loamy-skeletal, mixed, mesic, Dystric Xerochrepts	Barpeak Series	loamy-skeletal, mixed, mesic, Dystric Xerochrepts
Deadwood Family	loamy-skeletal, mixed, mesic, Dystric Xerochrepts	Sheetiron Series	loamy-skeletal, mixed, mesic, Dystric Xerochrepts
Chawanakee Family	loamy, mixed, mesic, Dystric Xerochrepts	Holkat Series	fine-loamy, mixed, mesic, Dystric Xerochrepts
Xerofluvents	coarse-loamy, mixed, mesic, Typic Xerofluvents	Xerofluvents	coarse-loamy, mixed, mesic, Typic Xerofluvents

Post-Fire Erosion

The Weaverville Watershed Analysis (2004) states that if a catastrophic fire were to occur in this area, severe erosion would occur on granitic soils and fine-textured nonmarine sediments. Catastrophic fire would remove soil cover and burn surficial organic matter, which would lead to rill and gully erosion in the granitics and sheet and rill erosion in the sedimentary units. Large landslides following the Lowden fire in adjacent watersheds (Figure 3) illustrate that mass movement also poses a post-fire risk in these basins. Post-fire erosion rates are discussed on page 15. Although fires cannot be predicted, communities in the Trinity River basin are reducing fuels under the guidance California Trinity County Fire Safe Council. The effects of fuels reduction work (Figure 4) on reducing fire frequency and severity and on soil erosion rates are presently not well known.

Land Ownership and Land Use

The steep headwater region of Rush Creek is managed by the U.S. Forest Service, whereas the downstream portion of the basin is primarily privately owned lands (Figure 14). Sierra Pacific Industries (SPI) is the dominant landowner in the basin (Figure 15). Timber harvest occurs on both USFS and SPI land.

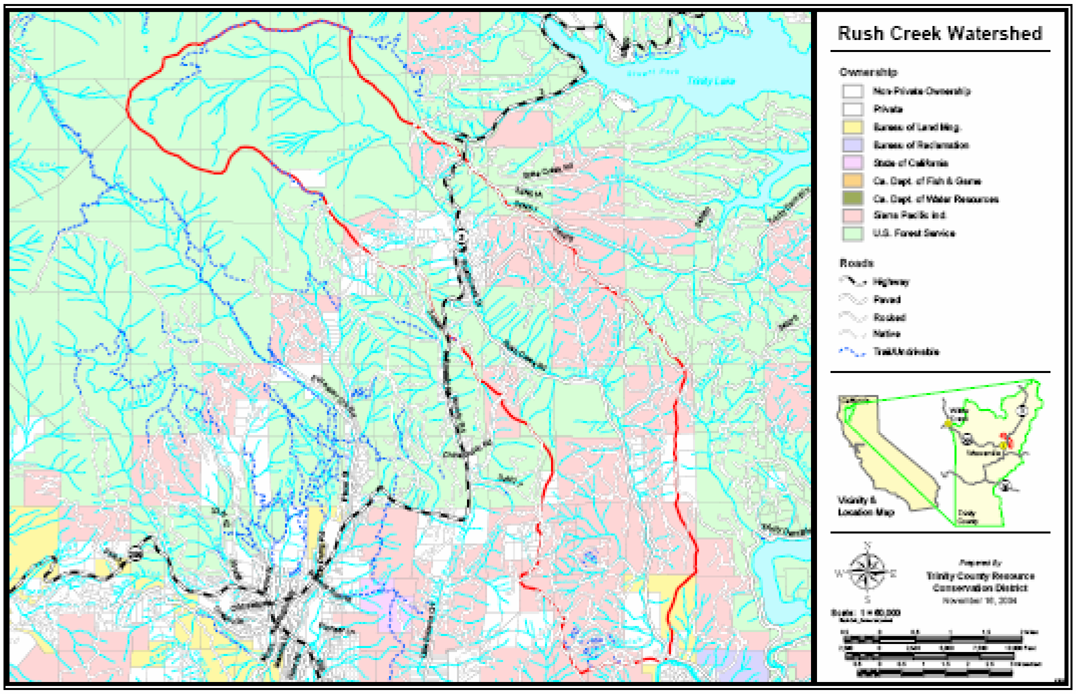


Figure 14. Land ownership patterns in the Rush Creek watershed.

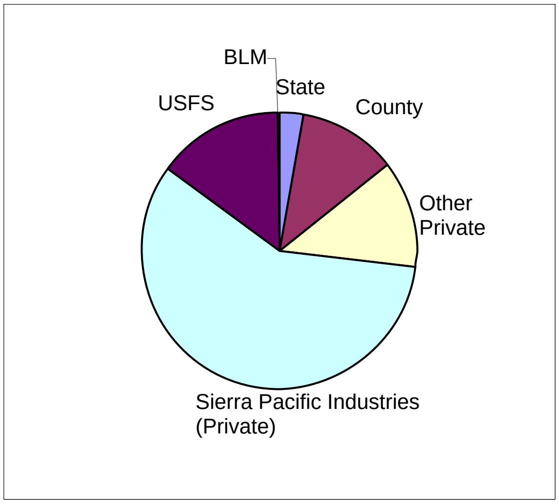


Figure 15. Distribution of land by ownership in the Rush Creek Watershed.

Trinity County is rural and has a low population density of only 4 people per square mile. There was a peak in new home construction in the county in the 1970's, based on U.S. Census Bureau data (Figure 16). Currently there are about 100 residences in the Rush Creek basin. At this time there is no grading ordinance in this area; however, construction-related erosion occurs on newly developed sites (Figure 17). Even though erosion from residential roads and building sites is not a major source of sediment in the basin, this type of erosion is easily preventable. The California Stormwater Quality Association (CASQA) Best Management Practices (BMP) Handbook is available at: *http://www.cabmphandbooks.com*. This handbook has several useful fact sheets for controlling erosion and runoff on construction sites and on unpaved areas. Because of the rural character of much of the development in Trinity County, there are more unpaved driveways and access roads than in an urban area, but specific erosion rates on these roads have not been measured.

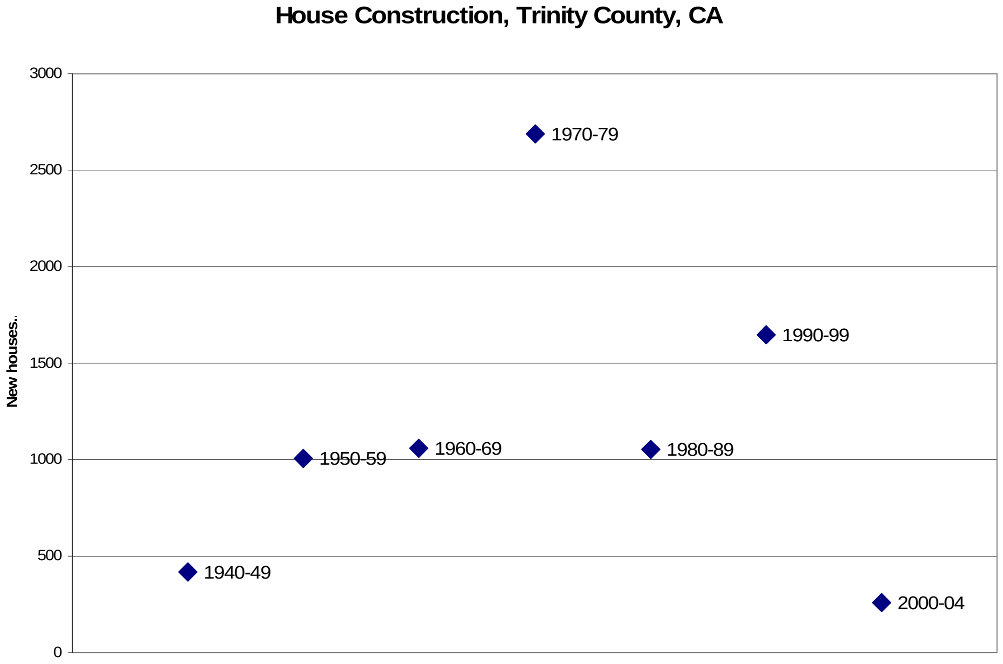


Figure 16. Trends in new home construction in Trinity County, CA.

Figure 17. Example of rill erosion on cutbank in new housing development near Weaverville, California.

Sediment Sources

Mass Movement

Documenting the history of past mass movement activity provides an estimate of the volume of material that has been delivered to streams and is an indication of locations of unstable areas. There have been some major landslides in the Rush Creek basin (Figure 18). In this study, an analysis of repeat aerial photography formed the basis of landslide quantification. Photos were used to determine the location and size of landslides in the Rush Creek basin (Appendix 4). Air photos from 1944, 1960, 1970, 1989, 1998 and 2003 were available for inspection. Landslides were classified by land ownership (U.S. Bureau of Land Management, Sierra Pacific Industries, U.S. Forest Service, and other private land), and by land use (harvest area, associated with a road, or natural). To calculate a volume of landslide, a depth of failure needs to be applied to each area. Representative depths for a range of landslide types and size were obtained in the field. Through air photo analysis, the amount of the landslide volume that was delivered to stream channels was also estimated.

Figure 18. Photo of a large landslide in the Rush Creek watershed. Landslides are a major sediment source in the Rush Creek watershed.

In order to predict where landslides will occur in the future, which is important in guiding future land use activities, slope stability models were used to characterize the terrain. In this study

SHALSTAB, a digital terrain model for mapping the pattern of potential shallow slope instability, was used initially to characterize areas of various slope stability classes in Rush Creek (Figure 19). The most unstable areas are in red, and the most stable are areas are shown in blue. The headwaters of Rush Creek have the steepest and most unstable slopes, but this is a mountainous wilderness area with no management control. Another potentially unstable area is in the downstream eastern portion of Rush Creek on the metasedimentary rocks of the Bragdon Formation. This SHALSTAB map should be considered a tool to identify stability problems, but field verification of unstable areas in necessary for planning specific land management actions.

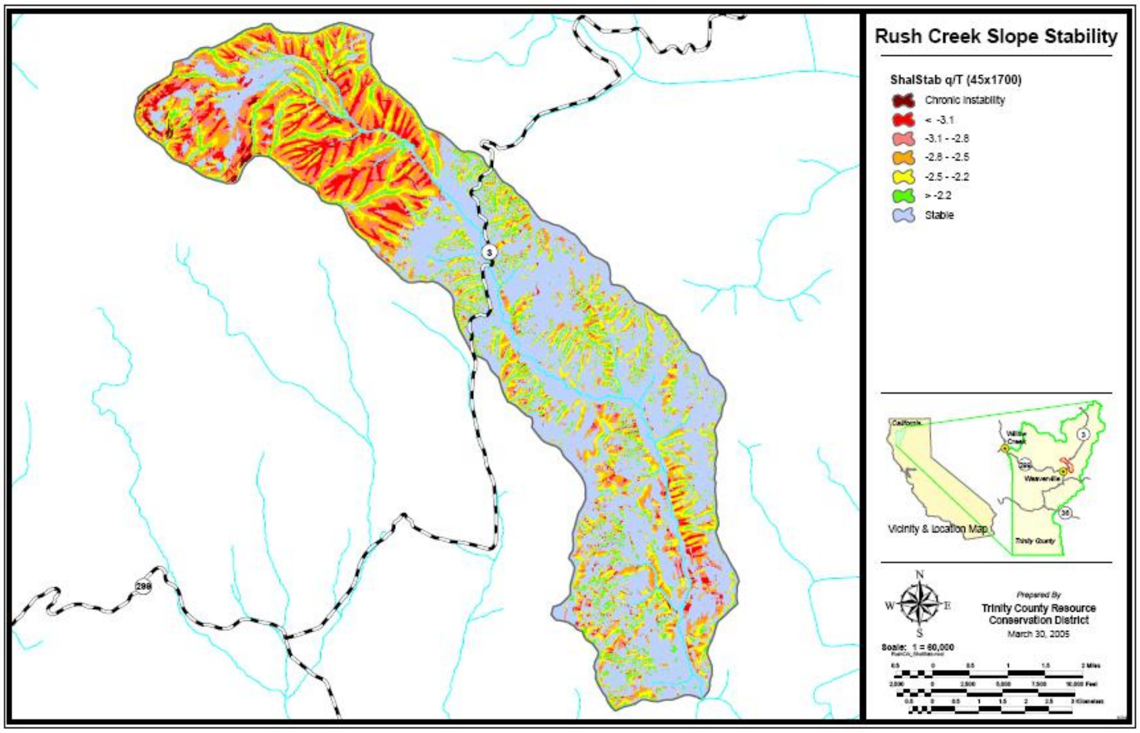


Figure 19. Slope stability map for Rush Creek watershed, based on SHALSTAB modeling. Red areas are the most unstable and blue areas are the most stable.

An alternative method of mapping slope instability is a model called SINMAP (Stability INdex MAPping). Fiori (in preparation) reports the SINMAP results for Rush Creek (Appendix 5), the volumes of material delivered by landslides in each air photo period by landownership, and whether the slides are associated with timber harvest, roads, or are natural.

Road-Related Erosion

Road density, at 4.5 miles/mi^2, is high in the Rush Creek basin. Some sub-basins have even higher densities. By far, the most common type of road is unpaved, or native, surface

(Table 9). Sierra Pacific Industries owns the majority of the road length in the basin (Figure 20). An inventory of road-stream crossings by Trinity County estimated the amount of road fill in county road crossings. Most crossings on county roads have 100 to 500 yd^3 of road fill (Figure 21). These results can be extrapolated to privately owned roads, based on the drainage area upstream of the crossings (Appendix 6). If the crossings are decommissioned, this is the volume of material that would have to be excavated. The County road inventory indicates that stream crossings represent the largest potential sediment input (Figure 22). However, if the culverts plugged (Figure 23) and the crossings failed, only 50 to 70% of the fill volume would actually be delivered to the streams, based on inventories in other northern California watersheds (unless a debris torrent was generated). Landslides originating on cutbanks or fillslopes and surface erosion from the road cutbank and road tread have the potential to contribute about the same mass of material, based on the county inventory (Figure 22). The relative stability of road reaches can be determined by overlaying road location with the slope stability mapping described above. Appendix 7 shows the relative stability rating of roads in the Rush Creek watershed.

Table 9. Types of roads in the Rush Creek Watershed

Road Type	Miles
Highway	3.1
Paved	9.3
Rocked	8.8
Native	75.9
Trail/Undrivable	3.9
Total	101.0

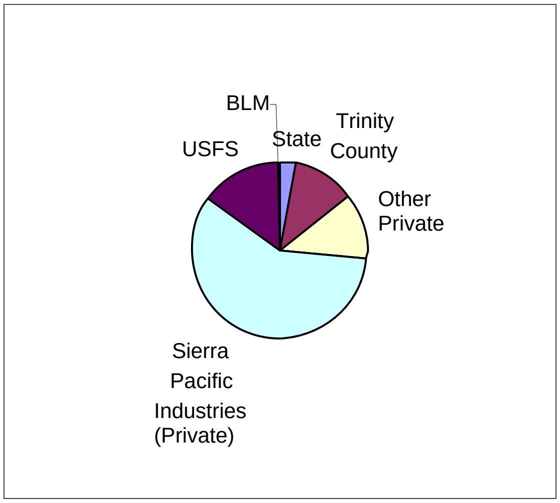


Figure 20. Distribution of roads in the Rush Creek watershed by ownership.

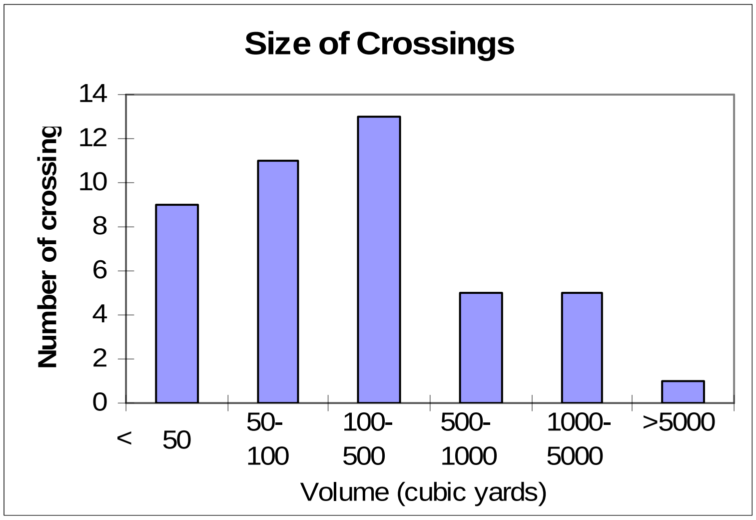


Figure 21. Volume of fill in stream crossings on Trinity County roads in the Rush Creek area.

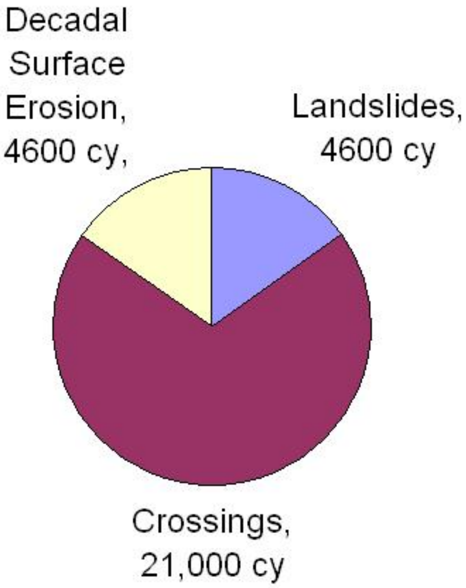


Figure 22. Potential sediment input volumes (in cubic yards) from Trinity County roads in the Rush Creek watershed, based on DIRT inventories.

Figure 23. Culverts plugged with sediment are a common problem on forest roads.

Road Cutbank Erosion Rates

In inventories of Trinity River basin roads, the erosion rates of cutbanks along roads have been estimated based on rates reported in the literature. Cutbank surface lowering rates used in Trinity County's road inventory were:

High: 0.05 ft/yr (15 mm/yr)
Moderate: 0.03 ft/yr (9 mm/yr)
Low: 0.01 ft/yr (3 mm/yr)

Most of the previous studies have been conducted on granitic terrain. No measurements on cutbank erosion rates had been collected on the Weaverville Formation, a prominent bedrock type in the Rush Creek basin. To verify that the rates based on other studies were reasonable for the Rush Creek watershed, we measured cutbank erosion rates through the use of erosion pins at five sites within the Weaverville Formation. Erosion pins measure overall surface lowering through erosion processes such as raindrop impact, sheet erosion, raveling or freeze-thaw processes. Locally rills may form on cutbanks as well. If rills are the predominant erosion process, other techniques such as the use of an erosion bridge would be needed (Weaver and Harris, 2005).

Grids of 10 erosion pins were installed at six locations in the Rush Creek basin in the fall of 2005 on several types of roads (Figures 24 to 28). Erosion pins were installed perpendicular to the cutbank surface before fall rains and were measured in the spring of 2006 following the rainy season. Initially the pins were pushed into the soil until the caps were flush with the ground surface, and then in the spring the distance from the soil surface to the top of each pin was measured. This effort should be considered a pilot study to define magnitude and variability in erosion rates, and results can be used to develop a broader sampling design.

Figure 24. Example of erosion pin installed in road cutbank. Pencil points to top of erosion pin exposed following winter storms.

The following is a description of the roads that had erosion pin grids installed. The general road descriptions were provided by Mark Lancaster, Trinity County, California.

China Gulch Road, County Road 230 - Approximately 0.75 miles of China Gulch Road is within the Rush Creek watershed. The road is entirely within Sierra Pacific Industries managed lands. The steep, single lane gravel road transects the slope from the ridge to Rush Creek. This road receives only minimal maintenance activity. It is typical of the county roads in the Weaverville Formation soils and contains areas with active cutbank retreat as evident by fresh soils, exposed roots, poorly vegetated banks, deposition in ditch channels and bank sloughing/slumping. Similar roads (outside of Rush Creek) are Browns Mountain Road, Roundy Road, Little Browns Creek Road, Dutch Creek Road, and many others). Ditch filling, flattening and widening occurs in flatter reaches and deepening and widening in steeper reaches. A few shallow bank slips occur along the road and a 1997 debris torrent began above uppermost stream crossing of the road. This slide remains partially perched upslope of the road.

Figure 25. Cutbank on China Gulch Road.

Rush Creek Road, County Road 204 - Rush Creek Road is within the Rush Creek watershed, but is located entirely within the lower, flatter benches along the creek. It is a two lane paved road linking Weaverville and Lewiston. There are several major soil types from deep colluviums to rock outcrops that display a variety of cutbank erosion rates. The soils could be described as having more clay in the north end of the road and sandier soils to the south end. The flat road appears to have less significant ditch lowering and filling rates then occur on China Gulch Road, but this road is well maintained with regular ditch cleaning. The road bisects the lower third of a very large deep seated landslide in Section 35 (near the intersection of Lost Bridge Road, a private road).

Figure 26. Cutbank on Rush Creek Road.

Trinity Dam Boulevard, County Road 105 - Trinity Dam Boulevard from the intersection of Highway 3 to the intersection with Forest Service Road 34N76 is within the Rush Creek watershed. Soils along Trinity Dam Blvd are similar to Rush Creek Road, with sandier soils near the intersection of Highway 3. The truly decomposed granitic soils on Trinity Dam Boulevard are outside of the Rush Creek watershed.

Figure 27. Cutbank on Trinity Dam Boulevard, which exhibits rilling as well as dry ravel.

Figure 28. Cutbank on USFS Rush Creek Campground Road.

Rush Creek Campground Road on USFS land was the northernmost road sampled in this study. At this site erosion pins were also installed along the streambank of a small tributary to measure rates of bank retreat.

Commonly, cutbanks of roads in the Rush Creek basin are sparsely vegetated, and soil is exposed to wet and dry cycles and freeze and thaw cycles. These cycles act to detach fine soil particles which then fall into the inboard ditch or onto the road surface. Depending on the degree of hydrologic connectivity to streams, the soil particles eroding from the cutbank are then delivered to streams by ditch runoff or road surface runoff. Figure 29 shows flow in an inboard ditch that can easily transport fine sediment to the culvert and then to a perennial stream.

Table 10. Road cutbank erosion rates based on erosion pin grids, Oct. 2005 to April 2006.

Site	Number of pins recovered	Hillslope Gradient	Average erosion (mm)	Maximum, minimum (mm)
Rush Creek campground road	10	45°	3	14, 0
China Gulch Road	10	70°	6	15, 2
Rush Creek Road	10	55°	1	11 (erosion), 5 (deposition)
Trinity Dam Blvd.	8	55°	2 (but several new rills)	10 (erosion), 2 (deposition)

The cutbank surface lowering rates measured during WY 06 on non-granitic soils were all less than the ‘9 mm/yr’ considered as the ‘moderate’ rate in the road inventory process, even though cutbank erosion rates were measured during one of the wettest winters on record. This may be because the cutbanks monitored in the present study have a higher clay content than granitic soils, which were used to formulate the road inventory estimate (see Appendix 2 for a list of soil properties). Nevertheless, locally cutbanks can contribute significantly to the fine sediment loading of small streams through transport of fines in the inboard ditch.

Figure 29. Runoff entering an inboard ditch, which then delivers the water and sediment through a culvert to a perennial stream.

Fine sediment from cutbank erosion can be prevented from entering streams by several means. On native or rocked roads, the most common method of controlling sediment input from cutbanks into streams is by disconnecting the road hydrologically, by installing ditch relief culverts, constructing cross road drains or outsloping the road tread. On paved roads, where the above techniques are more costly, wattles can be used to trap fine sediment and encourage revegetation of cutslopes (Figure 30) or benches can decrease runoff lengths and thus decrease rill erosion (Figure 31).

Figure 30. Wattles installed along the contour of a cutbank to trap fine sediment before it enters inboard ditch.

Figure 31. Benches constructed on a cutbank to decrease surface erosion and to encourage revegetation.

Road surface erosion

Road surface erosion is common in the Rush Creek basin (Figure 32). Erosion rates estimated for the Trinity River area are based on measurements reported in the literature. Some studies use the Universal Soil Loss Equation or models such as WEPP. Others have directly measured soil erosion through the use of silt fences or erosion pins. Road erosion rates are highly variable among sites and across years because of differences in variables such as road surfacing, grade, soil type, rainfall erosivity, level of traffic, and recency of grading. Fiori (in preparation) summarizes road surface erosion by air photo period and by land ownership, using the WEPP model. Total surface erosion from roads in the Rush Creek watershed during the period of 1924 to 1998 is estimated to be about 277,000 tons.

Figure 32. Ruts that formed during winter rains in road adjacent to Rush Creek, Yellow Notebook for scale.

Harvest unit erosion

The NRCS compiled the timber harvest history for Rush Creek (Appendix 8). From 1980 to 2004 5286 acres, or 37% of the basin, was under timber harvest plans. The computed surface erosion for harvest areas in the Trinity River Sediment Source Analysis (GMA, 2001) was 4 tons/acre, so the estimated erosion from harvest units in Rush Creek is about 21,000 tons during this period.

Stream Bank Erosion and Wood Loading

The USFS measured stream bank stability in Rush Creek in the 3400 ft. (1035 m) reach downstream of Baxter Gulch, according to Stream Condition Inventory protocols (2005). For their purpose stream bank stability was based on the cover of the banks. Cover can consist of perennial vegetation, rock, down wood or similar erosion resistant material. Observations were made on the left and right banks at 50 transects (100 bank observations in all). At each site banks were rated as 1 = stable, 2 = vulnerable and 3 = unstable. The average rank for Rush Creek in this reach was 2.5.

The USFS also measured 62 pieces of in-stream large woody debris (LWD) in a channel with a mean bankfull width of 30 ft. (about one piece of LWD for every two channel widths, or 97 pieces per mile). However, 24 of these pieces were < 4 m long and < 0.2 m in diameter, which is usually not considered to be significant in-channel wood. Mean gradient in this reach was 1.95 percent with 27 percent of the stream length in pools. The reach had 21 pools over 0.64 miles (33 pools/mile). No standards have been set by which these values can be compared to an unimpaired state, but in this reach Rush Creek does not meet the pool frequency standards of about 50 pools/mile or of 80 pieces of LWD/mile developed by NMFS (1996) for coastal salmonid streams. Both large wood in channels and pools can have a role in fine sediment storage in streams, and without these features sediment is generally routed downstream more quickly than in a more complex channel.

The USGS measured bank erosion along an actively eroding reach of Rush Creek in 2005, from the USFS campground to the Highway 3 Bridge. A survey rod was used to estimate average height and depth of erosion along stream banks, and the length of eroding bank was measured with an electronic distance meter. Figures 33 to 36 show examples of eroding stream banks in this reach. The particles size distribution of the bank material varies widely. Details of the bank erosion measurements are listed in Appendix 7. About 4200 m^3 of sediment was contributed to Rush Creek along a 1900 m reach during the last 20 years, or about 110 m^3/km of stream per year. Farther downstream bedrock outcrops are more common, and bank erosion rates are much lower, but have not been quantified.

Figure 33. Erosion of left bank of Rush Creek at Rush Creek Campground, contributing coarse sediment to Rush Creek.

Figure 34. Near-vertical streambank actively contributing sediment to Rush Creek.

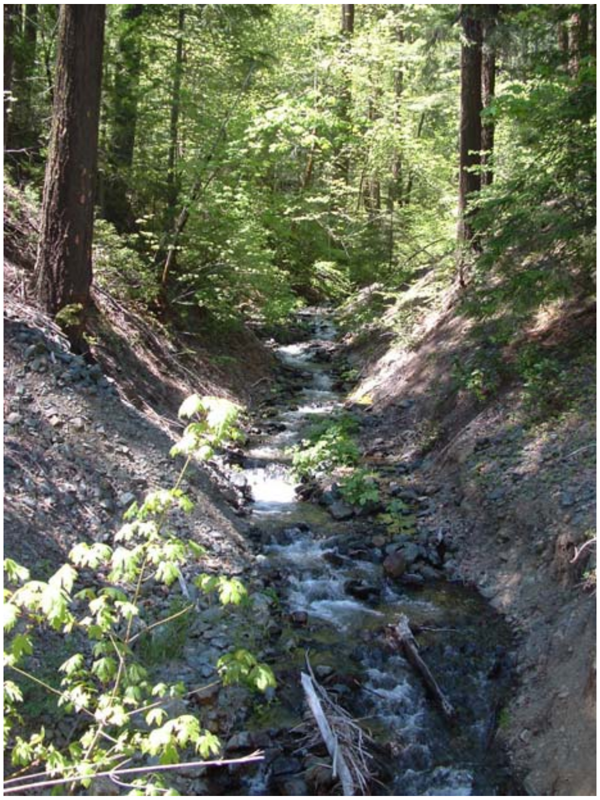


Figure 35. Low-order tributary of Rush Creek displaying dry ravel on streambanks contributing sediment directly to the channel.

Figure 36. Eroding left bank of Rush Creek upstream of Highway 3.

Flow History

Rush Creek is a tributary of the Trinity River which drains an area of 22.7 mi^2 and enters the mainstem Trinity River at about River Mile108. There has been some gaging of water and sediment discharge near the mouth since 1997, initially by the Hoopa Valley Tribe Fisheries Department and more recently operated by Graham Matthews and Associates for the Bureau of Reclamation, under general supervision of the U.S. Geological Survey (USGS). The gage is at 1700 ft. in elevation, and the USGS identification number is 11525530. Because the period of record at Rush Creek is too short to extrapolate 50- and 100-year flood magnitudes, McBain (2002) estimated these flood discharges by several other methods, using regional regression equations from Waananen and Crippen (1977), then modified results by using a unit-area, unit-precipitation, unit-elevation adjustment. According to his calculations, the 50-year and 100-year floods are 3200 cfs and 3800 cfs respectively (McBain, 2002, Table 16). Based on that analysis, the January 1997 peak flow of 4400 cfs is considered to have had a recurrence interval > 100 years (McBain, 2002, Table 16). The annual mean discharge, based on the USGS records, is 45 cfs. Peak flows typically occur during winter storms, but high monthly flows continue through the spring snowmelt season (Figure 37, Table 11). The late summer-early fall seasons exhibits low base flows.

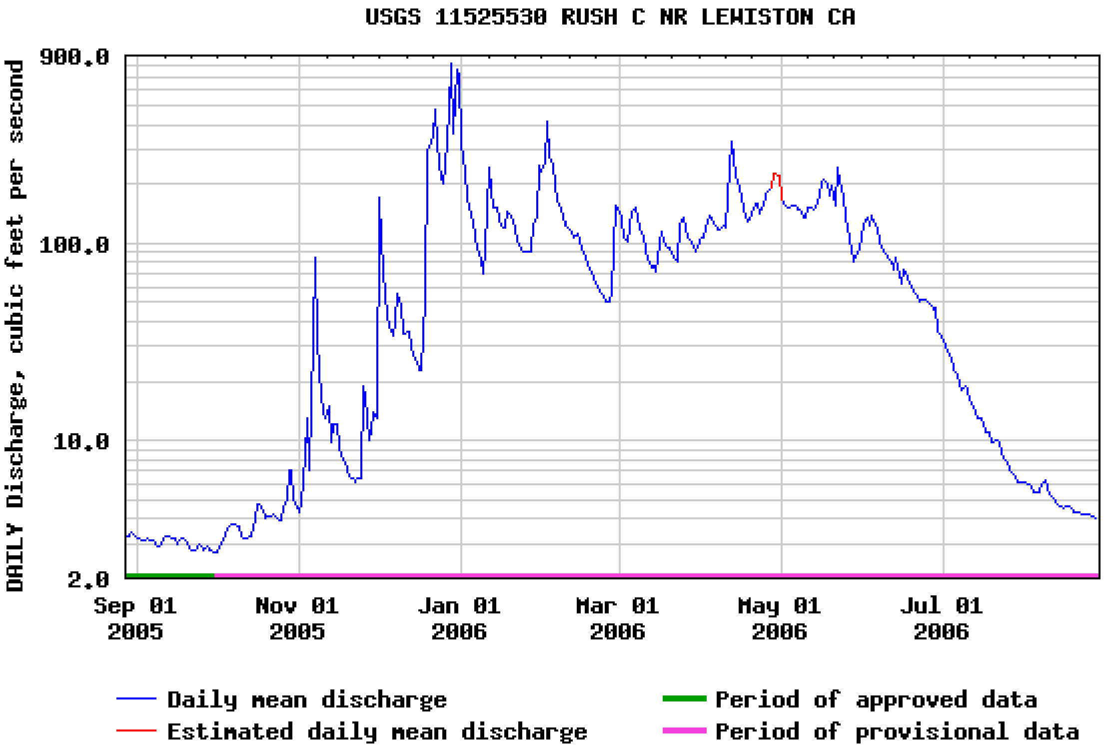


Figure 37. Typical annual hydrograph for Rush Creek.

Table 11. Average monthly discharge for Rush Creek.

YEAR	Monthly mean in cfs (Calculation period from 10-1-02 to 9-30-05)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003					102.2	53.7	9.80	4.13	2.34	2.51	10.1	56.4
2004	67.4	138.6	92.4	71.2	62.6	28.0	6.16	2.40	2.12	9.03	9.65	44.9
2005	54.5	51.9	84.8	68.5	159.1	63.6	17.6	4.63	3.03			
Mean of monthly Discharge	61	95	89	70.	108	48	11	3.7	2.5	5.8	9.9	51

Longitudinal Profile of Rush Creek

The longitudinal profile of a stream shows the slope of the river in different reaches. Channel gradient, or slope, is a major factor controlling sediment transport from a system. Figure 38 is a plot of channel bed elevation versus channel distance for Rush Creek, derived from 1:24,000 topographic maps. A level survey was conducted near the mouth of Rush Creek for more detailed profile data. The profile clearly shows that headwaters are very steep, which means that sediment is routed quickly through these reaches. The gradient decreases abruptly around Rush Creek Campground to about 3 percent, and much sediment is stored at about 10,000 m upstream of the mouth, in old tailings piles. Stream gradient decreases to about 0.85 percent near the mouth of Rush Creek.

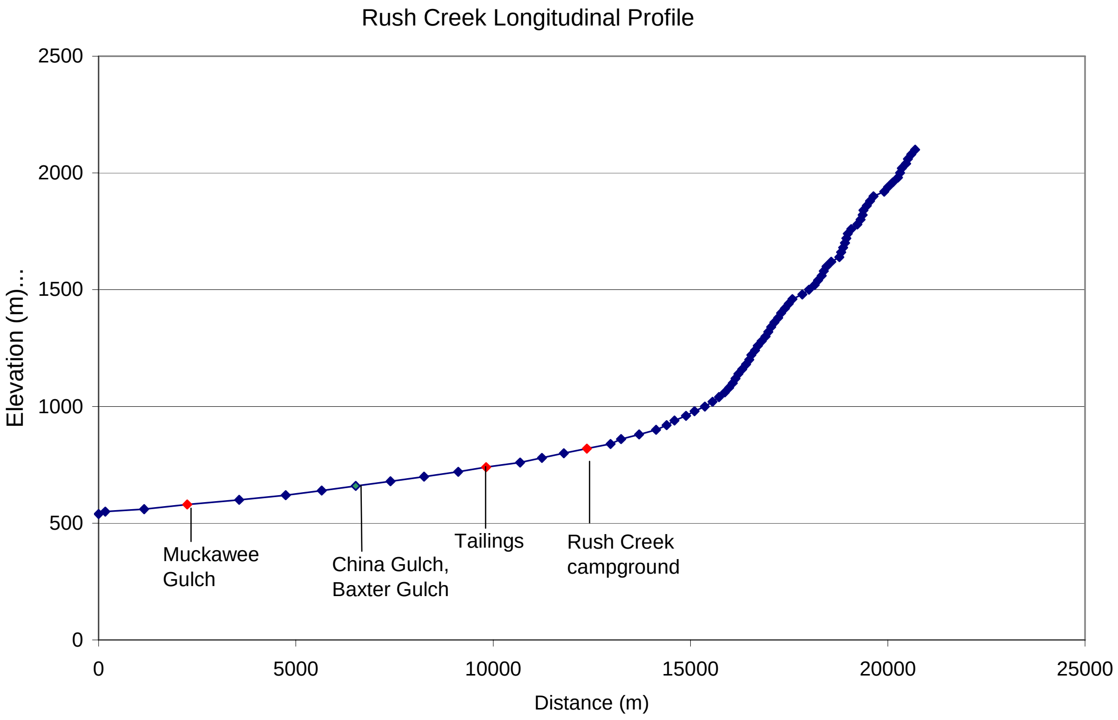


Figure 38. Longitudinal profile of Rush Creek.

Sediment Data

Since 1997, the Hoopa Valley Tribe or Graham Matthews and Associates have measured sediment transport in Rush Creek under general supervision of the U.S. Geological Survey as part of the Trinity River Restoration program. Water discharge and periodic sediment samples are measured at a gaging station near the mouth of Rush Creek. Annual sediment loads for Rush Creek from 1981 to 2000 were estimated by GMA (2001) and Wilcock (2004), based on sediment rating curves and synthetic flow records. Annual sediment loads in 2004 and 2006 were based on additional sediment and discharge measurements at the Rush Creek gaging station (GMA, 2006) (Table 12). This table can be updated as sediment records from additional years become available. High variability in estimates, especially during high flow events like January 1, 1997, illustrate the importance of continued monitoring and collecting sediment samples during high flows to better define sediment rating curves.

Table 12. Annual sediment yield from Rush Creek

WY	Bedload 0.5 – 8 mm (tons)	Bedload > 8 mm (tons)	Bedload (tons) (from Wilcock 2004 Table 6a	SSL (tons) **(from Wilcock 2004 Table 6a**	Total Load (tons) **(from Wilcock 2004)**	Total Load (tons) **(from GMA, 2001, 2005)**
1981	260	18	278	112	390	973
1982	818	109	927	547	1474	2852
1983	6915	5485	12400	50437	62837	44650
1984	1081	245	1326	1030	2356	4034
1985	109	15	124	71	195	566
1986	1375	560	1935	2764	4699	6142
1987	202	29	231	136	367	812
1988	47	3	50	24	74	374
1989	214	27	241	128	369	818
1990	47	2	49	19	68	261
1991	20	0	20	8	28	201
1992	561	59	620	299	919	1819
1993	563	32	595	219	814	1834
1994	5	0	5	5	10	167
1995	3479	1763	5242	11430	16672	17022
1996	405	9	414	126	540	1349
1997*	1373	828	2201	5736	7937	7611
1998	4987	2253	7240	13237	20477	22921
1999	1613	203	1816	912	2728	5060
2000	1613	203	1816	912	2728	5060
2001						341
Subtotal	*25687*	*11842*	*37530*	*88152*	*125682*	*118017*
2004 (GMA)			435	2415		2850
2005			-			
2006 (GMA)	773	1136	1975	12841		14,816
Average	*1260*	*618*	1815	4700	6284	5900

- *Estimates for WY 1997 by McBain and Trush (1997) are 30,500 tons of suspended load and 34,700 tons of bedload.

An output of 25,687 tons of fine bedload from Rush Creek from 1981 to 2000 is equivalent to 23,300 Mg during a 20 year period, or about 1280 tons/yr (1165 Mg/yr). Total bedload output during this period was 37530 tons, or 1876 tons/yr. Although the 1997 flood had a return interval of > 100 years (McBain, 2002), the estimated sediment load for WY 1997 is only about 15% of the WY 1983 loads (Table 12). The estimates of bedload output from Rush Creek can also be compared to the volume of material deposited in the Rush Creek delta (below).

Rush Creek Delta

One concern of landowners and land management agencies in the Trinity River basin has been the growth of a delta at the mouth of Rush Creek (Figure 39). The delta has formed a backwater pool upstream of the delta face, and coarse sediment from upstream reaches is not routed effectively through this pool. Periodic surveys of the delta have documented delta growth and scour after large flow events. The amount of sediment transported out of Rush Creek will be compared to the volume of sediment deposited in the delta.

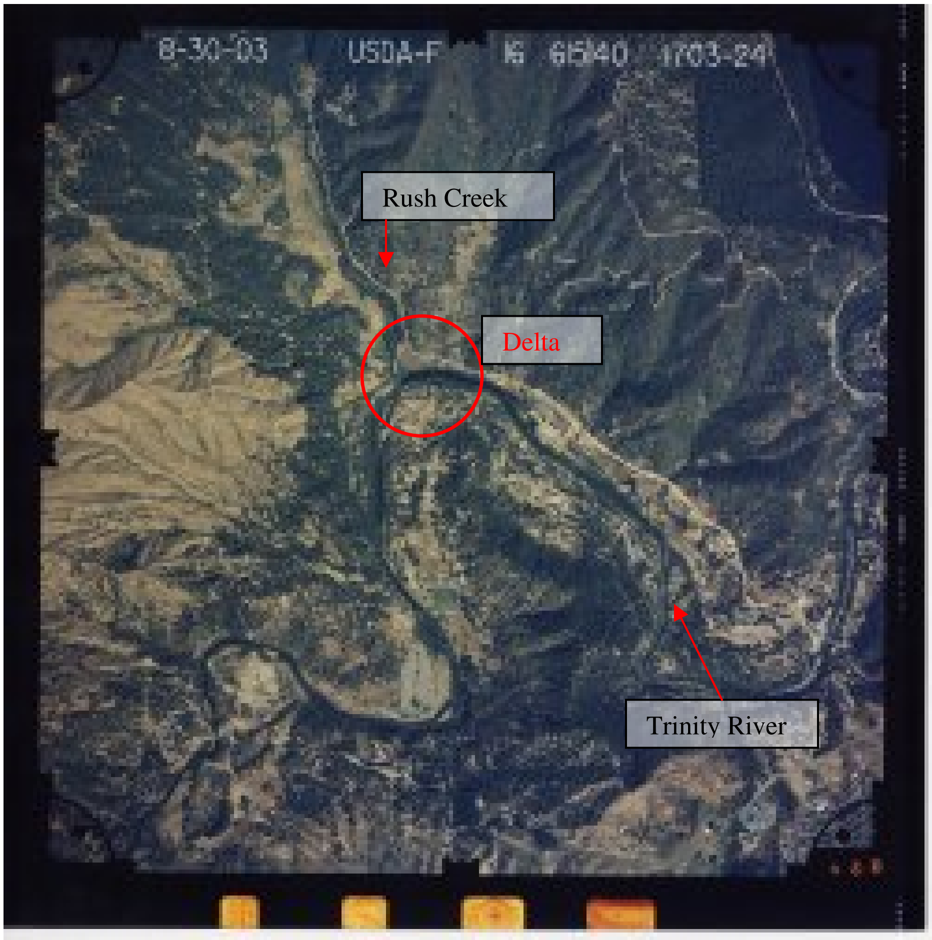


Figure 39. Photo of Rush Creek Delta, 2003.

Based on observations of the Rush Creek delta in WY 1995, delta removal by mainstem flows begins at flows greater than 3000 cfs (McBain and Trush, 1997, p. 91). Flows in the Trinity River are regulated by upstream dams, so peak flows transporting sediment from Rush Creek are usually not synchronous with the peak mainstem flows which can scour the delta. The timing of delta growth and scour is dependent on the timing of the tributary and mainstem flows. Bulk density of the delta material based on samples of deposited sediments was 1.9 tons/yd^3 (or 140 lbs/ft^3) (M&T, 1997, p. 163). Estimates of delta growth by M&T and GMA vary slightly, depending on what part of the delta system is considered:

Delta growth reported in WY 97: 7500 cy (M & T, 1997, p. 160 text)
7640 cy fill (Table on p. 160, Plate 8) from flood on 1/1/97.
8364 cy fill, Plate 8, (M & T), includes both 12/9/96 and 1/1/97 floods.
5817 cy net fill at delta, (M&T), includes scour at left bank (WY 97)
9300 cy fill at delta (GMA), or 6100 cy net fill.

A survey by GMA in December, 2006 showed 22,660 cy of delta growth since 8/1996, but the net change in the delta area was only 8150 cy of fill because scour had occurred along the left bank. The delta growth of 22,660 cy over 11 years averages to 2060 cy/yr, or 3900 tons/yr. This value is twice the amount of average bedload computed at the Rush Creek gaging station (Table 12). Bedload transport is a highly variable process, but with continued monitoring estimates of bedload yield can be refined.

In 2002 McBain and Trush conducted an analysis of the substrate composition of the Rush Creek delta. Sixteen percent of the material sampled in the delta was between 0.5 and 8 mm in diameter. So, if the annual growth rate of the delta (excluding scour on the left bank) is about 3900 tons/year and 16% of that deposition is fine sediment, then Rush Creek deposits about 624 tons/year of fine sediment in the Rush Creek delta. Average annual yield of fine sediment from Rush Creek is 1260 tons/year (Table 12), so about half of Rush Creek's fine sediment load gets routed downstream of the delta. About 80% of the delta's substrate is > 8mm in diameter, but only ¼ to ½ of bedload from Rush Creek is in this size range. This means, not surprisingly, that coarser sediment is preferentially deposited in the delta while finer sediment is more readily transported downstream.

A question that arises for the management of Trinity River sediment is how much sediment from tributaries, such as Rush Creek, is trapped in the delta or routed downstream. McBain and Trush (M&T)(1997, p. 108) attempted to use tracer rocks emplaced on the Rush Creek delta surface to test whether high mainstem flows transport coarser tributary bed material from the deltas and deposit it downstream. Because of problems with timing of flows and insertion of tracer rocks, accurate travel distances of emplaced rocks were not obtained. Nevertheless, about three-fourths of the rocks emplaced on the Rush Creek delta were recovered, but most rocks did not move much beyond their insertion point. Maximum travel distance for rock tracers at the Rush Creek delta increased from 100 ft. to almost 200 ft. with longer flow releases (M&T, 1997, p. 111). Because the tracer rocks were not in place for the entire water year and did not capture all the mainstem high flows, these estimates should be considered a minimum travel distance.

Table 13. Changes in volume of the Rush Creek delta, 1996- 2006.

Dates	Source	WY	Net Change (cy)	Tons*
8/1996 – 12/1996	GMA	1996-1997	760	1440
8/1996 – 12/1996	M&T		702	1330
8/1996 – 3/1997	GMA	1997	6100	11590
12/1996 – 3/1997	GMA	1997	1420	2700
12/1996 – 3/1997	M&T, p. 160	1997	7640	14520
3/1997 – 1/1998	GMA		3060	5810
1/1998 – 10/2000	GMA		-2680	-5090
10/2000 – 11/2002	GMA		303	580
11/2002 – 4/2003	GMA		1690	3210
4/2003 – 4/2004	GMA		560	1060
4/2004 – 12/2004	GMA		-210	-400
12/2004-11/2005	DWR	2006 provisional data	-710	-1350
				net t/yr
8/1996 – 12/1996	M&T	1997	702	1330
12/1996 – 3/1997	M&T, p. 160	1997	7640	14520
3/1997 – 1/1998	GMA	1998	3060	5810
1/1998 – 10/2000	GMA	1999, 2000	-2680	-5090
10/2000 – 11/2002	GMA	2001, 2002	303	580
11/2002 – 4/2003	GMA	2003	1690	3210
4/2003 – 4/2004	GMA	2004	560	1060
4/2004 – 12/2004	**GMA**	**2004**	**-210**	-400
12/2004 – 11/2005	**GMA**	**2005**	**-710**	-1350
8/1996 – 12/2006	GMA		8150	12490

*McBain and Trush (M&T) used a bulk density conversion factor of 1.9 t/cy, whereas GMA used 1.6 t/cy. For consistency, all values in this table used the 1.9 t/cy conversion.

Particle Size Distribution of Rush Creek Sediment

The particle size distributions of both surface and subsurface channel bed material were measured at several locations along Rush Creek. The surface, or armor, layer was sampled through pebble counts. The subsurface bed material was collected from the bed once the armor layer was removed by hand, and the samples were sieved in a lab. The median particle sizes of the armor layer in Rush Creek at both the USFS study reach downstream of Baxter Gulch and at the gaging station near the mouth were similar, about 45 mm (Figure 40).

The actual median particle size can be compared an expected D_{50}, calculated as:

$D_{50} = \rho \, h \, S / (\rho_s - \rho) \, 0.03$

Where ρ_s and ρ are sediment and fluid densities, respectively, S in channel gradient, h is bankfull depth, and 0.03 is assumed to be the critical Shields stress for movement of $D_{50.}$ Bankfull depth in the USFS reach is 0.24 m, based on five surveyed cross sections, and channel gradient based on a total station survey is 0.78%. The expected D_{50} in the USFS reach is:

$D_{50} = (1000 * 0.24 \text{ m} * 0.0078) / (1650 * 0.03) = 0.038\text{m}$, or 38 mm. Thus, the expected D_{50} is similar to the D_{50} calculated by pebble counts (45 mm), so the surface of the streambed does not indicate an unusually high sediment supply.

The subsurface samples of bed material show that much of the sediment in storage in the Rush Creek channel bed is in the range of concern for the Trinity River Restoration Program. Thirty to 54% of the subsurface bed material was less than 8 mm (Figure 41).

The bedload transported past the Rush Creek gaging station, located just upstream of the confluence with the Trinity River, is primarily in the size class defined as ‘fines’ (between 0.5 to 8 mm). An analysis of bedload samples collected in 2006 shows that the median particle size transported was usually less than 20 mm, but particles as large as 90 mm were sometimes transported (Figure 41). Table 14 lists the fractions of sediment in the bedload samples that were in the 0.5 to 8 mm range of concern. In WY 2006 the average fraction of bedload samples in the 0.5 to 8 mm range was 68%, in contrast with the delta deposits in which 80% of the substrate is > 8 mm.

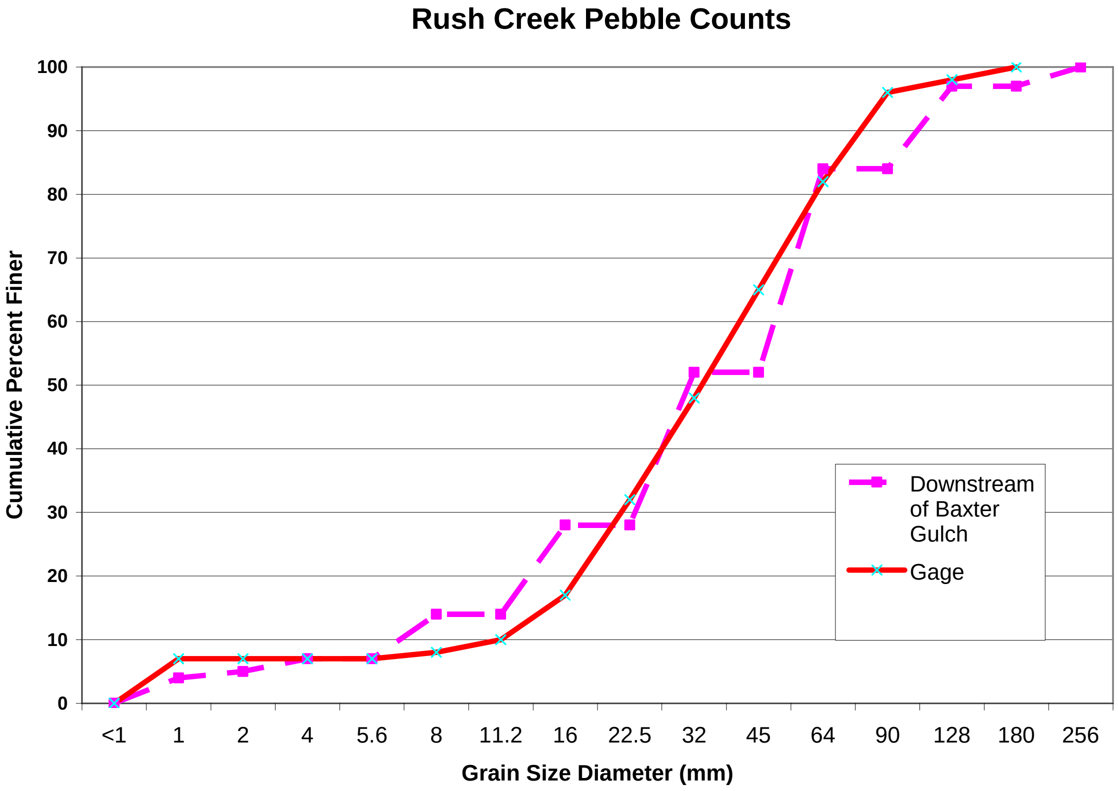


Figure 40. Particle size distributions of bed surface on Rush Creek.

Subsurface Particle Size, Rush Cr.

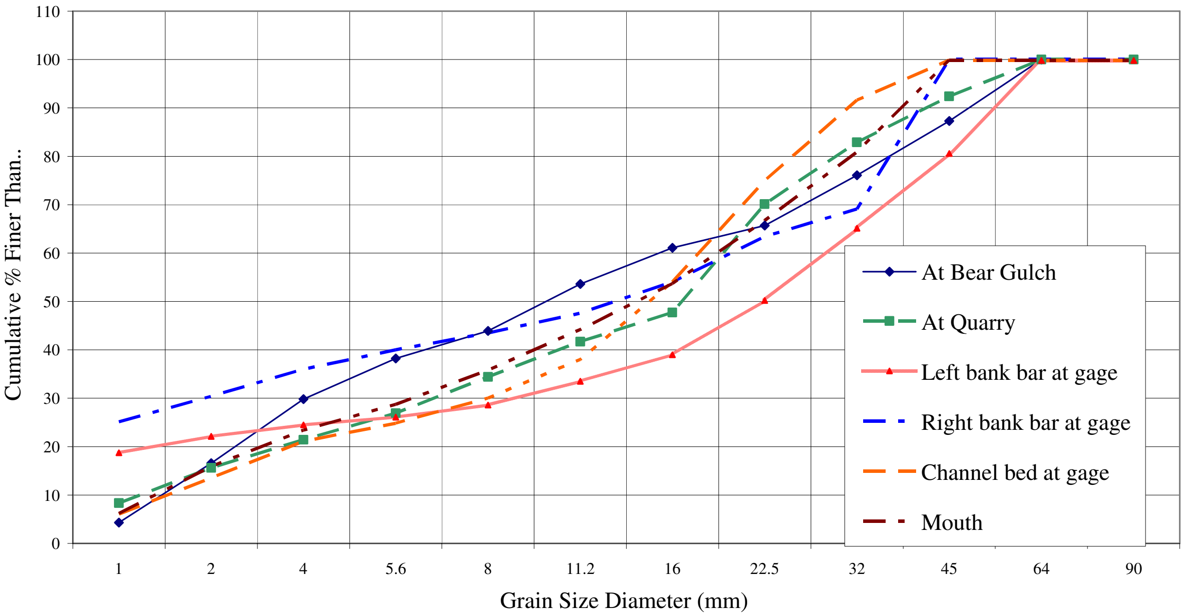


Figure 41. Particle size distributions of subsurface bed material samples in Rush Creek

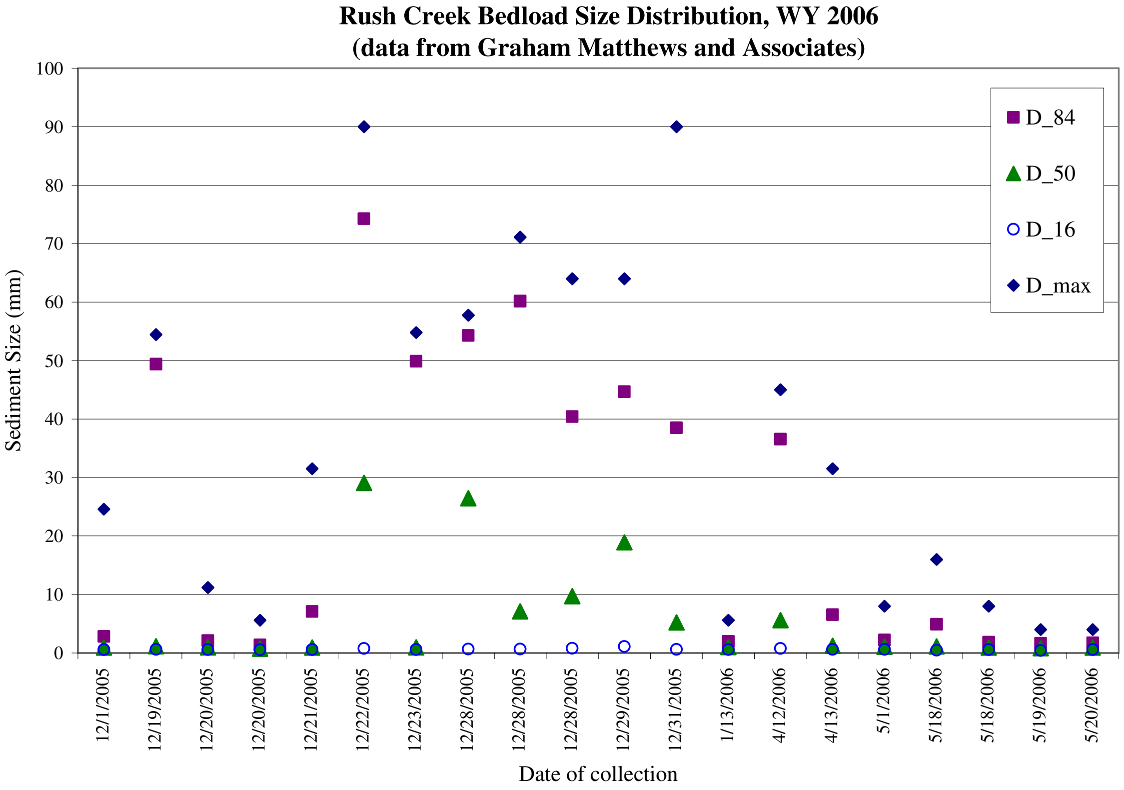


Figure 41. Particle sizes of bedload samples collected from Rush Creek.

Table 14. Percentages of bedload by size class, based on samples collected at the Rush Creek gaging station

Date	% < 0.5mm	% 0.5-8mm	% > 8mm
12/1/2005	8.0%	78.2%	13.8%
12/19/2005	5.5%	69.4%	25.0%
12/20/2005	6.8%	91.0%	2.3%
12/20/2005	11.2%	88.8%	0.0%
12/21/2005	4.8%	79.4%	15.9%
12/22/2005	5.4%	32.5%	62.2%
12/23/2005	5.8%	69.7%	24.5%
12/28/2005	6.9%	37.7%	55.3%
12/28/2005	9.8%	41.8%	48.4%
12/28/2005	5.1%	41.6%	53.3%
12/29/2005	2.3%	31.8%	66.0%
12/31/2005	10.9%	47.4%	41.7%
1/13/2006	7.4%	92.6%	0.0%
4/12/2006	4.2%	48.6%	47.1%
4/13/2006	5.6%	80.5%	14.0%
5/1/2006	2.2%	97.4%	0.4%
5/18/2006	17.4%	69.8%	12.8%
5/18/2006	8.3%	91.1%	0.5%
5/19/2006	22.0%	78.0%	0.0%
5/20/2006	5.7%	94.3%	0.0%
Average	**7.8%**	**68.1%**	**24.2%**

Sediment Yield in the Context of Total Maximum Daily Loads

In the Trinity River Total Maximum Daily Load for Sediment (TMDL), the estimate for background sediment yield in Rush Creek was 675 tons/mi^2/yr, with an additional 286 tons/mi^2/yr derived from management activities. The TMDL load allocation is defined as (background rate * 1.25), or 844 tons/mi^2/yr (USEPA, 2001, Table 5-3). The average sediment yield calculated for Rush Creek at the gaging station (Table 12) is 5900 to 6300 tons/year, or about 270 tons/mi^2/yr. Under these conditions Rush Creek is currently meeting the allocation goal of the TMDL.

Summary

Rush Creek contributes about 1260 tons of fine bedload to the mainstem of the Trinity River every year. About one-third of this sediment is deposited in the Rush Creek delta, and the rest is routed downstream of the mouth of Rush Creek. The primary sources of the fine sediment in the past were landslides and road surface erosion (Figure 42). Road fill in stream crossings represents a potential erosion source as well, but to date most of these crossings are still intact. The most landslide-prone area is in the headwaters, within a wilderness area, where management actions have minimal effect. Another area highly susceptible to landslides is on the east side of lower Rush Creek, where timber harvest and road development have taken place. Other sensitive areas are identified on the slope stability map included in this report.

Presently, the mainstem Trinity River stores about 30,200 Mg (33,000 tons) of fine bedload within its channel bed between the mouth of Rush Creek and the confluence with Grass Valley Creek, the next large contributor of fine sediment. Main channel storage in this sediment cell is equivalent to about 25 years of fine sediment output from Rush Creek. Consequently, there will be a lag time before the effects of erosion control efforts in Rush Creek are detected in the mainstem Trinity River. Nevertheless, shifts in sediment rating curves in Rush Creek itself can be used to detect time trends of sediment transport in this tributary watershed. Efforts towards landslide prevention, by using slope stability mapping as a tool, may be the most cost-effective sediment reduction technique for this area. Road upgrading and decommissioning, especially in landslide-prone areas, may decrease road-related landslides in the future, as well as decreasing the input of fine sediment from road surface erosion.

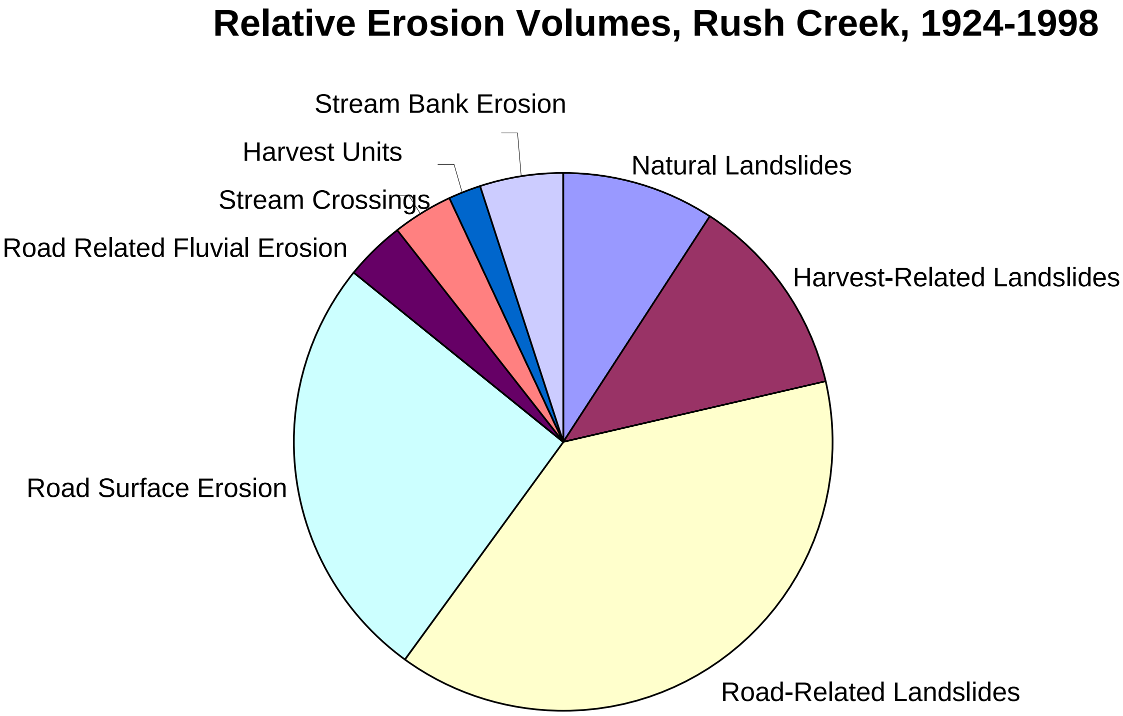


Figure 42. Relative importance of past erosion processes in Rush Creek, based on estimates by Fiori (in preparation) and this study.

Bibliographies

Part 1: General Watershed Analysis and Assessment References

Barbour, M.T, J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macrointerebrates, and fish. Second edition. E.P.A. 841-B-99-002. U.S. Environmental Protection Agency; Office of Water. Washington, D.C., 339 p.

Benda, L. and L.R. Miller. 1991. Geomorphological watershed analysis: a conceptual framework and review of techniques. TFW-SH10-91-001, 54 p.

Bilby, R.E., P.A. Bisson, C.C. Coutant, D. Goodman, R. Gramling, S. Hanna, E. Loudenslager, L. McDonald, D. Philipp, and B. Riddel. 2003. A Review of Strategies for Recovering Tributary Habitat. Independent Scientific Advisory Board for the Northwest Power Planning Council, the National Marine Fisheries Service, and the Columbia River Basin Indian Tribes, Portland, Oregon, 54 p.

Bradbury, B., W. Nehlsen, T.E. Nickelson, K.M.S. Moore, R.M. Hughes, D. Heller, J. Nicholas, D.L. Bottom, W.E. Weaver, and R.L. Beschta. 1995. Handbook for Prioritizing Watershed Protection and Restoration to Aid Recovery of Native Salmon. Pacific Rivers Council, Portland, OR. http://www.krisweb.com/biblio/gen_xxxx_bradburyetal_1995.pdf (accessed October 10, 2006).

Buffington, J.M., D.R. Montgomery, and H.M. Greenberg. 2004. Basin-scale availability of salmonid spawning gravel as influenced by channel type and hydraulic roughness in mountain catchments. Can. J. Fish. Aquat. Sci., 61:2085-2096.

Burroughs, E. R. Jr., R. J. Watts and D. F. Haber. 1984. Surfacing to reduce erosion of forest roads built in granitic soils. In Proceedings of a Symposium on Effects of Forest Land Use on Erosion and Slope Stability. University of Hawaii, Honolulu, Hawaii.

California Watershed Assessment Model. http://cwa.ucdavis.edu/

Chatwin, S.C., D.E. Howes, J.W. Schwab, and D.N. Swanston. 1994. A guide for management of landslide-prone terrain in the Pacific Northwest. Land management handbook number 18. Research Branch, Ministry of Forests, Victoria, British Columbia, 220 p.

Christensen, N.L, A.M. Bartuska, J.H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J.F. Franklin, J.A. MacMahon, R.F. Noss, D.J. Parson, C.H. Peterson, M.G. Turner, and R.G. Woodmansee. 1995. The Scientific Basis for Ecosystem Management: An Assessment by The Ecological Society of America, Washington, DC. Ecological Applications, 6:665-691.

Dietrich, W.E., J.W. Kirchner, H. Ikeda, and F. Iseya. 1989. Sediment supply and the development of the coarse surface layer in gravel-bedded rivers. Nature (London), 340:215-217.

Dietrich, W. E. and D. Montgomery 1998. SHALSTAB: a digital terrain model for mapping shallow landslide potential. National Council for Air and Stream Improvement, NCASI Technical Report, February 1, 1998 (http://socrates.Berkeley.edu/~geomorph/shalstab.html)

Dopelt, B., M.C. Scurlock, C.A. Frissell, and J. R. Karr. 1993. Entering the Watershed: A new approach to save America's river ecosystems. Island Press.

Dubè, K., W. Megahan, and M. McCalmon. 2004. Washington road surface erosion model. Prepared for the State of Washington Department of Natural Resources, 55 p.

Dunne, T. and L. B. Leopold. 1978. Water in Environmental Planning. W. H. Freeman. New York, 796 p.

Galgale, H., I. Smout, S. Gorantiwar, and M. Shinde. 2004. Model for computation of watershed morphologic characteristics using GIS. Presented at British Hydrological Society, International Conference on Hydrology: Science and Practice for the 21st Century, Imperial College London, United Kingdom.

Geppert, J. 2004. Reducing sediment delivery from rural roads. Salmonid Restoration Federation newsletter. Redway, CA.

Gomez, B. and M. Church. 1989. An assessment of bed load sediment transport formulae for gravel bed rivers. Water Resources Research 25 (6): 1161-1186.

Granger, D.E., J.W. Kirchner, and R. Finkel. 1996. Spatially averaged long-term erosion rates measured from in situ-produced cosmogenic nuclides in alluvial sediment. Journal of Geology, 104:249-257.

Kelsey, H., M. A. Madej, J. Pitlick, P. Stroud and M. Coghlan. 1981. Major sediment sources and limits to the effectiveness of erosion control techniques in the highly erosive watersheds of northern coastal California. p. 493-509 in Erosion and Sediment Transport in Pacific Rim Steeplands. T. R. H. Davies and A. J. Pearce, eds. IAHS Publication No. 132.

Kirchner, J.W., R.C. Finkel, C.S. Riebe, D.E. Granger, J.L. Clayton, J.G. King, and W. F. Megahan. 2001. Mountain erosion of 10 yr, 10 k.y. and 10 m.y. time scales. Geology, pages 591-594.

Leopold, L. B. 1994. A View of the River. Harvard University Press, Cambridge, MA. Harvard University Press, 298 p.

Leopold, L. B., M.G. Wolman, and J.P. Miller. 1964. Fluvial Processes in Geomorphology. W.H. Freeman and Company, San Francisco, 522 p.

Matthews, G. & Associates. 2001. Sediment source analysis for the mainstem Trinity River, Trinity County, CA. Contract # 68-C99-249, Work Assignment #0-34. Prepared for Tetra, Inc., Fairfax, Virginia.

McCammon, B., J. Rector, and K. Gebhardt. 1998. A Framework for Analyzing the Hydrologic Condition of Watersheds. U.S. Department of the Interior, Bureau of Land Management, 48 p.

Montgomery, D.R., T. Dunne, and W.E. Dietrich. 1993. Geomorphological watershed analysis project biennial report for the period from 10/1/91 to 6/30/93. TFW-SH10-93-001.

Montgomery, D.R., G.E. Grant, and K. Sullivan. 1995. Watershed analysis as a framework for implementing ecosystem management. Water Resources Bulletin, 31:1-18.

Montgomery, D.R, J.M. Buffington, N.P. Peterson, D. Schuett-Hames, and T.P. Quinn. 1996. Streambed scour, egg burial depths and the influence of salmonid spawning on bed surface mobility and embryo survival. Can. J. Fish. Aquat. Sci. 53:1061-1070.

Pack, R.T., D.G. Tarboton, and C.N. Goodwin. 1998. The SINMAP Approach to Terrain Stability Mapping, paper submitted to 8th Congress of the International Association of Engineering Geology, Vancouver, British Columbia, September 21-25.

Pack, R.T., D.G. Tarboton, and C.N. Goodwin. 2001. Assessing Terrain Stability in a GIS using SINMAP, in 15th annual GIS conference, GIS 2001, Vancouver, British Columbia, February 19-22. http://hydrology.neng.usu.edu/sinmap/gis2001.pdf

Province of British Columbia. 1996. Channel Assessment Procedure Field Guidebook. Vancouver, B.C. Canada. 95 p.

Regional Interagency Executive Committee (RIEC). 1995. Ecosystem Analysis at the Watershed Scale; Federal Guide for Watershed Analysis – Version 2.2. Regional Ecosystem Office. Portland, Oregon, 26 p.

Riebe, C.S., J.W. Kirchner, D.E. Granger, and R.C. Finkel. 2000. Erosional equilibrium and disequilibrium in the Sierra Nevada, inferred from cosmogenic ^{26}Al and ^{10}Be in alluvial sediment. Geology, 28:803-806.

Shilling, F., S. Sommarstrom, R. Kattelmann, B. Washburn, J. Florsheim, and R. Henly. 2005. California Watershed Assessment Manual Volume 1. Prepared for the California Resources Agency (http://cwam.ucdavis.edu).

Sidle, R.C. and H. Ochiai. 2006. Landslides: Processes, Prediction, and Land Use. Washington DC: American Geophysical Union, 350 p.

Simons, D. B., R. M. Li and T. J. Ward. 1980. Application of road sediment models to natural and simulated rainfall runoff sites, Colorado State University Report CER79-80DBS-RML-TJW66, Colorado State University, Fort Collins, Colorado, 40 pp.

Smelser, M.G. and J.C. Schmidt. 1998. An assessment methodology for determining historical changes in mountain streams. U.S.D.A.-Forest Service General Technical Report RMRS-GTR-6. Rocky Mountain Research Station, Fort Collins, Colorado, 29 p.

Stillwater Sciences. 2004. Sediment budget for Redwood Creek watershed, Marin County, California. Berkeley, CA 66 p.

Summer, W. and D.E. Walling. 2002. Modelling Erosion, Sediment Transport and Sediment Yield. International Hydrological Programme – VI. Technical Documents in Hydrology, No. 60, 263 p.

Swanston, D. N., R. R. Ziemer, and R. J. Janda. 1983. Influence of climate on progressive hillslope failure in Redwood Creek Valley, Northwest California, U. S. Geol. Survey Open-File Report 83-259. Menlo Park, CA. 49 pp.

Tetra Tech, Inc. 2000. National Management Measures to Control Nonpoint Source Pollution from Forestry. Prepared for Chris Solloway, Nonpoint Source Control Branch, Office of Water, U.S. Environmental Protection Agency. U.S.E.P.A contract No. 68-C7-0014, Work Assignment # 2-20. Fairfax, Virginia, 302 p.

Tysdal, L. M., W. J. Elliot, C. H. Luce, and T. A. Black. 1999. Modeling erosion from insloping low-volume roads with WEPP Watershed Model, Transportation Research Record 1652 (2): 250-256.

Woolhiser, D. K., R. E. Smith, and D. C. Goodrich. 1990. KINEROS, A Kinematic Runoff and Erosion Model, Documentation and User Manual, ARS-77, 130 pp. USDA Agricultural Research Service, Tucson, Arizona.

U.S. Environmental Protection Agency. 1998. South Fork Trinity River and Hayfork Creek sediment total maximum daily loads. Region 9, San Francisco, California.

U.S. Environmental Protection Agency. 1999. Protocol for Developing Sediment TMDLs. EPA 841-B-99-004. Washington DC.

U.S. Environmental Protection Agency. 2005. Handbook for Developing Watershed Plans to Restore and Protect Our Waters – Draft. U.S. Environmental Protection Agency, Office of Water, Washington, DC. 414 p.

U.S.D.A. Soil Conservation Service. 1990. Assessment of Hoadley Gulch, Indian Creek, Deadwood Creek and Rush Creek Watersheds. Contract # 8-AA-20-06190. Weaverville, California, 69 p.

U.S.D.A. Forest Service. 2003. North Fork Trinity River, East Fork North Fork Trinity River and Canyon Creek Watershed Analysis, 58 p.

U.S.D.A. Forest Service. 2004. Weaverville Watershed Analysis. Shasta-Trinity National Forest. http://www.fs.fed.us/r5/shastatrinity/documents/st-main/publications/watershed-analysis/weaverville/weaverville-wa.pdf (accessed 11/03/2006).

U.S.D.A. Forest Service. 2005. Browns Project Final Environmental Impact Statement, Trinity River Management Unit, Shasta Trinity National Forest, Pacific Southwest Region.

U. S. D. A., Forest Service, U.S. D. I. Bureau of Land Management. 1994. Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl. Washington D. C. 74 p.

Waddell, K.L. and Bassett, P.M. 1997. Timber resource statistics for the North Interior Resource Area of Northern California. Resource Bulletin-US Department of Agriculture, Forest Service PNW-RB 222, 49.

Walling, D.E. and A.L. Collins. 2005. Establishing Catchment Sediment Budgets. Abstract. American Geophysical Union. H24B-01.

Washington State Department of Natural Resources. 1997. Washington State Watershed Assessment Manual, version 4.0.

Wilcock, P.R., Barta, A.F., Shea, C.C., Kondolf, G.M., Matthew, W.V.G., and Pitlick, J. 1996. Observations of flow and sediment entrainment on a large gravel-bed river. Water Resources Research 32, 2897-2909.

Wilcock, P.R., Kondolf, G.M., Matthews, W.V.G, and Barta, A.F. 1996. Specification of sediment maintenance flows for a large gravel-bed river. Water Resources Research 32, 2911-2921.

Wright, J.E. and Wyld, S.J. 1986. Significance of xenocrystic Precambrian zircon contained within the southern continuation of the Josephine ophiolite: Devils Elbow ophiolite remnant, Klamath Mountains, northern California. Geology 14, 671-674.

Xiaoqing, Y. 2003. Manual on sediment management and measurement. World Meteorological Organization Operational Hydrology Report No. 47.

Ziemer, R. R. 1997. Temporal and spatial scales. In Watershed Restoration: Principles and Practices. J E. Williams, C. A. Wood, and M. P. Dombeck, eds. American Fisheries Society. Bethesda, MD. P. 80-95.

Part 2: Region Specific - Trinity River Literature

Also Check: http://www.krisweb.com/biblio/biblio_trinity.htm

Alt, D. and D. W. Hyndman. 2000. Roadside Geology of Northern and Central California. Mountain Press Publishing Co., Missoula, Montana, 369 p.
Baldwin, K.C. 2003. An assessment of potential effects on the timber economy of Trinity County, CA and the risks and severity of fire in Trinity National Forest from passage of the California Wild Heritage Act. Prepared for U.S. Bureau of Land Management, Redding, California, 14 p.

Barnard, K. and S. McBain. 1994. Standpipe to determine permeability, dissolved oxygen, and vertical particle size distribution in salmonid spawning gravels. As FHR Currents # 15. U.S. Forest Service, Region 5. Eureka, California, 12 p.

Barnhart, R.A. 1994. Salmon and steelhead populations of the Klamath-Trinity basin, California in T.J. Hassler (ed.) Klamath Basin fisheries symposium: proceedings of a symposium held in Eureka, California. 23-24 March 1994, pages 73-97. California Cooperative Fishery Research Unit, Humboldt State University, Arcata, California.

Bair, J.H. 2001. Riparian woody plant initiation, establishment, and mortality on rehabilitated banks of the Trinity River, California. MS Thesis, Humboldt State University, Arcata, California.

Berol, E. 1995. A river history: Conversations with long-term residents of the Lower South Fork Trinity River. Prepared for Patrick Truman & Associates and South Fork Coordinated Resource Management Planning Committee, 44 p.

Boles, G.L. 1981. Macroinvertebrate colonization of replacement substrate below a hypolimnial release reservoir. Hydrobiologia, 78:133-146.

Boles, G.L. 1990. Food habits of juvenile wild and hatchery steelhead trout, Oncorhynchus mykiss, in the Trinity River, California. California Department of Fish and Game, Inland Fisheries Administrative Report No. 90-10. Red Bluff, California, 9 p.

Borok, S.L. 1997. Evaluation of salmon and steelhead spawning habitat quality in the South Fork Trinity River basin, 1997. California Department of Fish and Game Inland Fisheries Administration Report No. 97, Unpublished.

Cook, C., A. Dresser, and M. Smith. 1999. Long Term Trend Monitoring Program for the South Fork Trinity River watershed. U.S.D.A. Forest Service, Six Rivers National Forest, Eureka, California, 89 p.

Cox, I. 1940. The Annals of Trinity County. Printed for Harold C. Holmes by John Henry Nash of the University of Oregon, Eugene, Oregon, 265 p.

de la Fuente, J., T. Laurent, D. Elder, R. Vandewater, A. Olson. 2000. Watershed condition assessment beta-test results of northern province forests. Pacific Southwest Region, US Forest Service.

Douglas, S.G. 1969. A study of the western triassic and paleozoic belt-Ironside Mountain batholith relationship, as exposed in the New River Gorge, Trinity County, California. Senior Thesis, Humboldt State University, Arcata, California.

Dresser, A.T., C. Cook, and M. Smith. 2001. Long term trend monitoring project for the South Fork Trinity River watershed. U.S.D.A. Forest Service, Six Rivers National Forest, Eureka, California, 89 p.

Egilbert, W.D. 1913. Trinity County California. California Lands for Wealth, California Fruit for Health, issued by Sunset Magazine Homeseekers' Bureau for the Supervisors of the Trinity County, California. San Francisco, California, 6 p.

Evenson, D.F. 2001. Egg pocket depth and particle size composition within chinook salmon redds in the Trinity River, California. MS Thesis, Humboldt State University, Arcata, California, 83 p.

Farber, S., D. Rankin, and T. Viel. 1998. Water temperatures in the South Fork Trinity River Watershed in Northern California. Prepared for the U.S. Environmental Protection Agency and the North Coast Regional Water Quality Control Board. Mt. Shasta, California, 39 p.

Finney, V.L., M.A. Cocke, and T.J. Viel. 1997. Re-establishing a mobile stream bed lower Clear Creek watershed, Shasta County, California, USA in Engineering geology and the environment: Proceedings symposium, Athens, pages 2675-2680.

Fiori, R. An analysis of production of fine sediment in the Rush Creek Calfiornia watershed. In preparation.

Fitzgerald, J. 2005. Browns Project Hydrologist Report. U.S. Forest Service. Weaverville, CA. 25 pp.

Foott, J.S., R.L. Walker, J.D. Williamson, and K.C. True. 1994. Health and physiology monitoring of chinook and steelhead smolts in the Trinity and Klamath Rivers. In: Proceedings of Klamath Basin Fisheries Symposium, March 1994, Eureka California. Published California Cooperative Fisheries Restoration Unit, Humboldt State University, Arcata, California.

Foster Wheeler. 2001. Hidden Valley, Plummer Creek, & Rattlesnake Creek Watershed Analysis. Prepared for U.S.D.A. Forest Service, Shasta-Trinity National Forests by Foster Wheeler Environmental Corporation. Redding, California, 165 p.

Fraticelli, L.A., J.P. Albers, W.P. Irwin and M.C. Blake Jr. 1987. Geologic map of the Redding 1X2 degree quadrangle, Shasta, Tehama, Humboldt, and Trinity Counties, California. DOI/USGS Open-File Report 87-257.

Freese, J.L. 1982. Selected aspects of the ecology of adult summer steelhead in Trinity River, California. MS Thesis, Humboldt State University, Arcata, California.

Gaeuman, D. 2007. Method for Estimating Fine Sediment Storage on the Mainstem Streambed. Trinity River Restoration Program Science Symposium Summaries. February 2007. Weaverville, CA.

Glase, J.D. 1993. Summer utilization of various habitat types by juvenile steelhead in two South Fork Trinity River tributaries, Northern California. MS Thesis, Humboldt State University, Arcata, California.

Graham Matthews and Associates. 2001. Gravel quality monitoring in the mainstem Trinity River. Prepared for the Trinity County Board of Supervisors. Weaverville, California, 44 p.

Graham Matthews and Associates. 2001. Sediment source analysis for the mainstem Trinity River, Trinity County, California. Volume 1: Text, tables, figures. Prepared for TetraTech, Inc., Weaverville, California, 190 p.

Graham Matthews and Associates. 2003a. WY2002 Flow Release Sediment Transport Monitoring Report. Report to Hoopa Valley Tribe, Hoopa, California.

Graham Matthews and Associates. 2003b. Bathymetric mapping of the Trinity River: Lewiston Dam to Grass Valley Creek. Report to Trinity County.

Hampton, M.A. 1992. Comparison of weighted usable area and observed densities of juvenile chinook salmon in the Trinity River, California in Western Division American Fisheries Society, July 13-16, 1992 Program Abstracts, 59 p.

Harris, R.R. and S.D. Kocher. 1998. Effects of county land use regulations and management on anadromous salmonids and their habitats: Humboldt, Del Norte, Mendocino, Siskiyou and Trinity Counties, California. Final report to the Five County Planning Group in the North Coast Coho Salmon Transboundary Evolutionarily Significant Unit. University of California Cooperative Extension.

Hassler (ed.) Klamath Basin fisheries symposium: proceedings of a symposium held in Eureka, California, March 23-24, 1994, pages 110-121. California Cooperative Fishery Research Unit, Humboldt State University, Arcata, California.

Hemphill, N. 2006. Trinity River Restoration Program Anadromous Fish Habitat Assessment - Draft. Trinity River Restoration Program, 31 p.

Higgins, P. 1996. Results of fine sediment monitoring in Rusch Creek using volunteers. Performed under contract to U.S. Bureau of Reclamation and US Fish and Wildlife Service, for the South Fork Trinity River CRMP. Weaverville, California.

Howell, D.W. 1983 Soil Survey of Trinity County, California, Weaverville Area. USDA Natural Resources Conservation Service. 371 p.

Irwin, W.P. 2003. A bibliography of Klamath Mountains geology, California and Oregon, listing authors from Aalto to Zucca for the years 1849 to Mid-2003. US Geological Survey open-file report; 03-306.

JHU/UCB (Johns Hopkins University/University California Berkeley). 1995. Wilcock, P.R., G.M. Dondolf, A.F. Barta, G.M. Matthews, and C.C. Shea. Spawning gravel flushing during trial reservoir releases on the Trinity River, Berkeley, Center for Environmental Design, University of California.

Jackman, R.E., W.G. Hunt, J.M. Jenkins, and P.J. Detrich. 1999. Prey of nesting bald eagles in northern California. Journal of Raptor Research 33:87-96.

Jameossanaie, A. and N. Lindsley-Griffin. 1993. Palynology and plate tectonics-a case study in the eastern Klamath Mountains of northern California, USA. Palynology, 17:11-45.

Johnson, A. H. 1973. The origin and distribution of clay-sized particles in the Trinity River basin, California. Senior Thesis, Humboldt State University, Arcata, California.

Johnston, R.H. 1997. Hydrologic budgets of regional aquifer systems of the United States for predevelopment and development conditions. Reston, Virginia: US Geological Survey Professional Paper no. 1425.

Jones, A.G., R. Krieg, E.B. Langworthy, H.C. Meckel, F.S. Morris, W. Robb, and H. Woods. 1981. Trinity County Historic Sites. Trinity County Historical Society, 422 p.

KRIS Bibliographic Resources – Trinity River. Date of access: June 12, 2006. <http://www.krisweb.com/biblio/biblio_trinity.htm>

Knott, J.M. 1974. Sediment discharge in the Trinity River basin, California in Water-Resources Investigations 49-73. Menlo Park, California, U.S. Geological Survey, 56 p.

Kondolf, G.M. 2004. Report on Trinity River Gravel Augmentation, Report to U.S. Bureau of Reclamation, Shasta Lake, California.

Kramer, S.H. 1993. Habitat specificity of wild juvenile (1+) steelhead within South Fork Trinity River tributaries during low summer flows. MS Thesis, Humboldt State University, Arcata, California.

Lisle, T.E. and S. Hilton. 1992. The volume of fine sediment in pools: an index of sediment supply in gravel-bed streams. Water Resources Bulletin, 28:371-383.

Luke, C. and D. Sterner. 2000. Possible effects of the Cantara spill on amphibian populations of the upper Sacramento River. California Department of Fish and Game, 86:41-60.

Macedo, R.A. 1992. Evaluation of side channels for increasing rearing habitat of juvenile salmonids, Trinity River, California. MS Thesis, Humboldt State University, Arcata, California.

Matthews, G. for Tetra Tech Inc. 1998. Summary and analysis of geomorphic data for the South Fork Trinity River. Weaverville, California: Matthews & Associates.

Matthews, G. & Associates. 2001. Sediment source analysis for the mainstem Trinity River, Trinity County, CA. Contract # 68-C99-249, Work Assignment #0-34. Prepared for Tetra, Inc., Fairfax, Virginia.

Matthews, S., M.J. Furniss, and T. Leskiw. 1990. A study of plant materials suitable for use in watershed and wildlife habitat improvement in the Trinity River watershed, California. U.S.D.A. Forest Service, Six Rivers National Forest, Eureka, California.

McBain and Trush. 1997. Trinity River Flow Maintenance Study. Performed under contract to the Hoopa Tribe. Contract #30255 by McBain and Trush. Arcata, California, 481 p.

McBain and Trush. 2001. Mainstem Trinity River, California, Photomonitoring – Final. Prepared for Hoopa Fisheries Tribe Fisheries Department, Arcata, California, 220 p.

McBain and Trush. 2002. Estimation of 50- and 100-year tributary accretion floods Lewiston Dam to Treadwell Bridge, Trinity River, California. Prepared for the Trinity River Restoration Program by S. McBain, Arcata, California, 35 p.

McBain and Trush Inc. 2003. ADMINISTRATIVE DRAFT – Coarse Sediment Management Plan Lewiston Dam to Grass Valley Creek, Trinity River, California Prepared for US Bureau of Reclamation, Northern California Area Office, Arcata, California, 101 p.

Milhous, R.T. 1995. Suspended and bed load in flushing flow analysis: Trinity River case study in Proceedings of the American Geophysics Union 15th Annual Hydrology Days.

Milhous, R.T. 1997. Reservoir construction, river sedimentation and tributary sediment size in Human impact on erosion and sedimentation. Proceedings of the international symposium, Rabat, Morocco, 1997, pages 275-282.

Moffett, J.W. and S.H. Smith. 1950. Biological investigations of the fishery resources of Trinity River, California. Washington, DC, US Fish and Wildlife Service Special Scientific Report: Fisheries No. 12.

North, P.A. 1992. A comparison of the macroinvertebrate benthos and drift of two side channels and a main stem of the Trinity River, California (with discussion on implications for rearing young-of-the-year salmonids). MS Thesis, Humboldt State University, Arcata, California.

Pacific Watershed Associates. 1994. Action plan for the restoration of the South Fork Trinity River watershed and its fisheries. Prepared for the US Bureau of reclamation and the Trinity River Task Force, Contract No. 2-CS-20-01100, Arcata, California.

Patrick Truman & Associates and Pacific Watershed Associates. 1996. Final Draft – Coordinated Resource Management Plan. Prepared for South Fork Trinity River Coordinated Resource Management Steering Committee, 52 p.

Pemberton, E.L. 1981. Sediment transport sampling for environmental data collection in Erosion and sediment transport measurement: Symposium IAHS Publication No. 133, 1981.

Phillips, P. A. 1989. The geology of the Weaverville Formation in the vicinity of Weaverville, California. MS Thesis, Humboldt State University, Arcata, California, 172 p.

Prokopovich, N.P. 1992. Cave pearls in the Trinity Dam, California. Association of Engineering Geologists, 29:189-192.

Raines, M. for Tetra Tech Inc. 1998. South Fork Trinity River sediment source analysis. Bellingham, Washington.

Reese, D.A. and H.H. Welsh Jr. 1998. Habitat use by western pond turtles in the Trinity River, California. Journal of Wildlife Management, 62:842-853.

Roth, B. 1984. A new species of Vespericola (Gastropoda: Pulmonata: Polygyridae) from the Klamath Mountains, California. Wasmann Journal of Biology, 42:84-91.

Sandifer, D.S. 1997. Native grasses and clear water: Restoration of the Grass Valley Creek watershed, Trinity County, California. Technical Notes, U.S. Department of Agriculture, Natural Resources Conservation Service, 5 p.

Sommarstrom, S. 5C Roads Manual: A water quality and stream habitat protection manual for county road maintenance in northwestern California watersheds.

Sommarstrom, S. Proceedings of the Conference on Decomposed Granitic Soils: Problems and Solutions, October 21-23, 1992. Redding, California, 241 p.

Smith, G.E. 1970. The king salmon (Oncorhynchus Tshawytscha) spawning escapement in the Upper Trinity River, 1969. MS Thesis, Humboldt State University, Arcata, California.

Spinelli, G.A. and M.E. Field. 2001. Evolution of continental slope gullies on the northern California margin. Journal of Sedimentary Research, Section B: Stratigraphy and Global Studies, 71:237-245.

Stokely, T. 2003. Issue Paper for the Trinity Management Council: Is there a causal link between restoration activities in the South Fork Trinity River and other tributaries and the Trinity River division of the CVP? – Draft. Hayfork, California, 13 p.

Trinity County Planning Department Natural Resources Division. Date? Trinity River Watershed Five Counties Road Erosion Inventory. Final Report for State Water Resources Control Board Proposition 204 Program. Contract #9-164-250-0.

Trinity County Resource Conservation District (TCRCD). 1998. Annual Report. Weaverville, CA.

Trinity County Resource Conservation District (TCRCD). 1999. Grass Valley Creek Watershed Restoration Project: Restoration in decomposed granite soils. Prepared by TCRCD and Natural Resources Conservation Service, Weaverville Field Office. Weaverville, California, 163 p.

Trinity County Resource Conservation District (TCRCD). 2003. South Fork Trinity River Water Quality Monitoring Project – Agreement No. P0010340 Final Report. Prepared for California Department of Fish and Game by TCRCD, with assistance from Graham Mathews. Weaverville, California 77 p.

Trso, M. 2004. Trinity River restoration program evaluation of Grass Valley Creek watershed restoration activities. Report prepared for the US Bureau of Reclamation Trinity River Restoration Program. 40 p.

U.S. Bureau of Land Management. 1995. Mainstem Trinity River watershed analysis. Redding, California, 56 p.

U.S. Bureau of Land Management. 1995. Mainstem Trinity watershed analysis. Section VI Detailed investigations. Redding, California, 186p.

U.S. Bureau of Reclamation. 2000. Mainstem Trinity River habitat and floodplain modifications information report. Draft. U.S. Bureau of Reclamation. Northern California Area Office. Shasta Lake, California, 28 p.

U.S. Bureau of Reclamation. 2002. Trinity River Restoration Program: Summary of the United States Secretary of the interior Record of Decision, December 19, 2000. Prepared by McBain & Trush, Inc. Arcata, California, 12 p.

U. S. Bureau of Reclamation Trinity River Restoration Program. 2007. Science Symposium Abstracts and Summaries. February 2007. Weaverville, CA. 63 p.

U.S.D.A. Forest Service. 2001. New Rider Watershed Analysis. Shasta Trinity National Forest. Redding, California, 20 p.

U.S.D.A. Forest Service. 2001. Upper Hayfork Creek Watershed Analysis. U.S.F.S. Pacific Southwest Region, Shasta Trinity National Forest, Hayfork Ranger District. Redding, California, 107 p.

U.S.D.A. Forest Service. 2003. Mainstem Trinity Watershed Analysis. Prepared by Natural Resources management Corporation for U.S.F.S., Pacific Southwest Region, Six River National Forest, Lower Trinity Ranger District. Eureka, California, 444 p.

U.S.D.A. Forest Service. 2003. North Fork Trinity River, East Fork North Fork Trinity River and Canyon Creek Watershed Analysis. Prepared by Shasta Trinity National Forest, Trinity River Management Unit. Redding, California, 59 p.

U.S.D.A. Soil Conservation Service. 1981. Grass Valley Creek Watershed Management Report. For the Trinity River Basin Fish and Wildlife Task Force, 241 p.

U.S.D.A. Soil Conservation Service. 1986. Sediment Study: Grass Valley Creek Watershed, Trinity County, California, 60 p.

U.S.D.A. Soil Conservation Service. 1990. Assessment of Hoadley Gulch, Indian Creek, Deadwood Creek, and Rush Creek Watersheds. For: Bureau of Reclamation, Weaverville, California, Project Manager Ed Solbos, Contract # 8-AA-20-06190, 69 p.

U.S.D.A Soil Conservation Service. 1992. Inventory of Sediment Sources, Grass Valley Creek Watershed, February 1992. For the: Trinity River Basin Fish and Wildlife Program, 43 p.

U.S.E.P.A. 1998. South Fork Trinity River and Hayfork Creek sediment total maximum daily loads (with attached comment responsiveness summary). San Francisco, California, 77 p.

U.S.E.P.A. 2001. Trinity River Total Maximum Daily Load for Sediment U.S.E.P.A., Region IX. San Francisco, California, 142 p.

U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Hoopa Valley Tribe, and Trinity County Natural Resource Division. 2000. Trinity River mainstem Fishery Restoration – Final Environmental Impact Statement/Report. Sacramento, California.

Waddell, K.L. and P.M. Bassett. 1997. Timber resource statistics for the North Interior Resource Area of Northern California. Resource Bulletin – U.S. Department of Agriculture, Forest Service PNW-RB 222, 49 p.

Wilcock, P.R., A.F. Barta, C.C. Shea, G.M. Kondolf, W.V.G. Matthew, and J. Pitlick. 1996. Observations of flow and sediment entrainment on a large gravel-bed river. Water Resources Research 32, pages 2897-2909.

Wilcock, P.R., G.M. Kondolf, W.V.G Matthews, and A.F. Barta. 1996. Specification of sediment maintenance flows for a large gravel-bed river. Water Resources Research 32, pages 2911-2921.

Wright, J.E. and S.J. Wyld. 1986. Significance of xenocrystic Precambrian zircon contained within the southern continuation of the Josephine ophiolite: Devils Elbow ophiolite remnant, Klamath Mountains, northern California. Geology 14:671-674.

Part 3: Monitoring Citations

Anderson, D.M. and L.H. MacDonald. 1998. Modeling Road Surface Sediment Production Using a Vector Geographic Information System. Earth Surface Processes and Landforms 23:95-107.

Archer, E.K., B.B. Roper, R.C. Henderson, N. Bouwes, S.C. Mellison, and J. L. Kershner. 2004. Testing Common Stream Sampling Methods for Broad-scale, Long-term Monitoring. U.S.D.A. Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-122, 15 p.

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadable Rivers: Periphyton, Benthic Macroinvertebrates and Fish. Second Edition. EPA 841-B-99-002. United States Environmental Protection Agency, Washington D.C.

Bartle, Hardy. 1999. Analyzing the Effectiveness of Common Road Construction and Deactivation Techniques. Province of British Columbia, Vol. 4 No. 2 of Streamline (BC's Watershed Restoration Bulletin), 8p.

Bilby, R.E., K. Sullivan, and S.H. Duncan. 1989. The Generation and Fate of Road Surface Sediment in Forested Watersheds of Southwestern Washington, Forest Science 35:453-468.

Bloom, A.L. 1998. An Assessment of Road Removal and Erosion Control Treatment Effectiveness: A Comparison of 1997 Storm Erosion Response Between Treated and Untreated Roads in the Redwood Creek Basin, Northwestern California. MS Thesis, Humboldt State University, Arcata, California, 81 p. + appendix.

Botkin, D.B., D.L. Peterson, and J.M. Calhoun, technical editors. 2000. The Scientific Basis for Validation Monitoring of Salmon for Conservation and Restoration Plans. Olympic Natural Resources Technical Report. University of Washington, Olympic Natural Resources Center, Forks, Washington.

Bunte, K. and S.R. Abt. 2001. Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams, Report RMRS-GTR-74, Rocky Mountain Research Station, U.S. Forest Service, Fort Collins, Colorado.

Bryant, M.D. 1995. Pulsed Monitoring for Watershed and Stream Restoration. Fisheries 20:6-13.

Bryant, M.D. 2005. An approach to effectiveness monitoring of floodplain channel aquatic habitat: salmonid relationships. Landscape and Urban Planning 72: 157-176.

California Department of Fish and Game (CDFG). 2003. California Stream Bioassessment Procedure. Protocol Brief for Biological and Physical/Habitat Assessment in Wadeable Streams. Water Pollution Control Laboratory. Aquatic Bioassessment Laboratory. Revision Date – December 2003.

Center for Dirt and Gravel Road Studies at Pennsylvania State University. 2005. Date of access: June 12, 2006. <http://www.dirtandgravelroads.org/>

Chatwin, S.C., D.E. Howe, J.W. Schwab, and D.N. Swan. 1994. A guide for management of landslide prone terrain in the Pacific Northwest. Land Management Handbook # 18. BC Ministry of Forests. Abstract and links to publication accessed on June 12, 2006. < http://www.for.gov.bc.ca/hfd/pubs/docs/Lmh/Lmh18.htm>

Clesceri, L.S., A.E. Greenberg, and A.D. Eaton. (eds). 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Water Works Association, and Water Environment Federation, 1,220 p.

Clifford, N.J., K.S. Richards, R.A. Brown, and S.N. Lane. 1995. Laboratory and Field Assessment of an Infrared Turbidity Probe and its Response to Particle Size and Variation in Suspended Sediment Concentration. Journal of Hydrological Sciences 40:771-791.

Coe, D. B. R. 2006. Sediment production and delivery from forest roads in the Sierra Nevada, California. Master of Science thesis. Colorado State University. Fort Collins, Colorado. 110 p. Found at: Http://www.bof.fire.ca.gov/pdfs/DrewCoe_FinalThesis.pdf

Coe, D. and L.H. MacDonald. 2001. Sediment Production and Delivery from Forest Roads in the Central Sierra Nevada, California. EOS Transactions AAAGU, 82(47), Fall meeting, Abstract #H51F-03.

Cooper, R.J., G.A. Gale, and L.A. Brennan. 1999. Answering Questions in Management and Research Using Large-scale Manipulative Experiments. In: R. Bonney, D.N. Pashley, R.J. Cooper, and L. Niles, eds. 1999. Strategies for Bird Conservation: The Partners in Flight Planning Process. Cornell Lab of Ornithology, 11 p.

Crawford, B.A. and L.E. Johnson. 2004. Field Sampling Protocols for Effectiveness Monitoring of Habitat Restoration and Acquisition Projects. Interagency Committee for Outdoor Recreation, Washington Salmon Recovery Funding Board.

Dale, V.H. and S.C. Beyeler. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators, pages 3-10.

Davies, K., M.A. Fullen, and C.A. Booth. 2006. A pilot project on the potential contribution of pal-mat geotextiles to soil conservation. Earth Surface Processes and Landforms 31:561-569.

Davis, J.C., G.W. Minshall, C.T. Robinson, and P. Landres. 2001. Monitoring wilderness stream ecosystems. U.S.D.A.-F.S. General Technical Report RMRS-GTR-70, Rocky Mountain Research Station, Ogden, Utah, 137 p.

de La Fuente, J. and P.A. Haessig. 1992. Proceedings of the Conference on Decomposed Granitic Soils: Problems and Solutions: October 21-23, 1992. Landslide and surface erosion rates in the English Peak Batholith and Ashland Pluton. Central Klamath Mountains, California and Oregon. pages 51-63.

Degraff, J.V. 2002. A Perspective For Achieving Improved Landslide Monitoring. 2002 Denver Annual Meeting (October 27-30, 2002), Session No. 16, Case Studies in Landslide Problem Solving, Landslide Monitoring, and Alarm Methodology: In Honor of David J. Varnes, Denver, Colorado.

Delong, D.C., Jr. 1996. Defining biodiversity. Wildlife Society Bulletin 24:738-749.

Dunne, T. 1977. Measurement of Erosion Within Catchments. IN: Evaluation of Erosion Conditions and Trends, Chapter 6, vol. 1, Rome, Italy, Kunkle and James, eds. pages. 64-75.

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman, New York.

Edwards, T.K. and G.D. Glysson. 1999. Field Methods for Measurement of Fluvial Sediment. U.S.G.S. – TWRI Book 3, Chapter C2. http://water.usgs.gov/pubs/twri/

Fitzgerald, R. 2004. Salmonid freshwater habitat targets for sediment-related parameters. Attachment 1 to Resolution No. R1-2004-0087. State of California North Coast Regional Water Quality Control Board, Santa Rosa, California, 53 p.

Fitzpatrick, F.A., I.R. Waite, P.J. D'Arconte, M.R. Meador, M.A. Maupin, and M.E. Gurtz. 1998. Revised Methods for Characterizing Stream Habitat in the National Water-Quality Assessment Program. U.S. Geological Survey Water-Resources Investigations Report 98-4052, 67 p.

Flosi, G., S. Downie, J. Hopelain, M. Bird, R. Coey, and B. Collins. 1998. California Salmonid Stream Habitat Restoration Manual, Third Edition. State of California, The Resources Agency, California Department of Fish and Game, Inland Fisheries Division. Sacramento, California.

Foltz, R.B. and E.R. Burroughs. 1990. Sediment Production from Forest Roads with Wheel Ruts. Watershed Planning and Analysis in Action Symposium, Proceedings of IR Conference Watershed Mgt/IR Div/ASCE, Durango, Colorado, July 9-11, 1990, pages 266-75.

Fox, D., W. Berolo, P. Carrega, and F. Darboux. Mapping erosion risk and selecting sites for simple erosion control measures after a forest fire in Mediterranean France. Earth Surface Processes and Landforms 31:606-621.

Franti, T.G. 1996. Bioengineering for hillslope, streambank and lakeshore erosion control. Coop ext., Inst. of Ag. And Nat. Resources, University of Nebraska, Lincoln.

Frazier, J.W., K.B. Roby, J.A. Boberg, K. Kenfield, J.B. Reiner, D. L. Azuma, J.L. Furnish, B.P. Staab, S.L. Grant. 2005. Stream Condition Inventory Technical Guide. USDA Forest Service, Pacific Southwest Region – Ecosystem Conservation Staff. Vallejo, California, 111 p.

Garboury, M. and R. Wong. 1999. A framework for conducting effectiveness evaluation of watershed restoration projects. Province of British Columbia. Ministry of Environment, Lands and Parks and Ministry of Forests. Watershed Restoration Technical Circular No. 12: 33p.

Gippel, C.J. 1995. Potential of Turbidity Monitoring for Measuring the Transport of Suspended Solids in Streams. Hydrological Processes 9:83-97.

Goldman, S.J., K. Jackson, and T.A. Bursztynsky. 1986. Erosion and Sediment Control Handbook. McGraw-Hill.

Gordon, N.D., T.A. McMahon, and B.L. Finlayson. 1992. Stream Hydrology, an Introduction for Ecologists. John Wiley and Sons. New York. 526 p.

Goudie, A. S. 1981. Geomorphological Techniques, Edited for the British Geomorphological Research Group, Chapter 4.2, Slope Processes, George Allen and Unwin, Boston, Massachusetts, pages 156-180.

Grace, J.M. 2002. Control of Sediment Export from the Forest Road Prism. Transactions of the A.S.C.E., 45 (4), pages 1127-1132.

Grace, J.M. 2003. Minimizing the Impacts of the Forest Road System. IN: Proceedings of the 34th Annual Conference of the International Erosion Control Association. ISSN 1092-2806. ICEA, pages 301-310.

Gray, D.H. and R.B. Sotir. 1996. Biotechnical and soil bioengineering slope stabilization: a practical guide for erosion control. John Wiley & Sons, Inc. New York, New York, 378 p.

Gregory, K.J. and D.E. Walling. 1973. The Measurement of Drainage Basin Processes. IN: Drainage Basin Form and Process, Chapter 3, John Wiley and Sons, New York, p. 93-180.

Haan, C.T., B.J. Barfield and J.C. Hayes. 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press, San Diego, California, pages 588.

Hall, F. C. March 2002. Photo Point Monitoring Handbook, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report, PNW-GTR-526, 48 p.

Hall, F.C. 2002. Photo point monitoring handbook: Part B-concepts and analysis. U.S.D.A.-F.S. General Technical Report PNW-GTR-526, Pacific Northwest Research Station, Portland, Oregon, 134 p.

Hann, J.J. and R.P.C. Morgan. 2006. Evaluating erosion control measures for biorestoration between the time of soil reinstatement and vegetation establishment. Earth Surface Processes and Landforms 31:589-597.

Harr, R. and R. Nichols. 1993. Stabilizing Forest Roads to Help Restore Fish Habitats: a Northwest Washington Example. Fisheries 18:18-22.

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-245. (Chapters 5-8).

Harrington, J. and M. Born. 1999. Measuring the Health of California Streams and Rivers: A Methods Manual for: Water Resources Professionals, Citizen Monitors, and Natural Resources Students. Second Edition. Sustainable Land Stewardship International Institute. Sacramento, California.

Harris, R.R. 2005. Monitoring the Effectiveness of Road System Upgrading and Decommissioning at the Watershed Scale – Final Report, prepared for California Department of Fish and Game. Salmon and Steelhead Trout Restoration Account Agreement No. P0210566. Center for Forestry, University of California, Berkeley, California.

Harris, R.R. M.J. DeLasaux, and S.D. Kocher. 2000. Process and Reality: Working with a Local Watershed Organization to Develop a Restoration Effectiveness Monitoring Program. Journal of Extension Volume 38, No. 2.

Hilton, S. and T.E. Lisle. 1993. Measuring the Fraction of Pool Volume Filled with Fine Sediment. Res. Note PSW-RN-414. Albany, California: Pacific Southwest Research Station, United States Forest Service, U.S.D.A, 11p.

Horel, G. 1997. Building roads with deactivation in mind. Presentation at the 1997 Coastal Forest Site rehabilitation Workshop, Nanaimo, British Columbia.

Ice, G.G. 1986. A Study of the Effectiveness of Sediment Traps for the Collection of Sediment from Small Forest Plot Studies. Technical Bulletin 483, NCASI, New York, 27 p.

Johnson, P.A., G.L. Gleason, and R.D. Hey. 1999. Rapid assessment of channel stability in vicinity of road crossing. Journal of Hydraulic Engineering 125:645-651.

Jones, J.A., F.J. Swanson, B.C. Wemple, and K.U. Snyder. 2000. Effects of Roads on Hydrology, Geomorphology, and Disturbance Patches in Stream Networks. Conservation Biology 14:76-85.

Kahklen, K. 2001. A Method for Measuring Sediment Production from Forest Roads. U.S.D.A. Forest Service, Pacific Northwest Research Station, Research Note PNW-RN-529, 17 p.

Kentucky Erosion Prevention and Sediment Control Filed Guide. Access date June 12, 2006. <http://www.tetratech-ffx.com/wstraining/pdf/esc_guide.pdf>

Kershner, J.L., E.K. Archer, M. Coles-Ritchie, E.R. Crowley, R.C. Henderson, K. Kratz, C.M. Quimby, D.L. Turner, L.C. Ulmer, M.R. Vinson. 2004. Guide to effective monitoring of aquatic and riparian resources. Gen. Tech. Rep. RMRS-GTR-121. Fort Collins, Co: U.S. Department of Agriculture, Rocky Mountain Research Station. 57 p.

Klein, R.D. 1987. Stream Channel Adjustments Following Logging Road Removal in Redwood National Park. MS Thesis, Humboldt State University, Arcata, California, 56 p. + appendix.

Klein, R.D. 2003. Erosion and Turbidity Monitoring Report Sanctuary Forest Stream Crossing Excavations in the Upper Mattole River Basin, 2002-2003. Prepared for: Sanctuary Forest, Inc. P.O. Box 166 Whitethorn, California 95589.

Knopp, C. 1993. Testing Indices of Cold Water Fish Habitat. Final Report for Development of Techniques for Measuring Beneficial Use Protection and Inclusion into the North Coast Region's Basin Plan by Amendment of the "Guidelines for Implementing and Enforcement of Discharge Prohibition Relating to Logging, Construction and Associated Activities," North Coast Regional Water Quality Control Board, Santa Rosa, California.

Kondolf, G.M. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society 129:262-281.

Kondolf, G. M. and H. Piegay (eds). 2003. Tools in Fluvial Geomorphology. Wiley and Sons. San Francisco, California, 688 p.

Leslie, M., W. Warttig, and M. Wise. 1999. Road deactivation effectiveness monitoring, Lost Shoe-Thunderous Creek watersheds and Toquart Bay area, South Island Forest District. International Forest Products Ltd, Vancouver, British Columbia, 24p.

Lewis, D.J., K.W. Tate, and J.M. Harper. 2000. Sediment Delivery Inventory and Monitoring – a Method for Water Quality Management. In: Rangeland Watersheds. University of California, California Rangelands Research and Information Center, ANR Publication 8014, 14 p.

Lieberman, J.A. and M.D. Hoover. 1948. The Effect of Uncontrolled Logging on Stream Turbidity. Water and Sewage Works, July, 1948, 4 p.

Lisle, T. E. and S. Hilton. 1992. The Volume of Fine Sediment in Pools: An Index of the Supply of Mobile Sediment in Stream Channels. Water Resources Bulletin 28:371-383.

Lisle, T. E. and S. Hilton. 1999. Fine Bed Material in Pools of Natural Gravel-bed Channels. Water Resources Research 35:1291-1304.

Luce, C.H., B.E. Rieman, J.B. Dunham, J.L. Clayton, J.G. King, and T.A. Black. 2001. Incorporating Aquatic Ecology into Decisions on Prioritization of Road Decommissioning, Water Resources IMACT, 3(3), pages 8-14.

Luce, C.H. 1997. Effectiveness of Road Ripping in Restoring Infiltration Capacity of Forest Roads. Restoration Ecology 5:265-270.

Luce, C.H. and T.A. Black. 1999. Sediment Production from Forest Roads in Western Oregon. Water Resources Research 35:2561-2570.

Linsley, R.K., M.A. Kohler, and J.L.H Paulhus. 1982. Hydrology for Engineers, Third Edition. McGraw-Hill, New York.

MacDonald, L.H. 1992. Sediment Monitoring: Reality and Hope. In: Anon. 1992. U.S.E.P.A. and U.S.F.S. Technical Workshop on Sediments. Washington D.C.: Terrene Institute. pages 81-87.

MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. United States Environmental Protection Agency Center for Streamside Studies, AR-10. 164 p.

MacDonald, L.H., R.W. Sampson, and D.M. Anderson. 2001. Runoff and Roads Erosion at the Plot and Segments Scale. St. John, U.S. Virgin Islands. Earth Surface Processes and Landforms 26:251-272.

Madej, M.A. 1999. What Can Thalweg Profiles Tell Us? A Case Study from Redwood Creek, CA. Watershed Management Council Networker. Summer 1999, 8(4).

Madej, M.A. 1999. Temporal and Spatial Variability in Thalweg Profiles of a Gravel-bed River. Earth Surface Processes and Landforms 24:1153-1164.

Madej, M.A. 2001. Erosion and Sediment Delivery Following Removal of Forest Roads. Earth Surface Processes and Landforms 26:175-190.

Madej, M.A., H. Kelsey, and W. Weaver. 1980. An evaluation of 1978 rehabilitation sites and erosion control techniques in Redwood National Park. U.S. National Park Service, Arcata, California. Technical Report No. 1, 113 p.

Madej, M.A., M. Wilzbach, K. Cummins, C. Ellis, and S. Hadden. 2004. The Significance of Suspended Organic Sediments to Turbidity, Sediment Flux, and Fish-Feeding Behavior. Paper presented at the Redwood Region Forest Science Symposium, 15-17 March 2004, Rohnert Park, California.

Maidment, D.R. 1993. Handbook of Hydrology. McGraw Hill, Inc. San Francisco, California.

Mati, B.M., R.P.C. Morgan, and J.N. Quinton. 2006. Soil erosion modeling with EUROSEM at Embori and Mukogodo catchments, Kenya. Earth Surface Processes and Landforms 31:579-588.

Megahan, W.F., K.A. Seyedbagheri, and P. C. Dodson. 1983. Long-term erosion on granitic roadcuts based on exposed tree roots. Earth Surface Processes and Landforms, 8:19-28.

Megahan, W. and G. Ketcheson. 1996. Predicting Downslope Movement of Granitic Sediments from Forest Roads in Idaho. Water Resources Bulletin 32:371-382.

Mills, K. 1997. Forest Roads, Drainage, and Sediment Delivery in the Kilchis River Watershed. Tillamook Bay National Estuary Project and the Oregon Department of Forestry, 24 p. + appendix.

Moll, J. 1996. A Guide for Road Closure and Obliteration in the Forest Service, San Dimas Technology and Development Center.

Montgomery, D.R. 1994. Road Surface Drainage, Channel Initiation, and Slope Instability. Water Resources Research 30:1925-1932.

Montgomery, D.R. and J.M. Buffington. 1998. Channel Processes, Classification, and Response. In: Naiman R.J. and R.E. Bilby, (eds) 1998. River Ecology and Management. Springer-Verlag, New York.

Morgan, A and Devin Smith. 1997. Trends in Disturbance and Recovery of Selected Salmonid Habitat Attributes Related to Forest Practices: A Literature Review and Monitoring Recommendations. Timber, Fish and Wildlife Monitoring Program, Northwest Indian Fisheries Commission, 57 p.

Mulder, B.S., B. Noon., T. Spies, M. Raphael, C. Palmer, A. Olsen, G. Reeves, and H. Welsh. 1999. The Strategy and Design of the Effectiveness Monitoring Program for the Northwest Forest Plan. U.S.D.A. Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report PNW-GTR-437. 138 p.

NCHRP 25-25(04) Compendium of Environmental Stewardship Practices in Construction and Maintenance. Access data June 12, 2006. <http://www.vennerconsulting.com/NCHRP/>

Natural Resource Conservation Service. 1997. A technical glossary of stream and river stabilization, restoration, and bioengineering terms. Natural Resources Conservation Service, Plant Material Technical Note No. 32. Accessed online June 12, 2006. <http://www.wsu.edu/pmc_nrcs/Docs/Technical_Note_9_Terminology.pdf>

Noon, B.R. 1999. Scientific framework for effectiveness monitoring of the Northwest Forest Plan. Pages 49-68. In: Mulder, B.S., B.R. Noon, and others, technical coordinators. The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan. U.S.D.A.-F.S. General Technical Report PNW-GTR-437, Pacific Northwest Research Station, Portland, Oregon.

Noon, B.R. 2003. Conceptual issues in monitoring ecological resources, pages 27-72. In: Busch, D.E., and J.C. Trexler, (eds). Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Covelo, California. [material for talk taken from other chapters as well, e.g., 8 steps of data mgmt from Palmer's (8th) chapter]

Northwest Hydraulic Consultants. 1999. Effectiveness monitoring, Willow Watershed, Quesnel Forest District. Northwest Hydraulic Consultants Ltd., North Vancouver, BC, 29p.

Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4:355-364.

Orsborn, J.F., A.W. Johnson, and M.T. Orsborn. 2001. The integration of basin streamflow and channel characteristics for channel condition analyses. Prepared for: EPA – Region 10, Surface Water Branch, Seattle, WA. Stephen C. Ralph, EPA Contract Officer. Grant No. X990717.

Pacific Watershed Associates. 2005. Evaluation of Road Decommissioning, CDFG Fisheries Restoration Grant Program, 1998 to 2003. California Department of Fish and Game Contract P0210559. Arcata, CA.

Peterson, P.N., A. Hendry, and T.P. Quinn. 1992. Assessment of Cumulative Effects on Salmonid Habitat: Some Suggested Parameters and Target Conditions. Prepared for the Washington Department of Natural Resources and The Cooperative Monitoring, Evaluation, and Research Committee Timber/Fish/Wildlife Agreement. Center for Streamside Studies, University of Washington. TFW-F3-92-001.

Piehl. B.T., R.L. Beschta and R.M. Pyles. 1988. Ditch-relief Culverts and Low Volume Forest Roads in the Oregon Coast Range. Northwest Science 62:91-98.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S.D.A.-F.S. General Technical Report INT-138, Intermountain Forest and Range Experiment Station, Ogden, Utah, 69p.

Platts, W.S., C. Armour, G.D. Booth, M. Bryant, J.L. Bufford, P. Cuplin, S. Jensen, G.W. Lienkaemper, G.W. Minshall, S.B. Monsen, R.L. Nelson, J.R. Sedell, and J.S. Tuhy. 1987. Methods for evaluating riparian habitats with applications to management. U.S.D.A.-F.S. General Technical Report INT-221.

Poole, G.C, C.A. Frissell, and S.C. Ralph. 1997. In-Stream Habitat Unit Classification: Inadequacies for Monitoring and some Consequences for Management. Journal of the American Water Resources Association 33:879-896.

Ramos, C. 1996. Quantification of Stream Channel Morphological Features: Recommended Procedures for Use in Watershed Analysis and TFW Ambient Monitoring. Northwest Indian Fisheries Commission. TFW-AM9-96-006.

Ray, G.A., and W.F. Megahan. 1978. Measuring Cross-sections Using a Sag Tape: a Generalized Procedure. General Technical Report INT-47. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Reid, L.M. and T. Dunne. 1984. Sediment Production from Forest Road Surfaces. Water Resources Research 20:1753-1761.

Reeves, G.H., D.B. Hohler, D/P/ Larsen, D.E. Busch, K.Kratz, K. Reynolds, K.F. Stein, T. Atzet, P. Hays, and M. Tehan. 2004. Effectiveness Monitoring for the Aquatic and Riparian Component of the Northwest Forest Plan: Conceptual Framework and Options. Gen. Tech. Rep. PNW-GTR-577. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 71 p.

Rickson, R.J. 2006. Controlling sediment at source: an evaluation of erosion control geotextiles. Earth Surface Processes and Landforms 31:550-560.

Riparian Roads Restoration Team. ***unable to access June 12, 2006. <http://fsweb.sdtdc.wo.fs.fed.us/programs/eng/RRR/>

Robichaud, P.R. and R.E. Brown. 2002. Silt Fences: an Economical Technique for Measuring Hillslope Soil Erosion. U.S.D.A. Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-94, 4 p.

Roni, P., (ed) 2005. Monitoring Stream and Watershed Restoration. American Fisheries Society. Bethesda, Maryland, 350 p.

Schiechtl, H. 1980. Bioengineering for land reclamation and conservation. The University of Alberta Press, Edmonton, Canada.

Schiechtl, H.M. and R. Stern. 1996. Ground bioengineering techniques for slope protection and erosion control. Trans. By L. Jaklitsch. Blackwell Scientific. Oxford, U.K. 146 p.

Schuett-Hames, D., R. Conrad, A. Pleus, and M. McHenry. 1999a. TFW Monitoring Program Method Manual for the Salmonid Spawning Gravel Composition Survey. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-001. DNR #101. March.

Schuett-Hames, D., A.E. Pleus, J. Ward, M. Fox, and J. Light. 1999b. TFW Monitoring Program Method Manual for the Large Woody Debris Survey. Prepared for the Washington State Department of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-004. DNR #106. June.

Schuster, R.L. and R.J. Krizek. 1978. Landslides - Analysis and Control. Transportation Research Board, Special Report 176, 228 p.

Shirazi, M.A., W.K. Seim, and D.H. Lewis. 1979. Characterization of Spawning Gravel and Stream System Evaluation. Updated edition of EPA Report EPA-800/3-79-109, October 1979.

Simpson Resource Company. 2004. Class I Channel Monitoring Protocol. In: Simpson's Draft Habitat Conservation Plan. February 5, 2004.

Skaugset, A and M.M. Allen. 1998. Forest Road Sediment and Drainage Monitoring Project Report for Private and State Lands in Western Oregon. Oregon Department of Forestry, Salem, Oregon, 20 p.

Skorseth, K. and A.A. Selim. 2000. Gravel Roads and Maintenance Manual. South Dakota Local Transportation Assistance Program. Access date June 12, 2006. <http://www.vennerconsulting.com/NCHRP/>

Smith, E.P. 2002. BACI Design, In: Encyclopedia of Environmetrics, A.H. El-Shaarawi and W.W. Piegorsch (eds), John Wiley and Sons, Ltd, Chichester, vol. 1, pages 141-148.

Somerville, D.E. and B.A. Pruitt. 2004. Physical Stream Assessment: A Review of Selected Protocols. Prepared for the U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division (Order No. 3W-0503-NATX). Washington, D.C., 207 p.

State of California, North Coast Regional Water Quality Control Board. 2006. Desired Salmonid Freshwater Habitat Conditions for Sediment-Related Indices. State of California, North Coast Regional Water Quality Control Board, Santa Rosa, California, 60 p.

Stednick, J. D. 1996. Monitoring the Effects of Timber Harvest on Annual Water Yield. Journal of Hydrology 176:79-95.

Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker. 1986. Environmental Impact Assessment: “Pseudoreplication” in Time? Ecology 67(4):929-940.

Switalski, T.A., J.A. Bissonette, T.H. DeLuca, C.H. Luce, and M.A. Madej. 2004. Benefits and Impacts of Road Removal. Frontiers in Ecology Environ 2004, The Ecological Society of America, 2(1), pages 21-28.

Tate, K.W., R.A. Dahlgren, M.J. Singer, B.H. Allen-Diaz, and E.R. Atwill. 1999. Timing, Frequency of Sampling Affect Accuracy of Water-Quality Monitoring. California Agriculture, 53:44-48.

Turner, A.K. and R.L. Schuster (eds). 1996. Landslides - Investigation and Mitigation, Transportation Research Board, Special Report 247, 645 p.

U.S.D.A.. 1997. Watershed restoration effectiveness monitoring protocol. Forest Service, Pacific Northwest Region, United States Department of Agriculture, 42p.

U.S.D.A. 2001. Forest Roads: a Synthesis of Scientific Information. H. Gucinski, M. Furniss, R. Ziemer and M. Brookes (eds). U.S. Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-509, 103 p.

U.S.D.A. Forest Service. 2000. Water Quality Management for Forest System Lands in California, Best Management Practices. USFS Pacific Southwest Region.

U.S.D.A. Forest Service. 2004. Best Management Practices Evaluation Program. 1992-2002 Results. USFS Pacific Southwest Region, 80 p.

U.S.D.A. Forest Service. 2001. Soil Bioengineering – An Alternative for Roadside Management, A Practical Guide. Publication TR 1737-19, BLM/ST/ST-03/001 1737. Copies available from: BLM National Business Center, Printed Material Distribution Service, BC-652 P.O. Box 25047 Denver, CO. <http://www.wsdot.wa.gov/eesc/design/roadside/SB/pdf/Soil%20bioeng.pdf>

U.S.D.A. Stream Systems Technology Center. Identifying bankfull stage in the eastern and western United States. DVD.

U.S.E.P.A. 1995. Volunteer Stream Monitoring: A Methods Manual. EPA QA/G-6 Guidance for the Preparation of Standard Operating Procedures (SOP's) for Quality Related Documents. EPA-841D 95001.

U.S.E.P.A. 1996. The Volunteer Monitor's Guide to Quality Assurance Project Plans. Office of Wetlands, Oceans, and Watersheds. EPA 841-B-96-003. 59 p.

U.S.G.S. 1999a. Techniques of Water-Resources Investigations (TWRI), Book 9.

U.S.G.S. 1999b. National Field Manual for the Collection of Water-Quality Data: U.S. Geological Survey Techniques of Water-Resources Investigations.

U.S.G.S. 2000. Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Site Selection, Field Operation, Calibration, Record Computation, and Reporting. Water-Resources Investigations Report 00-4252.

Vanoni, V. A. (ed.) 1975. Sedimentation Engineering. American Society of Civil Engineers. New York NUY. 745 pp.

Walters, C.J., J.S. Collie, and T. Webb. 1988. Experimental Designs for Estimating Transient Responses to Management Disturbances. Can. J. Fish. Aquat. Sci. 45: 530-538.

Washington Forest Practices Board (WFPB). 1997. Board Manual: Standard Methodology for Conducting Watershed Analysis. Version 4.0.

Washington Salmon Recovery Funding Board (WSRFB). 2003. Plan for Establishment of Intensively Monitored Watersheds for Effectiveness Monitoring. SRFB IMW-1, Olympia, Washington.

Weaver, W.E., R.A. Sonnevil, and R. Klein. 1987. Field Methods for Monitoring Erosion and Sedimentation in Steeplands of Northwestern California, USA. In: Erosion and Sedimentation in the Pacific Rim, Proceedings of the Corvallis Symposium, August, 1987, IAHS Publication no. 165, pages 509-510.

Weaver, W.E., M.M. Hecktner, D.K. Hagans, L.J. Reed, R.A. Sonnevil, and G.J. Bundros. 1987. An Evaluation of Experimental Rehabilitation Work, Redwood National Park. Redwood National Park, Technical Report no. 19, 163 p.

Weaver, W. E. and D.K. Hagans. 1994. Handbook for Forest and Ranch Roads: A Guide for Planning, Designing, Constructing, Reconstructing, Maintaining and Closing Wildland Roads. Prepared by Pacific Watershed Associates for the Mendocino County Resources Conservation District. Ukiah, California, 197 p.

Weaver, W. and R.R. Harris. 2005. Monitoring the Effectiveness of Upland Restoration – Final Report, prepared for California Department of Fish and Game. Salmon and Steelhead Trout Restoration Account Agreement No. P0210566. Prepared by Pacific Watershed Associates and Center for Forestry, University of California, Berkeley.

Wemple, B.C., F.J. Swanson, and J.A. Jones. 2001. Forest Roads and Geomorphic Process Interactions, Cascade Range, Oregon. Earth Surface Processes and Landforms 26:191-204.

Wemple, B.C. and J.A. Jones. 2003. Runoff Production on Forest Roads in a Steep, Mountain Catchment. Water Resources Research 39:8-1-8-18.

Wemple, B.C., J. A. Jones and G. E. Grant. 1996. Channel network extension by logging roads in two basins, Western Cascades, Oregon. Water Resources Bulletin. Vol. 32 No. 6, p. 1195-1207.

Wickham, J.D., J. Wu, and D.F. Bradford. 1997. A conceptual framework for selecting and analyzing stressor data to study species richness at large spatial scales. Environmental Management

Wilcock, P.R. 2001. Toward a practical method for estimating sediment transport rates in gravel-bed rivers. Earth Surface Processes and Landforms, 26:1395-1408.

Wolman, M. G. 1954. A method of sampling coarse bed material. American Geophysical Union, Transactions, 35: 951-956.

Woodsmith, R.D. and J.M. Buffington. 1996. Multivariate geomorphic analysis of forest streams: implications for assessment of land use impacts on channel condition. Earth Surface Processes and Landforms 21:377-393.

Woodsmith, R.D., J.R. Noel and M.L Dilger. 2005. An approach to effectiveness monitoring of floodplain channel aquatic habitat: channel condition assessment. Landscape and Urban Planning 72:177-204.

Part 4. Fire Impacts on Watersheds

Geological Society of America. 2003. Wildland Fire Impacts on Watersheds: Understanding, Planning and Response, CD-ROM. October 21-23, 2003 meeting at Sheraton Denver Tech Center Hotel, Englewood, Colorado.

U.S.D.A. Natural Resource Conservation District Klamath Basin Watershed Office. 2005. Fire and Watershed Effects Bibliography for Trinity River Restoration Program (TRRP): Tributary Assessments. Compiled by Randi B. Paris, Yreka, California. Available upon request.

Wondzell, S.M. and J.G. King. 2003. Postfire erosional processes in the Pacific Northwest and Rocky Mountain regions. Forest Ecology and Management, 178:75-87.

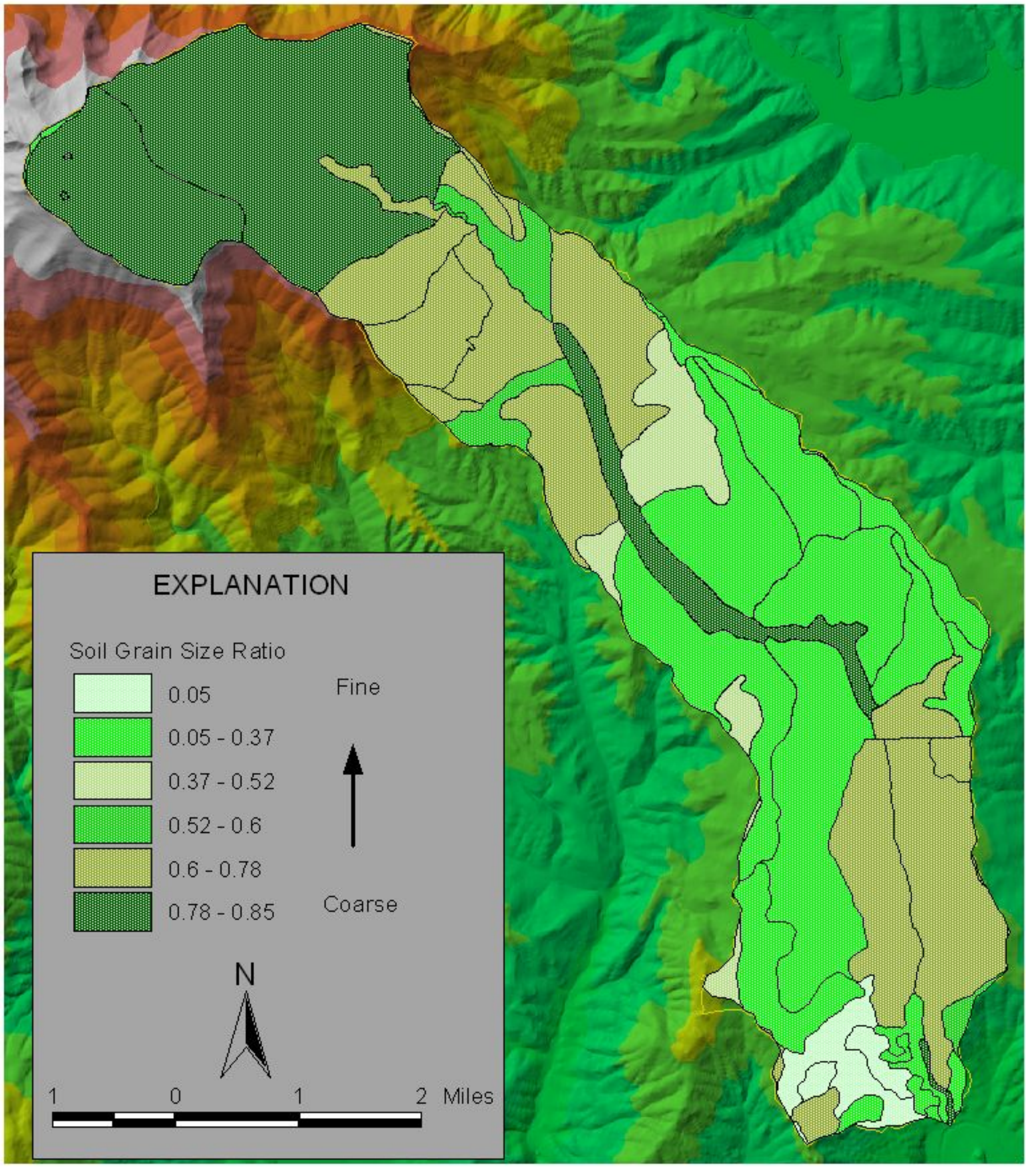
Appendices

Appendix 1. Erosion Control Products and Uses*

*Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

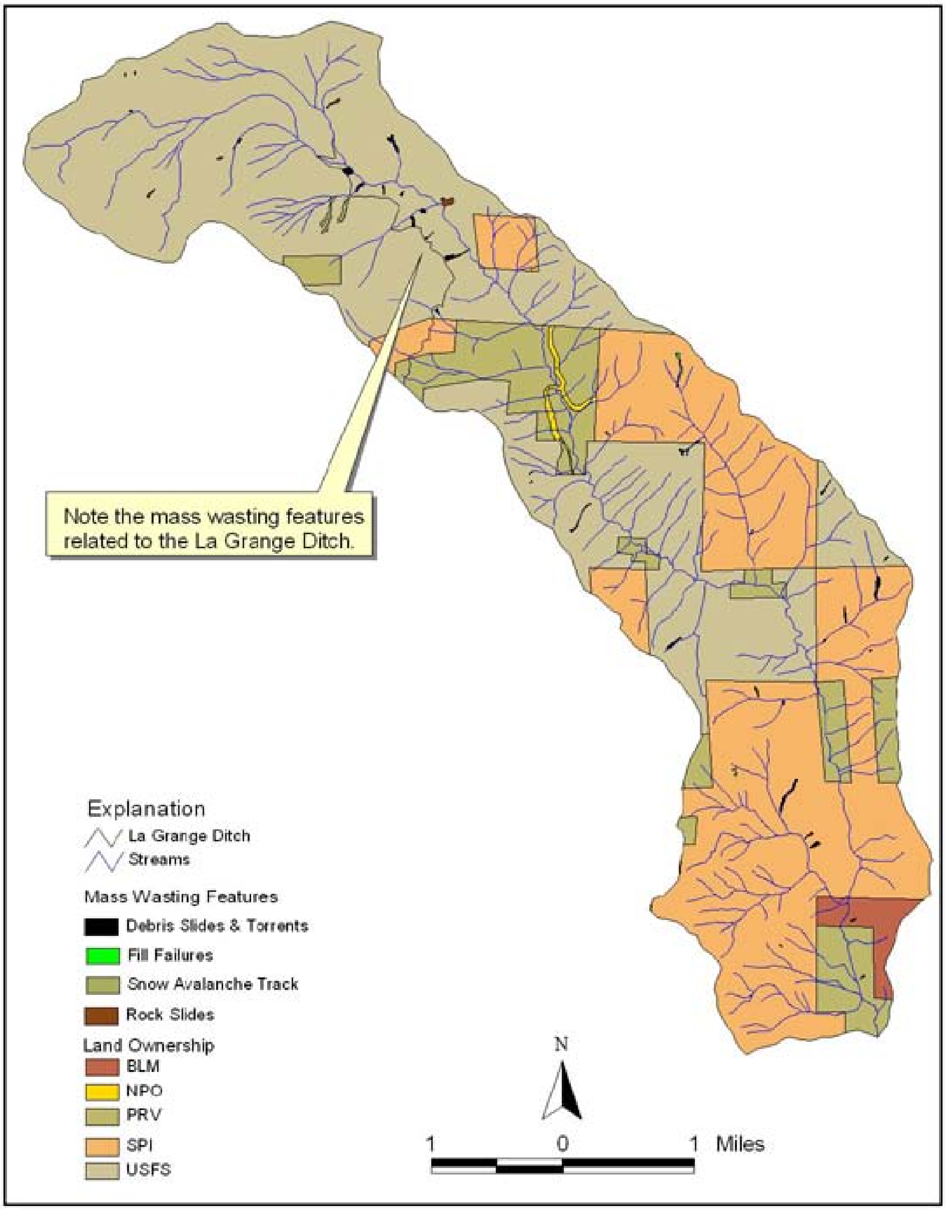
Appendix 2. Soil Characteristics of the Rush Creek Watershed

Appendix 3. Relative Particle Size of Soil Units in Rush Creek Watershed



from Fiori (in preparation).

Appendix 4. Map of Mass Wasting Features in the Rush Creek Watershed

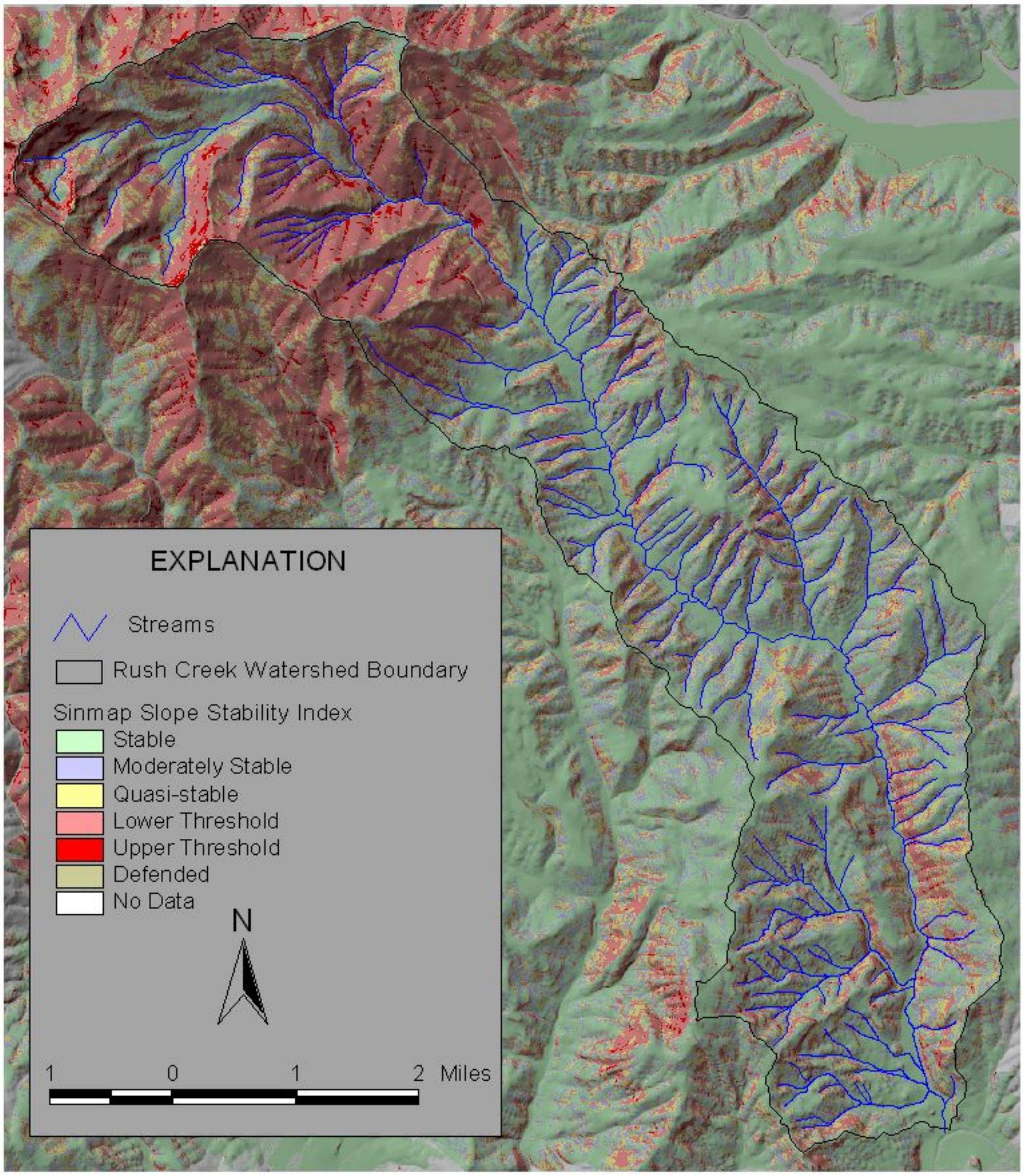


Note the mass wasting features related to the La Grange Ditch.

DRAFT - Rush Creek Mass Wasting Features - DRAFT

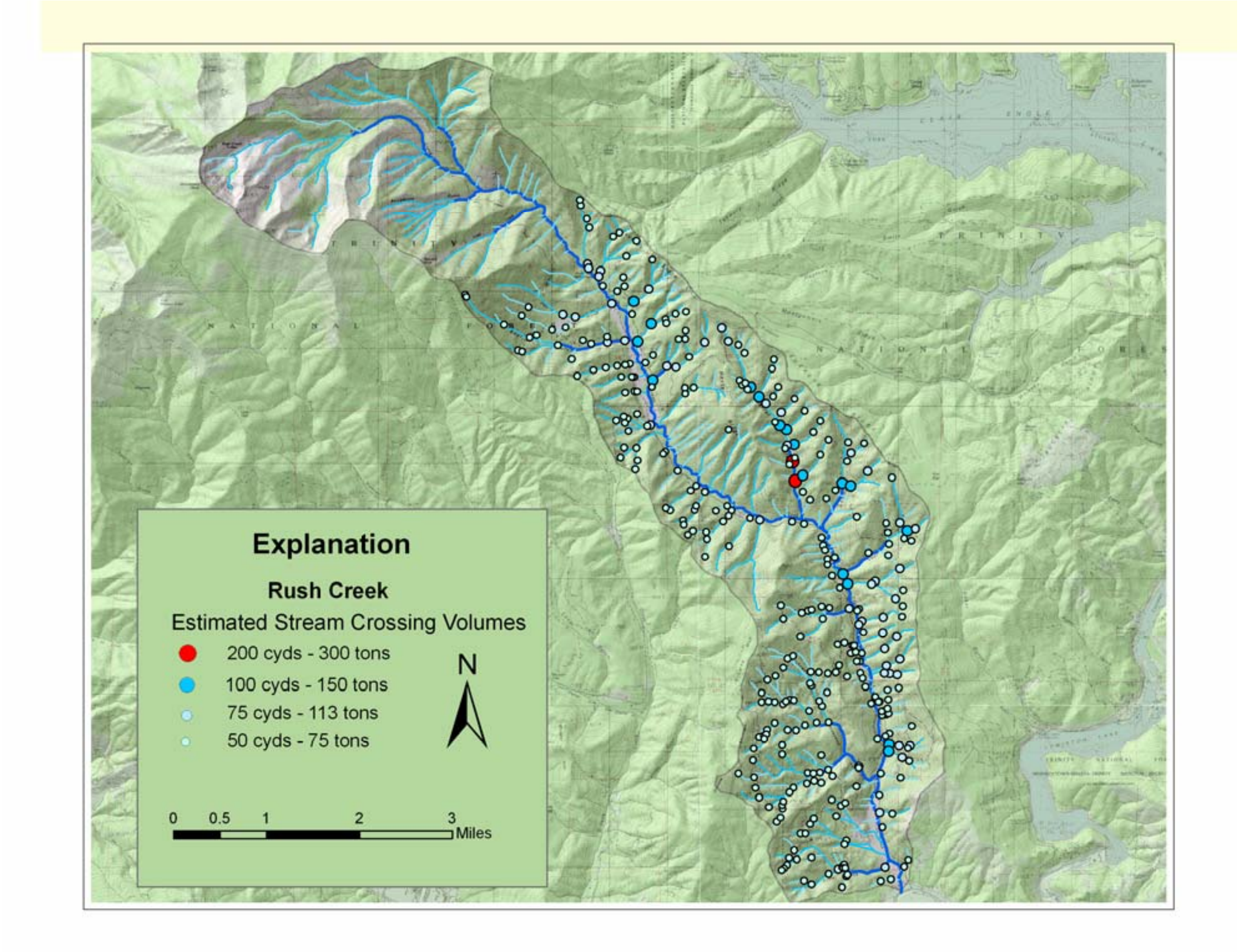
From Fiori (in preparation)

Appendix 5. Sinmap Slope Stability Map, Rush Creek Watershed



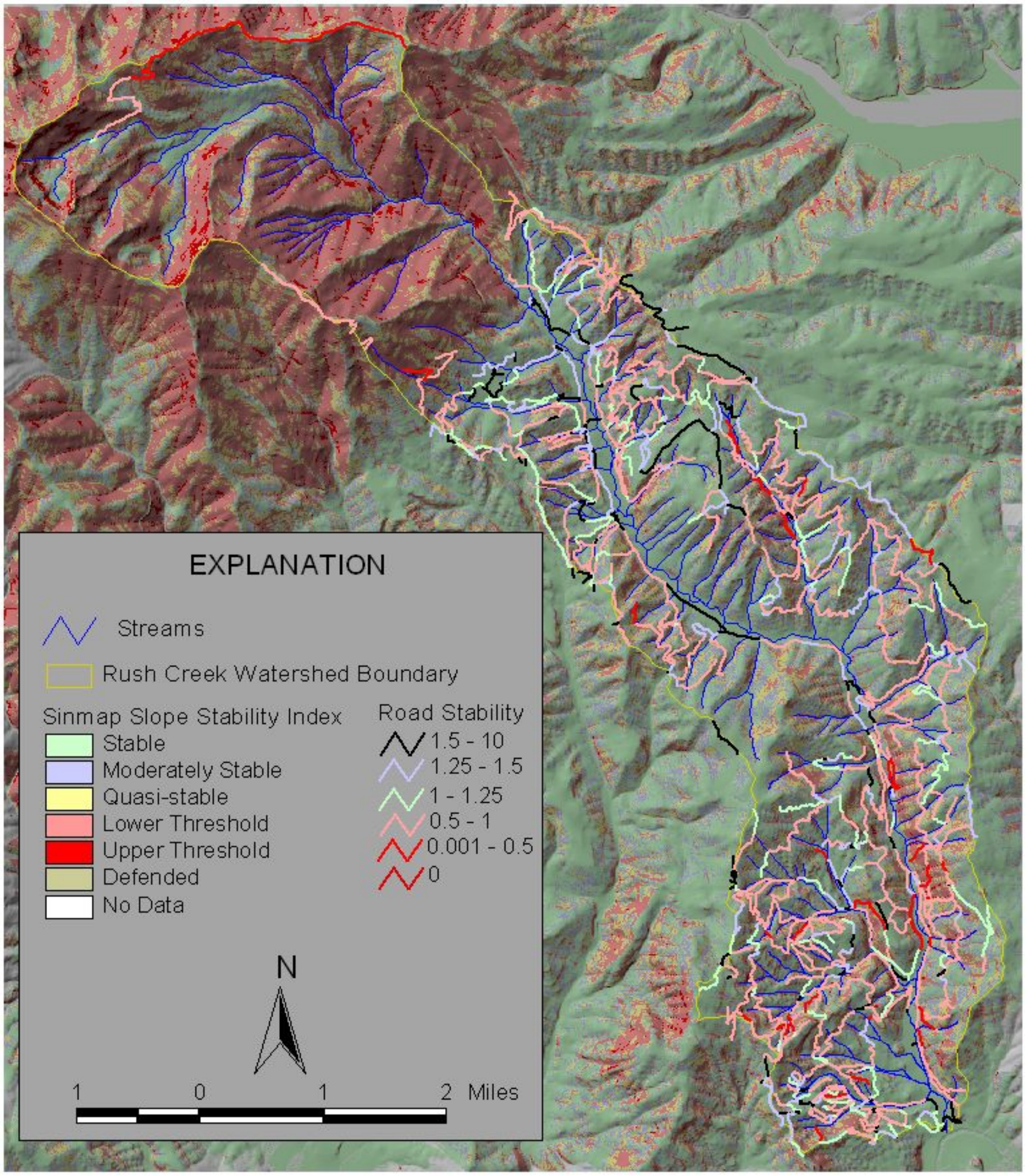
From Fiori (in preparation)

Appendix 6: Estimated Stream Crossing Volumes on Roads in the Rush Creek Watershed



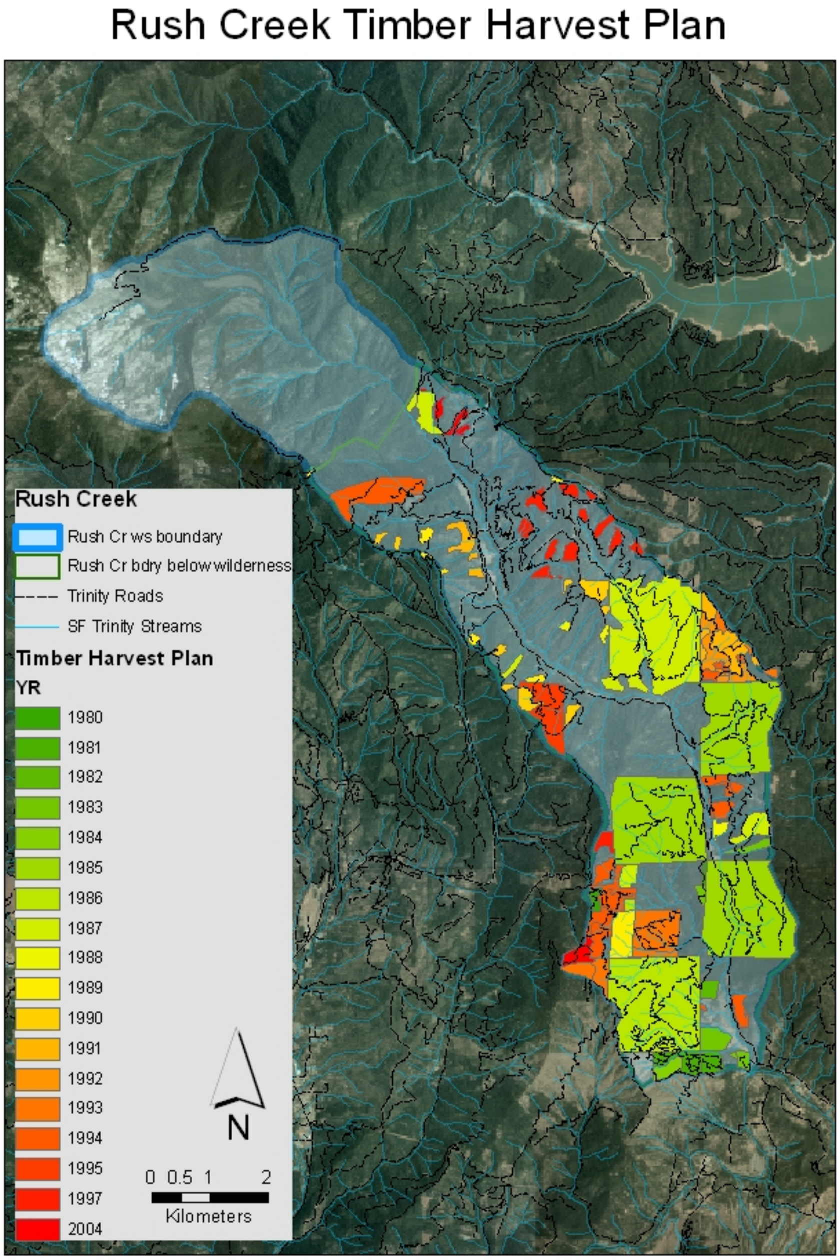
From Fiori (in preparation).

Appendix 7. Relative Stability Rating of Roads in the Rush Creek Watershed



From Fiori (in preparation)

Appendix 8. Timber Harvest History in Rush Creek



Compiled by NRCS, 2006.

Appendix 9: Rush Creek Bank Erosion Measurements

Rush Creek Bank Erosion Estimates (From Rush Creek Campground to Hwy 3 Bridge)

Site Number	Bank (L or R)	Length (ft)	Height (ft)	Depth (ft)	Volume (yd^3)	Activity Level*	Bank Material	Comments
1	L	54	8	4	64	A	CPS:B	Erosion on outside of meander bend. Left bank erosion, no vegetation, actively eroding
2	L	69	15	15	452	A	BCPS	Erosion on outside meander bend, actively eroding, exposed tree roots; crescent shaped void (volume = 1/2 area of ellipse * height)
3	L	39	12	6	104	A	BCPS	Active erosion, vertical banks
4	L	105	9	11	385	SA	PS:C:B	Bank erosion behind young alder stand (estimate 4 years old), finer grained bank material, grass and berry vegetated mid-slope
5	R	75	5	2	28	A	BCPS	Active bank erosion, exposed tree roots, vertical bank
6	L	90	5	7	117	A	PSCB	Exposed tree roots, undercut banks, 9.5' max undercut bank, large steel culvert lying at base of left bank
7	R	84	20	15	933	SA	S:BC	Large right bank erosion with lots of fines in bank material, vertical banks, small maples, alders (about 15 yrs old) and willows between exposed bank and stream, trees established on talus slope.
8	R	48	8	6	85	SA	S:B:C	Springs emerging from bank, moss on cutbank, thimble berry, small alders and elderberry vegetation, feature about 3 years old
9	L	78	8	6	139	A	SPCB	Actively eroding edge of terrace, unvegetated, outside meander bend
10	L	138	7	3	107	SA	SPBC	Erosional feature not active, well vegetated, erosion at base of terrace
11	L	114	9	2	76	A	BCPS	Vertical banks; actively eroding

Rush Creek Bank Erosion Estimates (From Rush Creek Campground to Hwy 3 Bridge)

CONTINUED

Site Number	**Bank (L or R)**	**Length (ft)**	**Height (ft)**	**Depth (ft)**	**Volume (yd^3)**	**Activity Level***	**Bank Material**	**Comments**
12	L	72	6	4	64	A	SPCB	Erosion of left bank high flow channel, channel separated from low flow channel by alder bar; looks like flood deposit being reworked. Material in deposit darker than red soils of streambanks
13	R	96	4	3	43	A	BC	Undercut banks, exposed tree roots, edge of terrace with old-growth trees
14	R	147	3	6	98	SA	BC	Not very active; banks mossy, alders established at base about 10-15 yrs old
15	L	141	3	3	47	A	S	High flow channel; adjacent Rush Creek Campground gate, fresh erosion
16	R	117	4	6	104	A	BC	at old concrete bridge abutment
17	L	231	3	2	51	A	BCPS	Left bank erosion at Rush Creek day use area
18	L	240	4	2	71	A	BC	Vertical banks; young alders at base
19	R	90	4	5	67	A	PCB	Active right bank erosion
20	L	198	3	3	66	A	SPC	Fine grained banks, red clay
21	L	210	3	3	70	SA	SP	Not actively eroding; on left bank behind gravel bar with elder berry vegetation
22	R	93	5	7	121	A	BC	Active erosion; tributary mouth upstream on right bank
23	L	117	5	7	152	A	SClayPC	Actively eroding, undercut banks; large trees undercut and fallen into channel
24	L	69	7	5	89	A	fines	Edge of old road, lots of fine sediment
25	L	60	12	3	80	A	fines	Left bank shallow landslide; fine grained landslide deposited on left bank gravel bar.
26	L	33	35	10	428	A	fines	Landslide
27	L	135	9	3	135	A	CPSClay	Left bank active erosion, exposed roots
28	L	123	2	1	9	A	CPB	Minor erosion
29	L	180	4	2	53	A	ClayP	Clay bank, vertical
30	L	63	3	2	14	A	SP	Undercut banks, exposed tree roots, active erosion

Rush Creek Bank Erosion Estimates (From Rush Creek Campground to Hwy 3 Bridge)
CONTINUED

Site Number	**Bank (L or R)**	**Length (ft)**	**Height (ft)**	**Depth (ft)**	**Volume (yd^3)**	**Activity Level***	**Bank Material**	**Comments**
31	R	135	3	3	45	A	BC	Active erosion, exposed roots, at confluence with right bank tributary or braided channel
32	L	99	4	5	73	A	BC	Active erosion, under cut banks, exposed roots, inflow coming in on right bank; upstream of power line that crosses creek
33	R	72	6	6	96	A	SPC	Vertical banks, exposed tree roots, riparian trees undercut and fallen in channel
34	L	153	15	2	170	A	B w fines above	L-bank erosion, vertical bank
35	R	192	6	4	171	SA	CPSB	Vertical bank, separated from channel by right bank gravel bar with young pines, maples and alders (roughly less than 5 years old)
36	L	183	5	3	102	A	PSCB	Active erosion
37	L	210	25	3	583	SA	PSC	Vertical bank; left bank erosion separated from main channel by high flow back channel. Looks like only erodes in higher flows, at road culvert in left bank
38	L	87	9	4	116	A	S, PC	
39	L	129	22	4	420	A	CSB	
40	L	69	20	3	153	A	CS	
				Active Erosion Total=		3747	yd^3	
				Semi-Active Erosion Total=		2433	yd^3	

*A = Active; SA = Semi-Active

Bank Material listed in order of dominance. B = Boulder, C = Cobble, P = Pebble, S = Sand