Water Quality Assessment and Modeling of the California Portion of the Truckee River Basin

David McGraw
Alan McKay
Guohong Duan
Thomas Bullard
Tim Minor
Jason Kuchnicki

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Prepared by
Division of Hydrologic Sciences, Desert Research Institute,
University and Community College System of Nevada, Las Vegas

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EXECUTIVE SUMMARY

The purpose of this study is to provide the technical analysis and review necessary to begin developing a Total Maximum Daily Load (TMDL) for sediment for the California portions of the Truckee River watershed. The general goal of a sediment TMDL analysis is to protect designated uses by characterizing existing and desired watershed conditions, evaluate the degree of impairment to the existing (and future) conditions, and identify land management and restoration actions needed to attain desired conditions (USEPA, 1999a). More specifically, the goals of this study are: 1) establish recommended reductions in sediment loads for designated reaches and sub-basins in the upper basin of the Truckee River; 2) develop a GIS-based watershed model capable of simulating erosional and sediment transport processes over multiple physiographic settings; 3) use the calibrated model to estimate sediment conditions under various land-use scenarios; and 4) interact with technical advisory groups to ensure stakeholder input from project inception through completion.

The water column indicator was chosen for this study because of the availability and quantity of data available as well as relative ease of collection over streambed sediment indicator data. Targets were determined using a watershed model to estimate the effect on sediment load from an assumed, “undisturbed” condition. The calibrated model was used to simulate increased canopy cover and removal of dirt roads, two parameters responsible for much of the sediment production in the basin. The intent of an increase in canopy cover is to simulate recovery of areas that experience a removal of vegetation resulting from some anthropogenic disturbance. Similarly, dirt roads are a disturbance that can be removed in the model. A comparison of model results from the calibrated, present condition to the target condition suggests a 47% reduction in sediment load is required in the Truckee River Basin to achieve the target.

The analysis and review includes creating an evaluation of general sources of sediment in the basin. This is accomplished in two ways: 1) collection and synthesis of sediment and flow records for the main stem of and tributaries to the Truckee, and 2) development of a watershed model to estimate sediment loadings under various land uses.

Using historic data, annual sediment load was estimated for ten major tributaries to the Truckee River. These include Bear Creek, Squaw Creek, Donner Creek, Trout Creek, Little Truckee River, Prosser Creek, Juniper Creek, Gray Creek, and Bronco Creek. Loads were estimated for the 1996 and 1997 calendar years.

To assess the watershed in greater detail, a watershed model capable of estimating sediment load was created. The model was calibrated to 1996 data and validated to 1997 data. Results from the modeling exercise show the relative magnitude of areas that contribute sediment to the Truckee River. In general, two conclusions can be made: 1) areas closer to the river affect in-stream sediment concentrations greater than those a greater distance from the river, and 2) areas at higher elevations (typically found with steep slopes) produce high sediment per unit area.

Additionally, sensitive landscapes are identified to assist land managers and planners in their decisions to add or modify land-use practices. The aerial photo analysis was performed to complement the previous two assessments and identified areas of erosion vulnerability (or

sensitivity) in the basin. Erosion vulnerability was determined primarily by the relative degree of soil development, or soil age. Aerial photos of the basin at scales ranging from 1:15,000 to 1:30,000 were used to identify geologic units. A detailed analysis was performed in Martis, Gray, and Bronco creeks. A coarser, basin-wide analysis was performed using the Landsat image from August 1999.

As preparation for the Implementation requirement of the final TMDL, an evaluation of relevant best management practices (BMPs) was performed in this study. Because of the inconsistency in scale between BMPs and the model, BMP effectiveness was evaluated in a general sense using the model. The change in sediment load resulting from revegetation, removal/redesign of dirt roads, and decreased application rate of road sand was quantified using the model. Significant reduction in suspended sediment load can be achieved by each of the three BMPs analyzed in this study. In addition, it is clear that BMPs are more effective when implemented in areas closer to the stream.

Included in this report is a review of existing monitoring and recommendations for future monitoring plan development. An ancillary benefit to collecting all relevant historic data and developing a model is a thorough understanding of data needs, data gaps, and potential high-sediment-producing areas. In the monitoring plan, areas of concern are identified and a discussion of monitoring techniques, advantages, and disadvantages is provided.

The format of this report follows the suggested outline in Protocol for Developing Sediment TMDLs (USEPA, 1999a).

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1. PROBLEM STATEMENT

1.1 Introduction

The purpose of this study is to provide technical support for a Total Maximum Daily Load (TMDL) for the Truckee River. A TMDL is a tool for implementing state water quality standards. It is based on the relationship between sources of pollutants and in-stream water quality. The TMDL establishes the allowable loadings for specific pollutants that a waterbody can receive without violating water quality standards, thereby providing the basis for states to establish water quality-based pollution controls (USEPA, 1999a).

An assessment of water quality is necessary to clearly identify the water quality standards being violated or threatened and to identify the pollutant(s) for which the TMDLs are being developed. Section 303(d)(1)(A) of the Clean Water Act (CWA) requires that "each state shall identify those waters within its boundaries for which the effluent limitations…are not stringent enough to implement any water quality standard applicable to such waters." The Truckee River is included on California's CWA Section 303(d) list as water quality limited due to sediment. The Truckee River spans three jurisdictions with Environmental Protection Agency (EPA) delegated authority to prepare TMDLs. In addition to California's Lahontan Regional Water Quality Control Board (LRWQCB), the Nevada Division of Environmental Protection (NDEP) and the Pyramid Lake Paiute Tribe (PLPT) can prepare TMDLs for their sections of the Truckee. NDEP adopted TMDLs for portions of the Truckee in Nevada. PLPT has submitted Water Quality Standards to EPA for the section of the Truckee on Tribal land.

1.2 Surface Water Quality Objectives Violated and Standards Not Attained

The Water Quality Control Plan for the Lahontan Region (CRWQCB, 2000) water quality objective for sediment reads, "The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect the water for beneficial uses." The current level of sedimentation was judged to exceed the existing narrative Non Degradation Objective, the narrative Water Quality Objectives for sediment, settleable materials and suspended materials. Narrative water quality objectives for the Truckee River include the following: nondegradation objective (Basin Plan page 3-2), nondegradation of aquatic communities and populations (Basin Plan page 3-5), sediment (Basin Plan page 3-6), settleable materials (Basin Plan page 3-6), suspended materials (Basin Plan page 3-6), and turbidity (Basin Plan page 3-7). There is an absence of numeric standards for sediment and related objectives. The judgment that water quality standards have been violated is based on reports, unpublished data collected by LRWQCB staff, complaint-driven sampling, and violations detected through Self-Monitoring Programs.

The purpose of the Truckee River TMDL is to identify reductions of sediment delivery to the river system that, when implemented, are expected to result in the attainment of applicable water quality standards and protection of water for all designated beneficial uses.

1.3 The Truckee River Watershed

The Truckee River watershed, with an area of approximately 2720 square miles, encompasses the entire Lake Tahoe, Truckee River, and Pyramid Lake systems. However, for the purposes of this TMDL, the planning area includes the portion of the watershed extending from the outflow of Lake Tahoe to the California/Nevada state line, or Hydrologic Unit 635.00. This includes 15 miles of channel from Tahoe City in Placer County, through the Town of Truckee in Nevada County, to the state line between Sierra and Washoe counties. This area encompasses 428 square miles of mountainous topography. The major tributaries to the Truckee River in California include: Bear Creek, Squaw Creek, Cabin Creek, Pole Creek, Donner Creek, Trout Creek, Prosser Creek, the Little Truckee River, Gray Creek, and Bronco Creek. Watershed impoundments include Lake Tahoe, Donner Lake, Independence Lake, Webber Lake, Boca Reservoir, Stampede Reservoir, Prosser Creek Reservoir, and Martis Creek Reservoir. For continuity of process, the study area includes portions of the Bronco and Gray creeks watersheds that originate in Nevada, but terminate in California. Figure 1 shows the major tributaries and political boundaries.

The source analysis part of the TMDL relies on an accurate characterization of the natural system. This characterization includes identifying climatic factors, geology, soils, vegetation, and streamflow, as well as identifying the spatial and temporal variability in each factor. The following is a brief description of the natural system parameters that have relevance to the TMDL:

1.3.1 Climate

Characterized by mild summers and cold winters, the climate of the study area is classified as humid continental (Convay et al., 1996). From 1948 to 2000, the average annual temperature (recorded at the Truckee Ranger Station) was 43.2°F (6.22°C). Highs averaged 78.3 °F (25.7 °C) during summer and 40.9°F (4.94 °C) during winter months. Lows averaged 58.9°F (14.9°C) during the summer and 28.4°F (-2.0°C) during the winter (www.wrcc.dri.edu). Other climatic characteristics of the study area are prevailing westerly winds, large temperature fluctuations, and infrequent, but severe storms (Garcia and Carmen, 1986). Precipitation measured at the Truckee Ranger Station averaged 32.51 inches (82.6 cm) annually, ranging from 16.04 inches to 54.62 inches (40.7 to 138.7 cm) for the period of record. Precipitation occurs predominantly as snowfall during winter months, generally increasing with elevation. Snowpacks in the Sierra Nevada have been observed year-round, and snowfall has occurred as late as July. Snowfall averages 208.2 inches (528.8 cm), but has been recorded as high as 401.4 inches (1019.5 cm) at the Ranger Station (www.wrcc.dri.edu).

1.3.2 Geology

The Truckee River watershed is in the Eastern Sierra Nevada, north of Lake Tahoe. The crest of the Sierra Nevada forms the western boundary of the watershed. A significant portion of the watershed is above 6,000 ft. Downstream of the Town of Truckee, the contributing sub-basins comprise a relatively minor areal component and the river has a steep gradient as it flows through the canyon alongside Interstate 80.

Altitudes in the study area range from about 5050 ft (1540 m) at the California-Nevada State line to 10,778 ft (3285m) at the summit of Mount Rose, Nevada. Tributary streams to the Truckee River are characterized by steep gradients in narrow, steep-walled canyons, except where the region was glaciated; in these areas, stream channels are broad and flat (Convay et al., 1996). Glaciated at least three times, the Sierra Nevada exhibits many glacial features such as cirques, glacial valleys, moraines, and outwash terrace deposits (Fox, 1982).

The geology of the Eastern Sierra Nevada in the Truckee River watershed is composed primarily of Cretaceous- and Tertiary-age plutonic and extrusive igneous rocks. Small occurrences of Jurassic metavolcanics are present northeast of Stampede Reservoir. Minor occurrences of sedimentary rock units are present. Quaternary glacial units are abundant in the major drainages.

Cretaceous granite and granodiorite are exposed along the western margins of the watershed along the crest of the Sierra Nevada. A prominent fault system extends 400 mi (643 km) from south-central to north-central California (Brown et al., 1986) and separates granitic units from younger volcanics exposed to the east. Vertical displacements have elevated the granitic rocks several thousand feet (Brown et al, 1986).

Tertiary rock units are dominated by Miocene- to Pliocene-age volcanics. These are composed primarily of andesitic lava flows, intercalated lavas, volcaniclastics, lahars, breccias, and debris flows, and remnants of volcanic cones (Birkeland, 1961; Saucedo and Wagner, 1992). Minor occurrences of Tertiary lacustrine deposits are found near Boca Reservoir and are related to damming of stream systems by volcanic units.

Quaternary geologic units include volcanic and sedimentary rocks. The volcanic rocks are composed of basalt, tuff and scoria and are found in the area just south of the Town of Truckee and the Hirschdale area. Sedimentary units in the region consist of relatively unconsolidated fluvio-lacustrine rocks associated with glacial outwash deposits and volcanics that dammed a paleo-Truckee River, and unconsolidated glacial deposits. Glacial units are common in the larger sub-basins along the western boundary of the Truckee River watershed. Fluvial deposits along major drainages are preserved in fluvial terraces. Hillslope deposits include thin mantles of weathered materials and thicker mass wasting deposits and debris flow deposits near the base of steep slopes.

Weathering characteristics of the basic rock units differ considerably. Massive granitic outcrops at high elevations have relatively thin weathering rinds. In contrast, the highly fractured granitic units near the major fault zones are more intensely weathered to a fine to coarse-grained grus. Volcanic rock units are more heterogeneous in texture and composition and tend to form deeper weathering profiles. Quaternary glacial deposits and other young surficial units have a variety of weathering characteristics depending on texture and age of the deposit.

1.3.3 Soils

Soils found within the study area have been mapped and classified by the Soil Conservation Service (1974; 1994). The soils in the Truckee River Basin include nearly level soils of valley floors to very steep soils of high elevation mountainsides. The soils are generally excessively drained to moderately well drained. At elevations above 6500 ft (1981 m), soils formed from weathered volcanic, metasedimentary and granitic rock, and include glacial and alluvial deposits. Soils at elevations ranging from approximately 4800 - 6500 ft (1463 - 1981 m) are formed primarily from weathered volcanic, rhyolitic and granitic rock, and alluvial deposits (Soil Conservation Service, 1994).

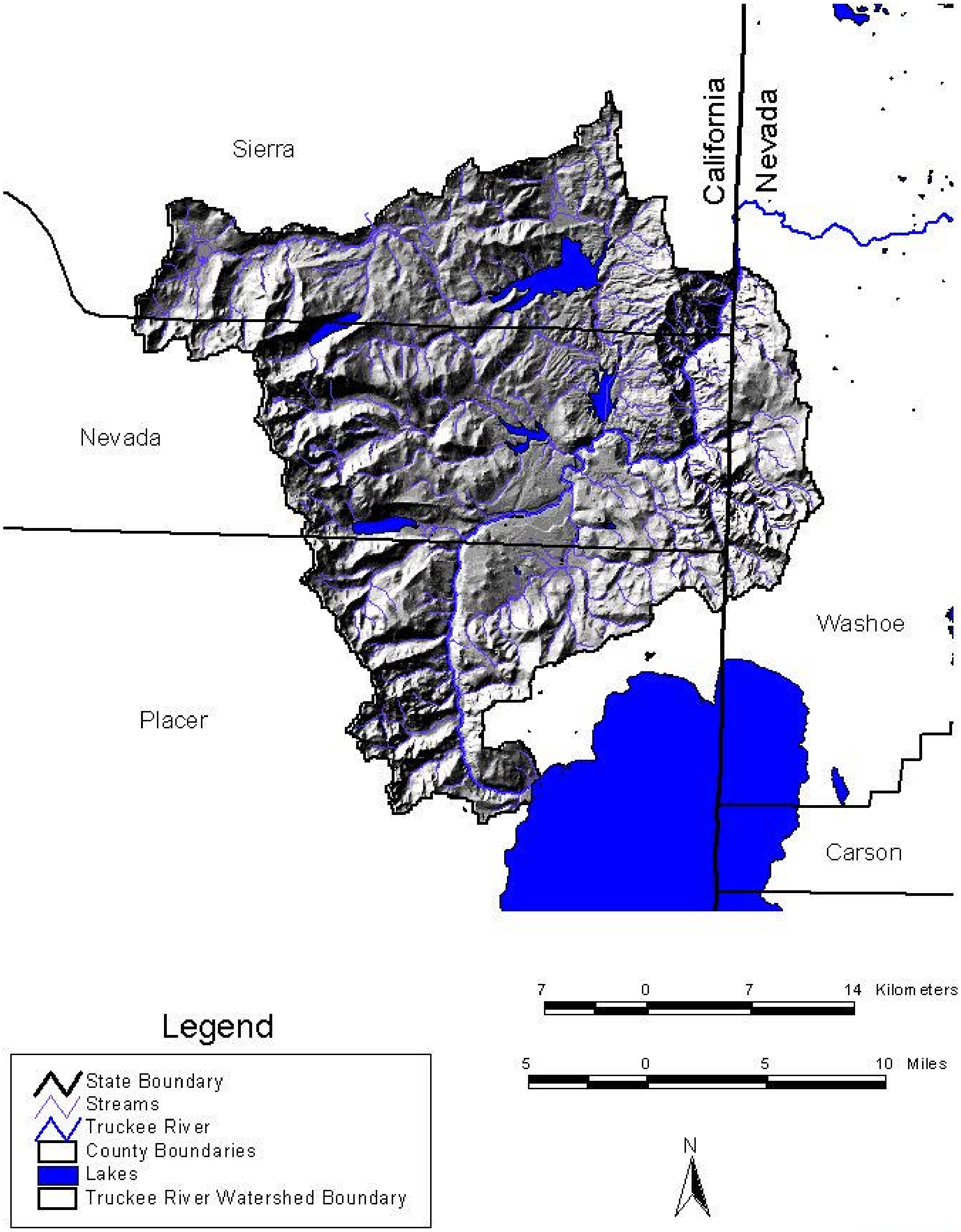


Figure 1. Site map.

Principal soil orders found in the region are Alfisols and Inceptisols (Soil Survey Staff, 1999). Common suborders are Umbrepts, and Xeralfs. Typical soil series found in the region are summarized in Table 1. Many of the soils are of great groups indicating aridic, ultic, and xeric climatic regimes. Some of the soil series and types reflect minimal soil development (entic soils). Most of the soils in the region are dry to moist and characterized by gray to brown surface horizons.

Alfisols typically have a light-colored ochric epipedeon, or surface horizon, an argillic horizon and are dry for much of the year. The moisture regime for Alfisols is typically ustic or xeric in this region. Xeralfs are mostly reddish Alfisols of regions that have a xeric moisture regime. Haploxeralfs are the Xeralfs that are generally thin, but not dark red Xeralfs. Ultic Xeralfs are distinguished primarily on the basis of their chemistry and may be an intergrade to Ultisols under increasing rainfall.

Table 1. Typical soil series found in Truckee River Basin.

Soil Series	Taxonomic Class	Typical Profile	Thickness Bt-horizon (in)	Thickness Bt-horizon (cm)	Max Redness B-horizon or profile (d/m)
Ahart	Andic Xerumbrepts	A-C			10YR
Euer	Ultic Haploxeralfs	A-Bt-C	9	23	
Euer Variant	Ultic Haploxeralfs	A-Bt	58	147	10YR/7.5YR
Fugawee	Ultic Haploxeralfs	A-Bt-C	28	71	5YR/5YR
Fugawee Variant	Ultic Haploxeralfs	A-Bt	13	33	7.5YR/10YR
Jorge	Ultic Haploxeralfs	O-A-Bt-C	28	71	10YR/7.5YR
Kyburz	Ultic Haploxeralfs	A-Bt-Cr	28	71	5YR/5YR
Martis	Ultic Haploxeralfs	A-Bt	50	127	10YR/7.5YR
Meiss	Lithic Cryumbrepts	A-R			10YR
Tallac	Pachic Xerumbrepts	A-C			10YR
Tahoma	Ultic Haploxeralfs	A-Bt	40	102	7.5YR/7.5YR
Tahoma Variant	Ultic Haploxeralfs	A-Bt	43	109	7.5YR/7.5YR
Tinker	Andic Haplumbrepts	A-B-C	12	30	7.5YR/7.5YR

Inceptisols are complicated soils and incorporate characteristics of a number of different soil orders. They may have nearly any type of diagnostic horizon and epipedon. They do not include argillic horizons, and the most common diagnostic horizons are an umbric or ochric epipedon and a cambic horizon. In the Truckee River Basin region, Inceptisols are represented by the suborder Umbrepts that include several Great Groups. Umpbrepts are typically dark reddish or brownish, well-drained, organic-matter-rich Inceptisols in mountainous regions. Cryumbrepts are Umbrepts of colder regions, such as those found in higher latitudes and high elevations. Xerumbrepts and Umbrepts, having a xeric moisture regime, are commonly associated with coniferous forests. Haplumbrepts are commonly associated with coniferous forests and may have a relatively short dry season. Andic Haplumbrepts are similar to Haplumbrepts with the primary distinction being in the low-density surface horizon and amorphous clays deriving from alteration of volcanic glass.

Aridic soils are dry, alkaline mineral soils containing small amounts of organic materials and light colored surface layers. Formed mostly in semiarid to arid environments, calcium carbonate, gypsum or salt layers may develop beneath the surface layer. In this region the accumulations generally are not substantial.

Ultic soils have some of the characteristics of the highly weathered Ultisols. The ultic soils in the Truckee River Basin region have develop primarily under forest vegetation. They are characterized by slightly acidic red to yellow layers overlying layers of clay.

On some of the youngest fluvial deposits, dry mineral soils lacking significant layering have formed. These may be entic in nature, meaning that they are weakly developed. These loamy to sandy soils typically are formed from alluvial material and occur with intermixed gravel and boulders (Convay et al., 1996).

1.3.4 Vegetation

Vegetation varies significantly throughout the study area. Mountain summits and peaks are generally barren, whereas high alpine meadows are composed of grasses and wildflowers. Headwater areas are distinguished by three different vegetative zones: 1) mountain hemlock, western white pine and California red fir in the highest elevations; 2) white fir, jeffery pine, ponderosa pine, sugar pine, and incense cedar in the mid-elevation ranges; and 3) pinyon pine, ponderosa pine, and western juniper in the lower elevations. Sagebrush, bitterbrush, rabbitbrush, and various grasses make up the lower elevations in the headwater areas. Riparian vegetation, primarily cottonwood, quaking aspen, dogwood, willow, sedges and grasses, grows along the Truckee River, some of its tributaries and along the margins of wetland areas (Bergman, 2001).

1.3.5 Streamflow

Generally, streamflow is low in late summer, gradually increases through autumn and winter, and peaks during the spring snowmelt. Peak discharges are usually in May or June. Streamflow gaging stations are maintained and operated by the U.S. Geological Survey (USGS) and were located to represent a range of climate, geology, vegetation, and human effects. Long-term trends in discharge and seasonal flow patterns for the various locations are evident in the hydrographs. It is important to note that regulation of impoundments located within the basin will be reflected in the hydrograph record.

For the Truckee River at the Farad station (USGS gage number 10346000), annual mean discharge ranges from 176 cfs in 1931 to 2567 cfs in 1983. The highest discharge at Farad for the period of record (1900 to present) is 17500 cfs on November 21, 1950.

1.4 Beneficial Uses

The Truckee River supports the following beneficial uses: MUN, AGR, GWR, REC-1, REC-2, COMM, COLD, WILD, RARE, MIGR, SPWN, WQE, and FLD. Summary definitions of these uses are provided below within the context of the study area. Complete definitions for these uses can be found in the Basin Plan. Increased sedimentation can be linked to the impairment of all of these beneficial uses. However, for reasons of clarity, this TMDL will address the impairment of the most sensitive beneficial uses: COLD, RARE, and WILD – implying that protection of the most sensitive uses will protect the others. If the natural range of variability of the physical system within which the native plants and animals evolved can be described, it is hoped that an increased sediment load that does not induce a threshold event can be described and allocated to protect all designated beneficial uses.

1.5 Impairment of Beneficial Uses by Increased Sediment

MUN: Downstream municipal and domestic users who draw their water from the Truckee River have had to shut off the intake on Sierra Pacific Power Company's (SPPCo) Chalk Bluff treatment plant and ration water due to excessive sediment loading during storm events.

AGR: The agricultural use of water in the TMDL study area is limited by climate to livestock grazing. Geomorphic responses to increased sediment load can include channel down-cutting, which in turn lowers the water table in meadow areas, thereby damaging range vegetation.

GWR: Land-use practices within the Truckee River watershed have increased impervious surfaces and reduced vegetative cover, resulting in lower infiltration rates, impacting quality and quantity of groundwater recharge. Communities in the TMDL study area (California) rely predominantly on groundwater for municipal supply. The Martis Valley aquifer supplies water to the most populated portion of the watershed.

REC-1: All rec-1 activities are supported by the Truckee River.

REC-2: Numerous complaints regarding the aesthetic concern of turbid water have been received and investigated by Regional Board staff.

COMM: Recreational fishing is impaired when COLD, MIGR, and SPWN are impaired.

WILD: See RARE. Healthy native vegetation to support wildlife requires a natural range of variability in physical and biological process and function. Excessive sediment and disturbed upland areas can exceed thresholds required by wildlife.

COLD: Cold freshwater habitat is impaired by an increase in the sediment budget in a large variety of ways involving physical and biological process linkage and response. The investigation of these relationships will form the basis of the Truckee River TMDL.

RARE: The willow flycatcher depends upon healthy willow vegetation that is damaged by geomorphic responses induced by excessive sediment loading. Lahontan Cutthroat Trout depend upon physical and biological system components adapted to a sediment regime in balance with its hydrologic regime. Changes in sediment discharge, frequency, magnitude, and timing outside the expected range of variability can induce threshold geomorphic events, resulting in unsuitable habitat.

MIGR: Changes to channel form and velocity distribution (pools, runs and riffles) resulting from increased sediment limit migration and movement of aquatic organisms.

SPAWN: Reproduction and rearing are limited by high bedload, poor pool quality, and inadequate substrate size. This is a result of increased sediment availability.

WQE: Increased sediment loading can compromise the natural ability of the meadows and wetlands to settle, treat, and store sediment through channel aggredation and increased rate of braiding, anastamose, or meander cut-off.

FLD: An increase in sediment loading can result in channel aggredation, reducing capacity for flood peak attenuation. Infiltration rates can be altered as well as discussed above in GWR.

In addition to alterations in sediment discharge, hydrologic alterations affecting flow and ultimately the system's ability to transport sediment must be considered. Changes to the hydrologic cycle include: snowmaking, ground-water pumping, infiltration rates reduced by impervious surface and vegetation removal, soil compaction, and re-routing of natural drainage patterns by dirt and paved roads.

2. WATER QUALITY INDICATORS AND POSSIBLE NUMERIC TARGETS

2.1 Background

The purpose of this section is to identify numeric or measurable indicators and target values that can be used to evaluate the TMDL and the restoration of water quality in the Truckee River. Key factors to consider include both scientific and technical validity, as well as practical issues such as cost and available data.

As described below, suspended sediment concentration (SSC) is chosen for the indicator of Truckee River water quality. SSC was chosen because of the relative abundance of data and the low cost of obtaining new data.

To establish the logic behind the choice of water quality indicator for the TMDL, it is first necessary to provide background on the entrainment, transport, and sources of sediment.

2.1.1 Entrainment and Transport

Upon delivery to a stream network, if conditions are appropriate, sediment particles may be entrained and transported downstream. The amount of sediment entrained is dependent upon the erosive power of the flow as well as the physical properties and positioning of the individual particles. The largest particle that can be entrained, referred to as the competence of the system, is directly dependent on the hydraulic conditions. The mechanics of stream competence has been the focus of many studies since Rubey (1938) determined that the volume (or weight) of the largest particle moved in a stream varies as the sixth power of the stream velocity. Derived from flume experiments, the Hjulstrom curve (Bloom, 1991) (Figure 2) presents the range in velocities required to entrain and transport particles of various sizes. It should be noted that this curve serves only as a general guide. Studies concerning the mechanics of entrainment remain complicated due to the following: particles are entrained by a combination of fluvial forces, including direct impact of the water, drag, and hydraulic lift, each of which may be best represented by a different parameter of flow; flow velocity is a parameter that changes continuously and can not be measured easily and accurately in turbulent systems; and the physical and chemical nature of the particles may lead to packing arrangements that result in atypical responses to similar flow conditions (Ritter et al., 1995).

Entrained sediment that is undergoing active transport in the stream system is referred to as the *sediment load*. Generally, fine-grained particles will be transported in the water column for long distances downstream. Referred to as *suspended load*, these particles may experience intermittent periods of deposition. The maximum concentration of the suspended load is limited by water velocity and turbulence. The smallest particles are flushed through the system rapidly. These particles are referred to as *wash load*, as they do not experience deposition onto the stream bed. Coarse particles may enter suspension for short periods of time; however, they are more apt to be transported by rolling, sliding or bouncing along the channel bottom. Whether a single particle is transported as bedload or suspended load depends on the flow regime. Medium-sized particles that are transported in suspension at higher flows may become part of the bedload when the discharge lowers during seasonal or diurnal discharge fluctuations (Waters, 1995).

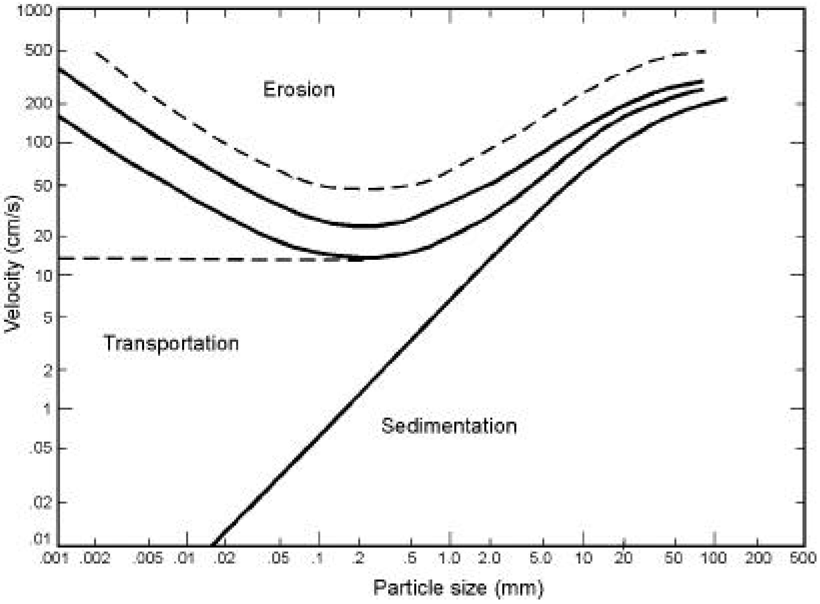


Figure 2. Hjulstrom curve describing the range in velocities required to entrain and transport particles of various sizes.

2.1.2 Sediment Sources

G. K. Gilbert (1877) initiated the notion that some sort of equilibrium exists between watershed processes and landforms created by them. The concept of dynamic equilibrium suggests that landforms within a system will retain their character as long as fundamental controls do not change (Ritter et al., 1995). If controls cause system disequilibrium, the processes will adjust in an attempt to re-establish the stability that was lost. Anthropogenic activities often create an imbalance in system dynamics, acting to accelerate erosion and transport processes in a watershed. Agriculture, forestry, mining, urban/recreational development, and other human-associated activities have been shown to be direct sources of sediment (USEPA, 1999a). For example, timber harvest alters the vegetation characteristics of a basin, increases overland flow and results in gully formation on the slopes. Similarly, harvesting in the riparian zone will reduce the amount of vegetation that acts to dissipate stream energy, causing increased streambank erosion. Forest roads act as a source of erosion and sedimentation, affecting both hydrologic and geomorphic processes. The compacted surfaces increase runoff rates (Reid and Dunne, 1984; Duncan et al., 1987), change peak flow timing and magnitudes (Harr et al., 1975), and trigger landslides (Swanson and Dryness, 1975). Furthermore, roads and ditches extend the hydrologic network by concentrating storm runoff and transporting sediment to nearby stream channels.

2.2 Indicators

The TMDL protocol developed under the Clean Water Act provides states with an organizational framework to maintain target pollutant levels at or below the assimilative capacity of a waterbody. An indicator is a quantitative measure of the relationship between a pollutant and its source (USEPA, 1999a). The identification of water quality indicators is required for the development of any TMDL. The purpose of this component is "to identify numeric or measurable indicators and pollutant values that can be used to evaluate attainment of water quality standards in a listed water body" (USEPA, 1999a). Indicator selection for a specific waterbody depends on local water quality criteria developed to protect the physical, biological and chemical integrity of the water; scientific and technical validity; and practical considerations, such as budget, etc.

Water quality measures that have been used as indicators include water column sediment concentrations, streambed sediments, geomorphic/channel conditions, biological and habitat conditions, and riparian/hillslope parameters (USEPA, 1999a). Processes adversely affecting water quality are complex, often exhibiting significant temporal and spatial variability. Therefore, more than one indicator and associated numeric target may be necessary to account for the complexities of the processes in operation and the potential lack of certainty regarding the effectiveness of an individual indicator.

This section will introduce the water column and streambed sediment indicators that were chosen for this study. Selection criteria included factors such as relevance of the indicators to the scope of the study, previous work using the indicators in the study area, scientific and technical validity, and other practical considerations. This section is designed to provide background information concerning the selected indicators as well as present relevant studies that have been conducted using each. By far, the majority of these studies have been located in the Pacific Northwest; however, any available data or information regarding pertinent work within the Truckee River Basin will also be described.

2.2.1 Water Column Indicators

Excessive sedimentation was determined to be the most influential factor adversely affecting fisheries habitat in streams according to a national survey conducted by the U.S. Fish and Wildlife Service in 1982 (Judy et al., 1984). Loading studies usually evaluate sedimentation based on suspended and bedload fractions. Suspended sediment load and bedload are direct indicators of sediment loading that is directly associated with aquatic life impairment and degradation of habitat (USEPA, 1999a). Because transport rates of bedload are difficult to measure, are highly variable in space and time, and might not definitively relate to designated-use impacts (MacDonald et al., 1991), bedload was not considered for use as an indicator for this study. As discussed in the previous section, suspended sediment and turbidity are associated with degradation of aquatic species health and habitat in environments where anthropogenic activities have altered geomorphic and hydrologic processes. Therefore, use of these parameters as indicators for TMDL development is appropriate.

Turbidity is a measure of the amount of light that is scattered or absorbed by a fluid (Greenberg et al., 1992). This optical property does not provide a quantitative measure of sediment loading in a waterbody, so it is considered an indirect indicator (USEPA, 1999a). Many studies have calculated sediment loads by developing a regression equation between suspended sediment concentration (SSC) and turbidity. In most cases, this is a reasonable technique, since suspended sediment is usually the major constituent contributing to turbidity. However, materials such as colloids, plankton and organic detritus, and other properties like mineral content, can also reduce light transmission through the water column. Using turbidity to estimate suspended sediment loads is advantageous because it is generally easy and inexpensive to measure. Numerous studies have derived empirical relations for this reason (Truhlar, 1976; Sigler et al., 1984; Lloyd et al., 1987). Because the geologic properties, climatic conditions, and geomorphic and hydrologic processes are highly variable in space and time, SSC-turbidity relations should be based on local and, if possible, multiyear data sets (USGS, 1998).

The deleterious effects of both suspended sediment and turbidity on aquatic environments have been studied intensively. Many literature reviews concerning the effects on aquatic organisms are available (e.g., MacDonald et al., 1991; Newcombe and MacDonald, 1991;), so only the major points will be discussed here. Most of the effects of elevated suspended sediment and turbidity levels on primary producers relate to reduced light penetration. This acts to decrease the rate of photosynthesis of these organisms, with periphyton and algae being most severely affected (Gregory et al., 1987). Surfaces of aquatic plants may also become coated with sediments, which will also cause declines in primary productivity. This, in turn, can adversely affect the productivity of higher trophic levels. It should be noted that nutrients adsorbed on sediments also influence growth rates, biomass and species composition of periphyton (Waters, 1995).

Benthic invertebrate populations also suffer from high turbidity and SSCs. Feeding structures of filter feeders become clogged, reducing feeding efficiency and growth rates of these organisms. Persistent conditions have been observed to increase drift rates of these creatures and to reduce population densities and diversity (Birtwell et al., 1984). This may be a behavioral response related to the reduction in light and the affects on primary production, or abrasive damage to respiratory organs. Mayfly nymphs were found to enter drift in response to deposition of sediment (Ciborowski et al., 1979). The nymphs apparently attempted to relocate to a more favorable habitat that provided a cleaner substrate on which they could graze. Dislodgement due to scouring of the streambed substrate may also be partially responsible. In any case, drift increases the susceptibility of these organisms to predation. The review completed by Newcombe and MacDonald (1991) summarized the effects of suspended sediment on macroinvertebrates.

Fish are affected in a variety of ways, including lethal, sublethal and behavioral effects. They are directly affected through reduction in the respiratory capacity of gills, reduced growth rates, diminished resistance to disease or lethal affects. Suspended sediments may modify behavioral activities of fish, such as migration patterns. At turbidity levels of 50 nephelometric turbidity units (ntu), some species of salmonids were displaced (Sigler et al., 1984). Other experiments saw that feeding rates of Lahontan Cutthroat Trout varied inversely with turbidity, indicating reduced efficiency of methods used to catch prey with elevated turbidity levels (Vinyard and Yuan, 1996). Newcombe and MacDonald (1991) summarize the effects of suspended sediment on fish.

2.2.2 Streambed Sediment Indicators

Bed material composition is an extremely important component of stream channels that may directly or indirectly impair aquatic life habitat in many ways and during key life stages (USEPA, 1999). A typical characteristic of gravel-bed channels receiving large sediment inputs relative to their transport capacity is an abundance of fine sediment on the bed surface (Lisle, 1982). Dietrich et al. (1989) concluded from flume experiments that, as sediment supply increases, fine particles become more abundant on the bed surface, which then becomes less resistant to transport. Streambed sediment indicators measure various physical attributes of a particular waterbody and are appropriate for use in environments where coldwater fisheries habitat is a primary concern (USEPA, 1999a).

Studies of the effects of substrate composition on the biologic functionality of streams are numerous and offer a variety of conclusions. Levels of dissolved oxygen (DO) were found by Tagart (1976, 1984, cited in Chapman, 1988) to be inversely proportional to the percentage of fine particles less than 0.85 mm in diameter. Decomposition of organics deposited in gravels with fine particles consumes oxygen, thus lowering DO concentrations. Fine particles reduce the overall permeability of gravels, inhibiting interchange with highly oxygenated stream water. Low intergravel DO concentrations can result in lethal effects to eggs and morphological defects to newly hatched alevines. Many studies have demonstrated that survival-to-emergence ratios of salmonids decrease as the amount of fine particles in the substrate increases (Lotspeich and Everest, 1981; Shirazi and Seim, 1981; Chapman, 1988; Young et al., 1991b). Bailey and Wolcott (1976) determined from laboratory experiments that concentrations as high as 25% of fine particles (diameter less than 0.833 mm) reduced the hatching success of Lahontan Cutthroat Trout to about 45%. Other experiments have shown similar results (for example, Cederholm, 1981). Even if the eggs hatch, a tight packing arrangement of the particles can trap fry in the gravel.

Sediment accumulation on the bed surface affects fish in all life stages. First, deposited sediment reduces the abundance of prey available to the fish, as similar responses of macroinvertebrate populations to excessive fines in the substrate have been observed. In a stream sedimentation experiment, Bjornn et al. (1977) demonstrated that fish population declines were correlated to reduced pool volumes. Furthermore, sediment accumulation may result in shallow, wide stream reaches where temperature and DO deviate from optimum levels for longer periods. Persistent conditions may reduce growth rates (Meeuwig, 2000).

Several substrate indicators have been used in TMDL studies. These include streambed particle size distribution indicators, streambed coverage measures, streambed armoring or transport capacity measures, and sediment supply measures. A comprehensive review of these indicators is provided in MacDonald et al. (1991). USEPA protocol recommends that selection of specific indicators should be based on a thorough understanding of the designated or existing use impacts of primary concern. Because percent fines within spawning gravels is directly related to the fisheries habitat beneficial use of the Truckee River, it will be considered as an indicator for this study.

As mentioned above, key factors to consider in selecting a water quality indicator include both scientific and technical validity, as well as practical issues such as cost and available data. A thorough discussion of data quality and availability is included in the Monitoring Plan section of this report. In summary, the water column indicator was chosen for this study because of the availability and quantity of data as well as relative ease of collection in comparison to streambed sediment indicator data.

2.3 Target Values

2.3.1 Overview

For each numeric indicator used in a TMDL, a target condition needs to be established to provide measurable goals and a clear link to water quality standards attainment. Quantification of the target condition for a selected indicator offers a means to evaluate the relative water quality of an impaired waterbody. Water quality standards are achieved when the selected indicators measure at or below the numeric target values for the specific parameters (USEPA, 1999a). To evaluate if a waterbody is of suitable water quality, two steps must be taken. First, the target value must be defined numerically, then it must be compared to the existing conditions in the waterbody of concern.

So the question remains: "How are numeric target values developed for sediment loadings?" Many watershed plans use narrative objectives that lack quantitative threshold values. A more relevant question is: "What *should* streams in managed forests be like?" Peterson et al. (1992) points out that they should approximate those streams draining unmanaged forests, because those conditions have sustained ecologically diverse communities and healthy populations over long periods of time, prior to development. Thus, they represent a unifying basis to evaluate channel conditions. The Forest Ecosystem Management Assessment Team (1993) contended that the major benefit of an ecosystem approach is that all associated organisms, together with their environments, are considered in management decisions, as opposed to managing for individual species. Implementing an integrated approach to managing watersheds also fosters inter-ownership cooperation and improved efficiency in balancing ecological and economic objectives. Watershed management is then based on current conditions and on an understanding of natural patterns and disturbance regimes; this approach is needed to direct ecosystems to a sustainable future. Based on these applications and benefits, the U.S. Fish and Wildlife Service concluded that "ecosystem management plans should be developed to determine and manage for future desired conditions of at least the Truckee and Walker River basins…" (USFWS, 1995).

When adjusted for flow, turbidity levels in relatively undisturbed tributary streams were determined to be significantly lower than those in a highly disturbed nearby stream in the South Fork Eel River basin, California (USEPA, 1999b). This is an example of defining target values through the use of reference or index sites. Knopf (1993) uses the term index, since relatively few watersheds have seen little anthropogenic influence. Index watersheds are those that have either seen minimal influence or have recovered from human influences. Such watersheds should contain representative characteristics of the region to which they are being applied. USEPA protocol states that selection of an appropriate reference site should reflect a clear understanding of the overall system. Ideally, the index will be located within, or adjacent to, the watershed of which the water quality is being evaluated. More distant watersheds may also be used if they share similar watershed characteristics, such as geology, soils, topography, land use, and processes (USEPA, 1999a).

A numeric target may also be established on the basis of the direct impacts on the beneficial uses of a water body. As described previously, turbidity and suspended sediment concentrations above certain levels and durations directly affect aquatic organisms. An appropriate target value may therefore be based on the level of turbidity or suspended sediment associated with adverse impacts to these organisms and the duration of flows with concentrations above a specific level (USEPA, 1999a). Newcombe and MacDonald (1991) compiled a data base from over 70 papers on the effects of suspended sediment and turbidity on aquatic ecosystems. Tabulation of the data gives threshold numeric values for the effects of suspended sediment concentration and turbidity on the performance of macroinvertebrates for a specific length of exposure to these conditions.

Indicator relationships and/or dynamic functions may be used to define target values. Often, a relationship exists between suspended sediment load and water discharge (Leopold and Maddock, 1953). Endicott and McMahon (1996) used a regression equation to define the relationship between concentration and stream discharge in the development of a TMDL report for Deep Creek, Montana. This approach incorporates system dynamics by acknowledging that sediment loading often varies substantially with flow. Furthermore, in a TMDL report for Silver Creek, Arizona (cited in USEPA, 1999a), researchers used the correlation of turbidity and suspended sediment to set a target for suspended sediment as a watershed-specific function of the turbidity.

2.3.2 Current Study

Sediment TMDLs have been completed for the Garcia River (USEPA, 1998a) and the South Fork Trinity River and Hayfork Creek (USEPA, 1998b). Targets for the Garcia River study focused on substrate indicators, including: percent fines less than 0.85 mm, percent fines less than 6.5 mm, and median particle size diameter. Pool frequency and V* were also listed as targets. The South Fork Trinity River and Hayfork Creek study presented targets relating to fish population recovery (naturally reproducing escapement), channel form and structure recovery (number of mainstem pools, V*, increased channel complexity), substrate size distribution (percent fine sediment less than 0.85 mm), and sediment delivery (e.g., dirt road stream crossings, road location). Neither of these recent TMDLs focused on SSC. As stated above, the water column indicator was chosen for this study. Likewise, SSC in the water column is chosen for the target.

Inspection of the Truckee River Basin suggests large variability in canopy cover, geology, and soils. These basin attributes have a large influence on sediment production; therefore, a large variability in sediment rates can be expected from the basin. To determine sediment load in unmanaged or pristine watersheds, it is necessary to determine the degree of disturbance the watershed has experienced. Unfortunately, such information was not available for this study. However, it is possible to use a watershed model to provide a coarse estimate of undisturbed conditions. Results from such a modeling exercise can provide a general idea of the level of disturbance at each model element, and may serve to identify areas that should receive additional attention.

The watershed model used for this study is described in detail in section 3.3.2. To summarize, a model capable of estimating sediment loads was calibrated to historic conditions. The calibrated model was then used to simulate increased canopy cover and removal of dirt roads – two parameters responsible for much of the sediment production in the basin. An increase in canopy cover is meant to simulate recovery of areas that experience a removal of vegetation resulting from some anthropogenic disturbance. Similarly, dirt roads are a disturbance that can be removed in the model.

Figures 3 and 4 show the results of the modeling exercise. 'Present conditions' in Figure 3 represent estimated sediment load in 1997 and 'target' represents the estimated sediment load under increased canopy cover and without dirt roads. Figure 4 shows the reduction in mass required for each model element to achieve the target. Based on this analysis, a 47% reduction in sediment load is required in the Truckee River Basin to achieve the target. Recall that the target is coarsely estimated using assumptions of relative disturbance. However, the results do identify areas of concern.

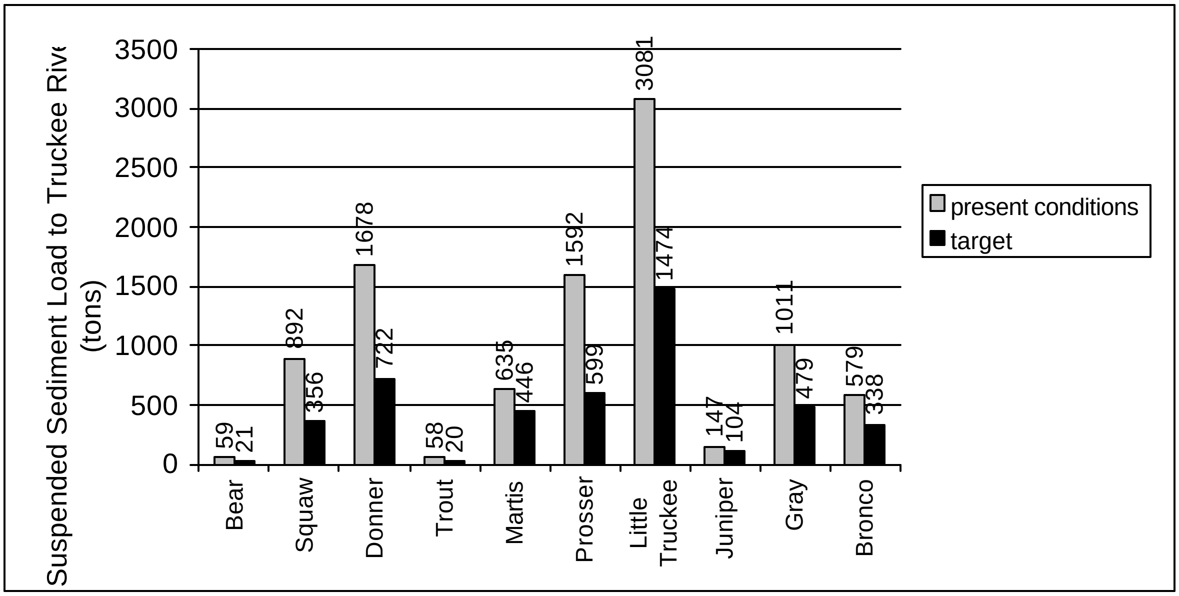


Figure 3. Difference in suspended sediment load between present conditions and target for major sub-basins.

3. SOURCE ANALYSIS

3.1 Objective

The objective of the TMDL source assessment is to compile an inventory of all sources of sediment to the waterbody as well as to evaluate the type, magnitude, timing, and location of sediment loading (USEPA, 1999a). The protocols also state that it is likely that a combination of techniques will be needed depending on the complexity of the source loading and watershed delivery processes. The Truckee River is indeed a complex watershed; therefore, multiple techniques were used in this study to assess sources of sediment. Sources may be identified in a variety of ways. According to EPA protocol (1999a), a key problem to address is identification of the appropriate source assessment method.

The EPA protocol gives some guidance on source assessment methods, placing all methods into at least one of the following categories: 1) Indices; 2) Erosion Models; and 3) Direct Measurement Estimates. Those methods in the Index category do not provide load estimates but do identify vulnerable landscapes and predict areas of future erosion. Erosion Models generally estimate sedimentation through the application of sedimentation prediction algorithms or erosion hazard ratings for different land parcels. The general strategy of Direct Measurement Estimates is to use past erosion rates to characterize trends, predict future amounts, and plan restorative actions.

In this study, sediment sources were evaluated or predicted by three methods: 1) compilation of anecdotal, historic, and new data (Direct Measurement Estimate); 2) prediction using a watershed model (Erosion Model); and 3) assessment of sensitive landscapes (Index). Each method represents a different level of effort and a different level of detail. However, we feel there is no one correct method for this complex basin. Also, a comparison of the methods will serve as validation of results.

3.2 Data Description

A critical first step in assessing the watershed for a TMDL is to gather all appropriate data and information, including that obtained from literature review, spatial data to parameterize the model, and historic and recent sediment and turbidity data.

3.2.1 Spatial Data

The geographic information systems (GIS) component of the study consisted of two primary objectives: 1) construction of a spatial database of pertinent data sets specific to the analysis of the Truckee River watershed; 2) use of the spatial database as input data into the AnnAGNPS watershed model and analysis of the database for source assessment.

3.2.1.1 Spatial Database Construction

The Desert Research Institute (DRI) used a combination of existing in-house, public domain, and newly created digital data sets to build the Truckee River watershed GIS database. The data are described in Appendix C, complete with metadata descriptions for each data set. Most of DRI's in-house data were already projected into Universal Transverse Mercator (UTM) zone 11, datum NAD83 for a previous project with SPPCo. Almost all of the public domain data were projected into UTM zone 10, NAD27.

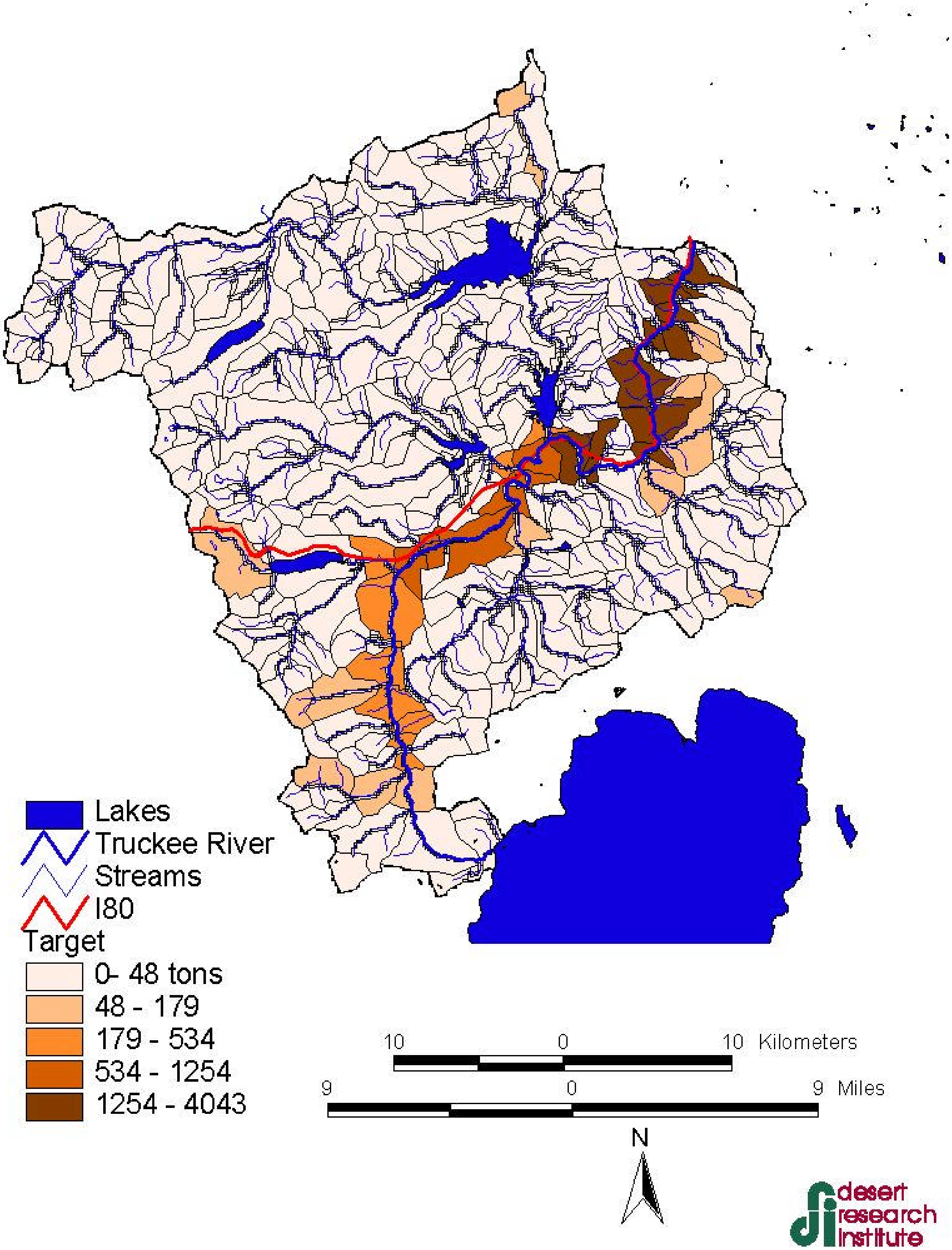


Figure 4. Reduction in suspended sediment mass required to achieve target.

Some data received by DRI were not rectified to an existing coordinate system. DRI received two compact discs containing scanned, unrectified aerial photography of the Squaw

Valley basin from Squaw Valley Ski Corporation. Many of these same aerial photographs were obtained in analog stereo format from the Tahoe National Forest (TNF) Truckee office. The historic aerial photographs obtained from TNF are listed in Appendix B. The Truckee office loaned the original historical photographs to DRI, where color copies were made. The photographic copies were used by DRI personnel to interpret and map sensitive landscape units for selected major basins in the Truckee River watershed. Due to the prohibitive cost of rectifying all of the aerial photographs for inclusion in the project database, DRI transposed the mapped locations of the sensitive landscape units to rectified Landsat satellite imagery already integrated into the database.

DRI's ArcView version 3.2 was used to construct the spatial database. Arc/Info version 8.0.2 (both Arc and the Grid module) was used to perform some of the spatial processing, but the database platform was developed in ArcView. All data were reprojected to UTM zone 10, datum NAD27 for the final database coordinate system. All Arc/Info coverages obtained from public domain sources and DRI archives were converted to ArcView shapefiles. The primary components of the database are ArcView shapefiles, grids, and image files, i.e., data formats representing vector data (points, lines, polygons), raster data (cell-based data structure), and image data (satellite imagery, scanned photographs), respectively. Each ArcView shapefile has a feature attribute table that contains fields of descriptive characteristics for the data set. Each grid has a value attribute table that contains descriptive fields for the data set's cells. Some tables in the database are stand alone, i.e., they do not have a spatial feature component per se, but rather, contain descriptive information that can be linked to a related spatial data set using a field common to both tables, like a unit identifier or basin identification number. A good example of this kind of data linkage is the numerous tables containing Natural Resource Conservation Service (NRCS) State Soil Geographic (STATSGO) Data Base parameters such as map unit, layer, and composition data that can be linked to a spatial data layer that contains the actual polygons that represent the MuId and Muname for the soil type.

3.2.1.2 Input for AnnAGNPS Model and Subsequent Analysis of Model Results

Spatial data developed for the project database were used by DRI modelers to run the AnnAGNPS sediment model. Specifically, the following data sets were used:

- 30-m Digital Elevation Model (DEM) data from the USGS;
- an Interstate 80 highway data layer, derived from USGS Digital LineGraph (DLG) data;
- a streams data layer generated from USGS DLG data;
- the hydrographic boundary for the Truckee River Basin, derived from USGS DLG data;
- a dirt roads database derived from the TNF data and the USGS DLG data;
- a land-cover database derived from a combination of the TNF timber type data set, a UNR-Biological Resource Research Center (BRRC) vegetation database, the USFWS Gap vegetation data set, and image interpretation of a Landsat Enhanced Thematic Mapper (ETM) scene of the study area acquired in August 1999;

- a canopy cover percentage database derived from the same four sources as the land cover database; and
- an NRCS STATSGO soils data layer of the study area.

Almost all of the public domain data described above were processed and/or updated in preparation for their use in the model. The individual 7.5 minute DEM quadrangles were combined and then an averaging filter was run over the resultant mosaic to smooth the boundaries between quadrangles. The Interstate 80 highway data layer was selected and cut from a master road database. The stream data layer was cut from a larger USGS DLG database. The hydrographic boundary data layer was cut from a larger database of hydrographic basins for California and Nevada. The dirt roads database was created in several steps; first, the TNF data set for the California side of the basin and the USGS DLG data set for the Nevada side were merged and then clipped using the hydrographic basin for the Truckee River. The resultant data layer was then edited to update dirt roads that have since been paved in several geographic regions, including Tahoe-Donner, Donner Lake, and the Glenshire area, using the August 1999 Landsat ETM satellite image and aerial photographs from the TNF.

The development of the land cover and canopy cover percentage databases involved the integration and merging of the TNF, BRRC, and USFWS vegetation data sets, as no one vegetation data set covered the entire study area. The Landsat satellite data were used to update wildfire burn and regrowth areas and determine accurate land cover at the intersection of the input data sets. Some of the data sets, in particular the TNF timber data, were rather old (the TNF timber type data were originally created in 1979-1980 by the Forest Service). The resultant, integrated attribute tables of land cover and canopy cover percentage then had to be edited and checked for completeness and consistency with respect to land cover categories and canopy cover percentage classes. Figures 5 and 6 show the spatial variability in land cover and canopy cover.

Original plans to use the high resolution (1:24,000 scale) NRCS SSURGO soils data for the study area were modified when it was discovered that the only SSURGO-level or SSURGO-equivalent soils data set available for the California side of the study area was the TNF Level 3 soils resource inventory. Although the spatial scale of the data set was adequate for sediment modeling purposes (1:24,000 scale), the critical soil parameters necessary for AnnAGNPS were not available in the limited attribute table associated with the Level 3 data. AnnAGNPS requires the following parameters for each soil unit: soil type, full soil profile descriptions, layer depth, bulk density for each layer, hydrological soil group, K factor, impervious depth, and specific gravity. The only attribute parameters available from the TNF data set were map unit name, slope class, and a soil phase related to erodibility. Other parameters were available from a document file (Adobe Acrobat PDF format) obtained from the TNF, but were limited to soil profile descriptions, some soil properties (effective root depth, water capacity class, available water capacity, permeability, erosion hazard) and some soil management interpretations, all of which would had to have been entered into the attribute table for the approximately 3000 Level 3 soil unit polygons found in the study area, then cross-correlated with the SSURGO map units in an attempt to add the missing parameters to the TNF Level 3 soil units. It was decided that it was not cost-effective to properly attribute the TNF Level 3 data and, as a result, the coarser (1:250,000 scale equivalent) NRCS STATSGO data set was used. The STATSGO database contains almost all of the parameters required for AnnAGNPS in a properly attributed format. Figure 7 shows the spatial variability in soil data.

Once processed, edited and evaluated for completeness in ArcView, the above-described data parameters were imported into AnnAGNPS for development of watershed sub-basins and model runs. Watershed sub-basin data in ASCII raster format were then exported out of AnnAGNPS back to ArcView. A total of 869 sub-basins were generated for the entire Truckee River watershed. The ASCII raster sub-basin files were converted to ArcView grids, then converted to ArcView shapefiles for viewing with the other geographic data in the database.

3.2.1.3 Scale, Accuracy and Reliability

The development of the project GIS database was driven, as well as constrained, by the availability of existing spatial data sets for the Truckee River watershed. As such, certain scale and reliability limitations, which affect accuracy, had to be addressed and reported. As most of the original data sets used in the project were from public domain sources and in digital form, almost all of the data used in this study did conform to National Map Accuracy Standards (U.S. Bureau of the Budget, 1947). Data in the database that do not comply with National Map Accuracy Standards include the mapped sensitive landscape units, as these were transposed by eye from relatively large-scale aerial photographs (1:15,840 to 1:24,000 scale) to 15-meter Landsat ETM satellite data. Error estimates for this procedure are approximately 50 to 100 meters (with respect to geomorphic contacts and landscape boundaries).

The scale and accuracy issues related to the soil data used have been discussed as they relate to the model. Although the level of detail in the NRCS STATSGO soil attribute tables is often at the pedon sampling scale, these parameters have been aggregated and generalized for relatively large area, small scale (1:250,000) spatial units. As a result, specific sub-unit soil detail is most likely not integrated to the development of sediment loads for the individual sub-basins calculated by the AnnAGNPS model. Parameters such as layer depths, K values and bulk density values were therefore averaged, resulting in coarser representations of these data per sub-basin. A worthwhile follow-up exercise to this project would be to perform a sensitivity analysis of how different scale soils data affects the AnnAGNPS results at the sub-basin and major basin level.

Scale differences and accuracies also played a significant role in the integration of the DEM into the model results. A preliminary analysis of the available elevation data for the study area revealed that 10-meter elevation data were available for the southern portion of the region, but only 30-meter data were available for the northern portion. Because AnnAGNPS uses the DEM at a cell size of 150 meters, there was no value in using the 10-meter DEM. This was not done during this project because of computer resource and time constraints. As in the case of the coarse- versus fine-scale soils data discussion above, a worthwhile follow-up exercise with respect to the DEM data would be to run the model at the full spatial resolution of the DEM, to determine how it would affect the accuracy of the resultant sediment mass loadings.

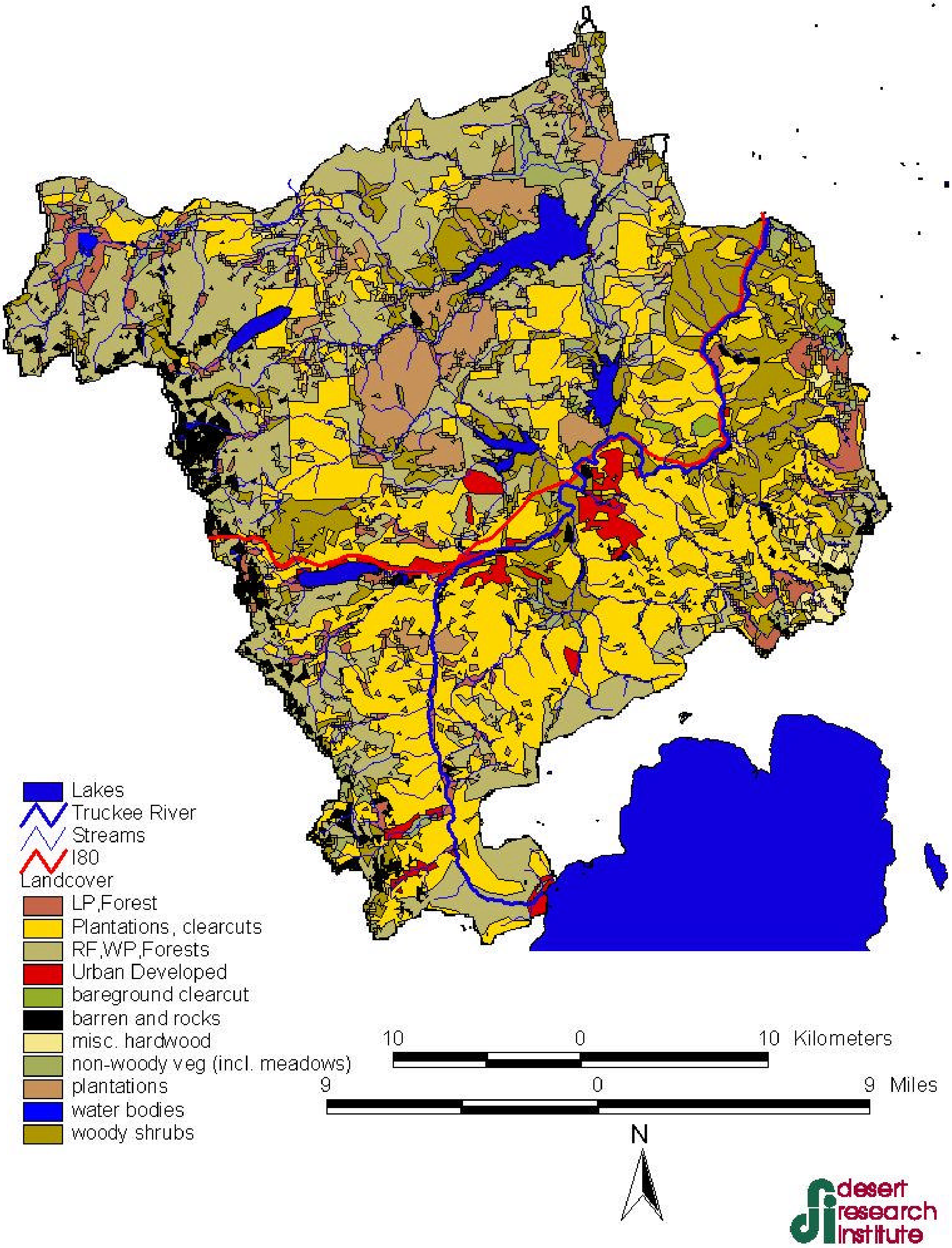


Figure 5. Land cover data layer.

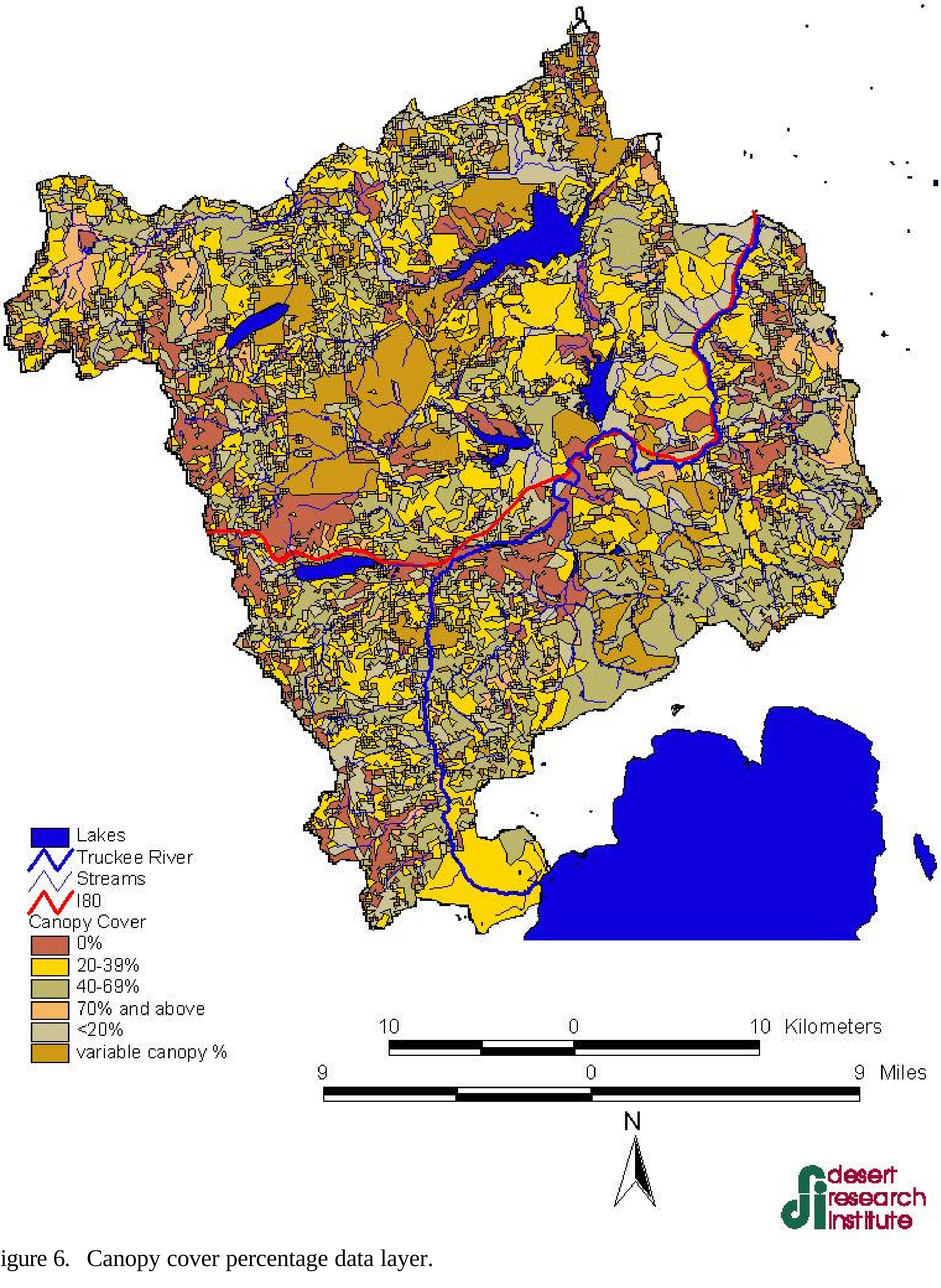


Figure 6. Canopy cover percentage data layer.

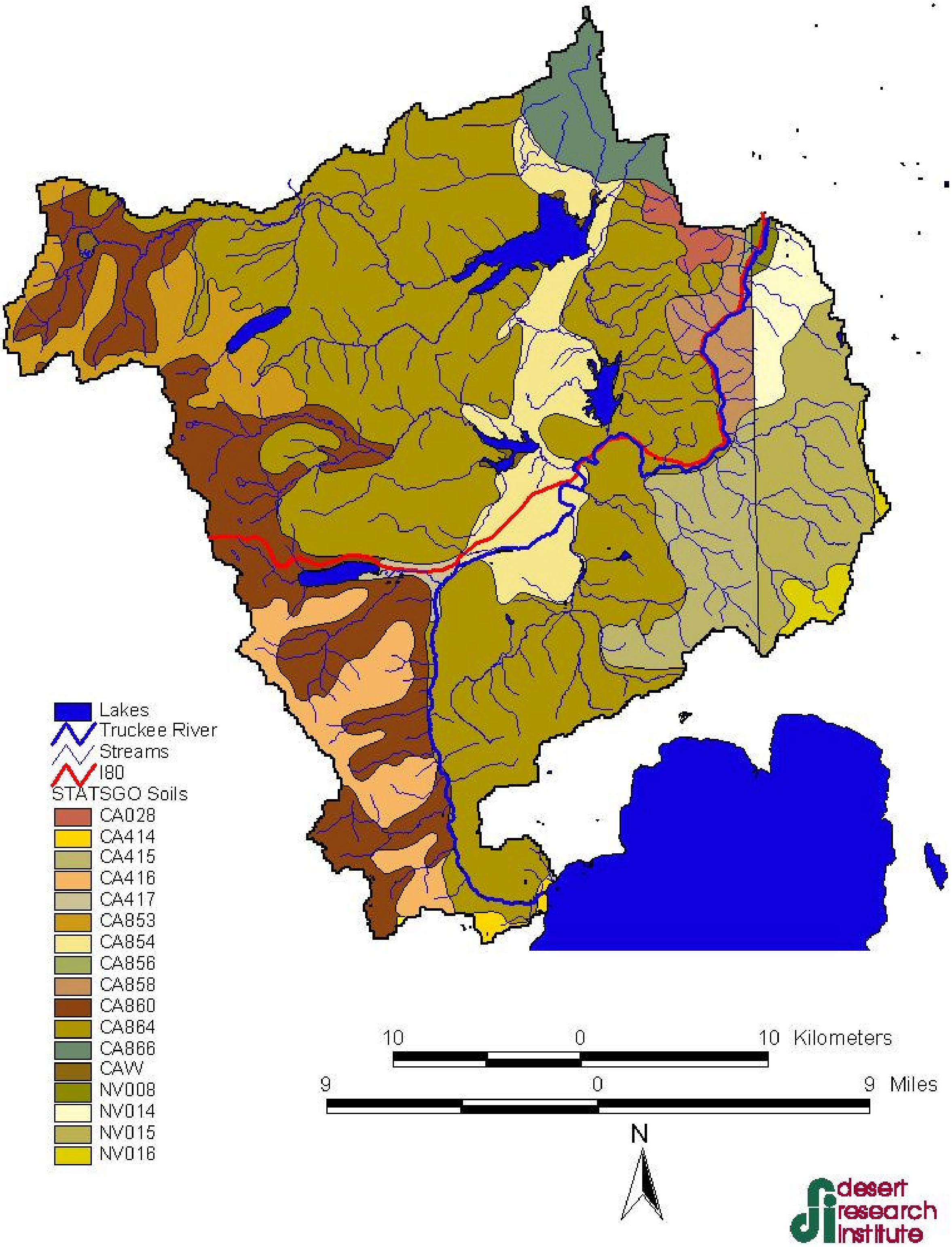


Figure 7. NRCS STATSGO soil layer.

The land cover and canopy cover data development efforts, for the most part, were not hindered by coarse-scale aggregation issues or lack of spatial accuracy. To the contrary, the detail of most input data sets used was at a finer scale than that required by the model spatial resolution. The TNF timber type and BRRC vegetation survey data were both mapped at the 1:24,000 scale. Although the USFWS California Gap data were mapped at a relatively coarse Minimum Mapping Unit (MMU) of 1 km^2, the land cover and canopy cover found in those portions of the basin covered by these data were refined using the Landsat ETM satellite imagery.

All the vector data used for the model, the I-80 highway and dirt roads data, were derived from 1:24,000-scale map data converted to DLGs, and therefore exceeded the resolution requirements of the AnnAGNPS model.

3.2.2 Suspended Sediment Loading

In addition to the aforementioned spatial data, it is important to compile all relevant historic data related to sediment for a TMDL analysis. The relationships developed below (e.g., the relationship between flow and SSC) become more useful as the amount of data increases. Additionally, longer periods of record increase the probability that extreme events are included in the data set which, in turn, increases the range of validity of the relationships.

3.2.2.1 Historic Data

Historic data were obtained from five sources: The USGS, DRI, LRWQCB, the SPPCo, and the California Department of Water Resources (CalDWR). Table 2 lists the data provided by each source (site, period of record, data type, collection method, and collecting agency) used in this study. Figure 32 of the monitoring section of this report shows corresponding locations of the sampling sites. The sampling and analysis methods used to obtain the individual data sets vary according to the collection agency, and only a short description of the techniques is provided below.

3.2.2.1.1 Suspended Sediment Data: USGS

The sampling method used by the USGS to collect the samples is the equal-width-increment (EWI), which involves dividing the cross section into between 15 and 20 areas of equal width. Vertically integrated samples are then obtained at the centroid of each area using specialized sampling equipment (to be discussed in a later section). Because this technique allows complete vertical and horizontal integration throughout the water column, the sample obtained represents the *average* SSC moving past the cross section at that specific time.

Table 2. Historic suspended sediment and turbidity data summary.

Location	Parameter	Period of Record	Values	Collection Method	Collecting Agency
Bear Ck	TSS	1/96 - 7/97	9	Integrated, Grab	LRWQCB
Squaw Ck	TSS	1/96 - 3/97	13	Integrated, Grab	LRWQCB
Donner Ck	TSS	12/95 - 9/97	22	Integrated, Grab	LRWQCB
Trout Ck	TSS	10/73 - 1/75 1/95 - 7/97	21	Integrated, Grab	LRWQCB
Martis Ck	SSC	5/75 - 8/85	22	Integrated	USGS
Prosser Ck	TSS	12/95 - 9/97	15	Integrated, Grab	LRWQCB
T R at Floriston	TSS	12/95 - 9/97	21	Integrated, Grab	LRWQCB
	Tu	12/95 - 9/97	21	Integrated, Grab	LRWQCB
T R at Farad	SSC	2/74 - 10/77 4/93 - 3/95	60	Integrated	USGS
	TSS	2/79 - 12/00	246	Grab	DRI
		1/96 - 9/97	21	Integrated, Grab	LRWQCB
	Tu	1/96 - 9/97	21	Integrated, Grab	LRWQCB
		1/96 - 12/00	365	Point (meter)	SPPCo
		3/75 - 10/77	32	Integrated	USGS
Gray Ck	TSS	01/01/96	1	Integrated, Grab	LRWQCB

3.2.2.1.2 Suspended Sediment Data: Desert Research Institute

DRI collects “grab” samples as a part of its Truckee River Monitoring Program, which has been in operation for over 30 years. Although this monitoring program collects samples at locations along the length of the Truckee River, only samples collected at California sites are presented in this study; these were not analyzed for SSC and turbidity before the year 1989. Grab samples are collected by first rinsing the sampling container with river water three times. Next, at a location where flow in the downstream direction is evident, the container is held under the surface until it becomes full. This sampling method has several problems associated with it: 1) the sample is one that has been neither vertically nor horizontally integrated, allowing for the sampling of only one point in the water column; and 2) the rate of intake is not the same as the stream velocity at the sampling point. For these reasons, the sample may not accurately represent the average SSC that was moving past the entire cross section at the time of sampling. USGS protocol permits this sampling technique to be used only in cases where the water velocities are so great that complete mixing can be assumed or when the stream is too shallow to permit effective use of the sampler.

3.2.2.1.3 Suspended Sediment Data: LRWQCB

LRWQCB employed a combination of the grab and integrated techniques. Some samples obtained were strictly grab samples. Others, however, were completely integrated, horizontally and vertically, throughout the cross section. Horizontal integration was achieved through the EWI method. By this method, a volume of water proportional to the flow is obtained at equally spaced verticals along a cross section. First, the cross section was subdivided into equal widths. Sampling then occurred along a vertical profile of the water column, located at the centroid of each section (referred to as a vertical). Lowering and raising a sample container through the water column allowed for the acquisition of a vertically integrated water sample. It should be noted that sample containers used by LRWQCB did not adhere to USGS protocol. Instruments specially designed to intake water at the same rate as the water velocity were not used. Nevertheless, it is assumed that the equal spacing between the verticals allowed for a total sample volume proportional to the total streamflow to be obtained.

3.2.2.1.4 Turbidity Data: Sierra Pacific Power Company

Turbidity is measured continuously in the Truckee River by the SPPCo and the CalDWR. Again, Table 2 lists the data provided by each source (site, period of record, data type, collection method) used in this study. To meet the water supply requirements of the Reno/Sparks metropolis, SPPCo operates and maintains a water diversion at Farad, California. Excessive SSCs have clogged the water purveyor's filter system in the past, usually during flood events. To provide an early warning signal that SSC might be reaching excessive levels, SPPCo monitors turbidity levels of river water at this site.

3.2.2.1.5 Turbidity Data: California Department of Water Resources

In an effort to better monitor SSC throughout the basin, the CalDWR has set up a network of turbidimeters along the length of the Truckee River. At the time this report was written, data from three sites were available. The turbidimeters are components of the YSI 6600 Sonde multi-parameter monitoring instruments. Readings are logged every hour, and represent the average of several measurements. The instruments filter out anomalous values before the average is recorded.

3.2.2.1.6 Turbidity Data: Desert Research Institute

DRI laboratories analyze for turbidity on the same samples that are collected as a part of their Truckee River Monitoring Program. The laboratory performs USEPA Method No. 180.1, "Determination of Turbidity by Nephelometry - Revision 2.0" (USEPA, 1993). This is run on an aliquot of the original sample, which has been vigorously shaken to resuspend any material that may have settled out. The sub-sample is then put into a Hach 2100® turbidimeter, which outputs the reading.

The response of a turbidimeter to a given suspension is governed mainly by the light source, detector and optical geometry. Nephelometric turbidimeters measure light scattered at an angle (commonly 90° or 180°) to the beam. Meters are calibrated to give a linear response to standards. A calibrated instrument should show a linear response to varying SSC, provided that the physical properties of the suspended materials remain constant (Gippel, 1995). Such instruments have been shown to be more sensitive to fine-grained materials (Foster et al., 1992), making it difficult to perceive changes in SSC unless they are associated with changes in the concentration of fine materials (Lewis, 1996). Particle shape, composition and water color also affect the turbidity of water (Gippel, 1989). Although these complications may affect a turbidity reading, Gippel (1995) states that adequate relations between turbidity and SSC can be made in most situations. In this case, turbidity sampling will actually improve sediment load estimates because the ease and cost enable for it to be sampled much more frequently than SSC.

3.2.2.2 Recent Data Collected for this Study

The limited extent of the historic sediment data required the collection of a complementary data set for this study. It was believed monitoring SSC and turbidity under various flow regimes would provide detailed information concerning variability of loading rates throughout the study area. Samples were collected throughout the basin during the period of snowmelt runoff for the year 2000. A description of the sample locations and the collection and analyses methods is provided below.

3.2.2.2.1 Monitoring locations

Sampling locations included the major tributaries to the Truckee River, as well as the Truckee River itself. Sampling sites along the Truckee River were located at USGS stream gages, so that the water discharge at the time of sampling could be obtained. The monitoring network at the sub-basin level consisted of the major tributaries to the Truckee River: Bear Creek, Squaw Creek, Pole Creek, Donner Creek, Trout Creek, Martis Creek, Juniper Creek, Gray Creek and Bronco Creek. Prosser Creek and the Little Truckee River are also major tributaries, but were not sampled as intensively as the others. This was because it was assumed that the reservoirs formed by the impoundments along their length would act as a sediment trap for the majority of these sub-basins. Martis Creek contains a dam as well; however, recent discussion amongst land managers concerning its removal merited its inclusion in the monitoring network. Samples collected at the tributary level were specifically taken near the input of each stream to the Truckee River. Because many of the sub-basins contain high-gradient streams with large variability of substrate materials and because the seasonal variability in flow regimes complicates channel geometry, cross-sectional location of sampling points were not fixed for the duration of the study. Rather, the locations were selected as close to the original sampling point as possible, where the most reliable results could be obtained.

3.2.2.2.2 Sampling methods

Computation of instantaneous suspended sediment discharge necessitated stream flow measurements of ungaged tributaries at the time of sampling. This was accomplished using standard USGS methods (USGS, 2000). The nature of the geology in the study area produced high-gradient streams that provide less than ideal conditions for discharge measurements. The straightest reaches offering the most uniform bed and flow conditions were selected for measurement of discharge. After determining the stream width, spacing of the verticals was calculated so that no less than 20 verticals would be used. An exception to this case was for streams less than 5 ft wide, where vertical spacing widths were 0.5 ft. At each vertical, velocity, depth, and distance from the initial point were recorded. Depths were estimated to the nearest hundredth of a foot. Velocity measurements were taken at 0.6 of the depth with a Marsh-McBirney, Inc. FLO-MATE™ 2000 electronic flow meter. Recorded measurements reflect the velocity averaged over a 40-second interval. Once the velocity, depth, and distance of the cross section were determined, the mid-section method was used to determine the discharge in each increment, according to the equation:

$$Q_n = (w_{i+1} - w_i)\left(\frac{d_{i+1} + d_i}{2}\right)\left(\frac{v_{i+1} + v_i}{2}\right) \quad (1)$$

where n is the individual increment number, w_i is the horizontal distance from the initial point, d_i is the water depths for each section, and v_i is the measured velocity for each section. The total stream discharge was computed simply as the sum of the increment discharges. If any of the individual segments was originally in excess of ten percent of the total discharge, the segment was broken down into a smaller increment until this criteria was fulfilled.

Suspended sediment sampling followed standard USGS field methods as described in Edwards and Glysson (1986). All samples obtained were completely integrated, horizontally and vertically, throughout the cross section. Samples were collected using instruments specially designed to intake water at the same rate as the water velocity. Lowering and raising the instruments through the water column allows for the acquisition of a vertically integrated water sample. A hand-held DH-81-type sediment sampler was used at locations that were able to be waded. When high flows prevented the use of this device, a cable-and-reel type sampler was used. Samplers contained the largest nozzle available (5/16”) to enable collection of large particles.

Horizontal integration was achieved through the EWI method. A minimum of 10 verticals were used for streams over five feet wide. For streams less than this width, as many verticals as possible were used. The EWI method requires that all verticals be traversed using a constant transit rate that is less than 0.4 of the maximum velocity determined during the discharge measurement. The equal spacing between the verticals yielded a total sample volume proportional to the total streamflow.

3.2.2.2.3 Sampling schedule

Leopold and Maddock (1953) reported that suspended sediment discharge is usually highly correlated with water discharge in most fluvial systems. To determine if a similar relationship exists for the Truckee River system, it was necessary to collect suspended sediment samples over a wide range of flow regimes. Snowmelt results in high fluctuations in flow over the melt season, but the amount of snowmelt contributing to streamflow at any one time is dependent upon many intrinsic and extrinsic factors. The most influential of these is temperature. Therefore, the sampling schedule did not follow any particular schedule. It was originally believed that weekly sampling would allow for enough data to define the relationship between sediment and water discharge. However, because most of the melt occurred in a relatively short time span this year, the schedule was modified so that gaps in the data could be avoided.

Generally, samples were collected in two groups: above the Town of Truckee and below the Town of Truckee. The above Truckee sites consisted of the following: Truckee River at Tahoe City, Bear Creek, Squaw Creek, North Fork of Squaw Creek, Truckee River near Truckee, and Donner Creek (at Highway 89). The below Truckee sites were: Trout, Martis, Juniper, Gray and Bronco creeks, and Truckee River at Farad. The sites in each group would be sampled in the course of one day, and sampling of the groups would be rotated. It is important to note that duplicate samples were collected at all sites. Visual comparisons between the samples were made. If the samples matched well, one was discarded and the other taken in for analysis. If a difference was evident, both were discarded and two more samples were collected and compared. One duplicate sample from every round was taken in for analysis so that the error associated with the sampling methods could be quantified.

3.2.2.2.4 Sample analysis

All samples were analyzed at the DRI laboratory to determine the concentration of suspended sediments in units of mass of solids per volume of water (mg/l). To avoid complications inherent in the TSS method (discussed previously in the Historic Data section), SSCs were determined using the entire volume of the sample. This was accomplished by first emptying the entire sample into a graduated cylinder and recording the volume of water to the nearest milliliter. The water was then poured through a standard, preweighed 0.4-micron glass fiber filter. Both the graduated cylinder and original sample container were then rinsed to ensure that all solid materials were excavated to the filter. A vacuum was applied to the filtering apparatus to ensure that all water was removed. The samples were transferred to an evaporating dish, and allowed to dry in an oven overnight. The filter was reweighed with the dry materials. Concentration was determined by subtracting the original filter weight and dividing by the water volume.

Some samples were also analyzed by the DRI laboratory for turbidity, using the same methods as described in the Historic Data section. Turbidity was determined using an aliquot of roughly 5-10 mg of the sample.

3.2.2.3 Data Analysis and Calculations

Using historic and recently acquired data described above, sediment yields were computed for each of the major tributary watersheds, as well as the total load exiting the California portion of the watershed. As a reminder, computation of sediment load using historic and recent data serves two purposes: 1) to characterize the watershed using actual data, and 2) to calibrate and validate the model.

In an attempt to compute sediment loads for each tributary, a number of problems were encountered and a number of assumptions were made. Computations based on field data are limited by the following complications: 1) size of the data sets for tributary streams; 2) differences in the sampling and analysis techniques used by the different agencies; 3) lack of continuous flow records for a large portion of the watershed; and 4) the use and extrapolation of instantaneous sediment discharge measurements for the computation of annual sediment yields. This section will describe the methods used to resolve these problems to calculate suspended sediment loads throughout the Truckee River watershed.

3.2.2.3.1 Integration of Data Sets

The most significant limitation in computing sediment loads relates to the size and quality of data sets. Ideally, data sets will be composed of a minimum of at least 30 observations. At the tributary level, this was rarely the case for individual data sets. To lengthen the data records, all data sets were integrated regardless of the sampling and/or analyses that were used to obtain them. Despite the problems associated with grab sampling, it was assumed that this technique produced reliable results. This assumption is supported by data collected during the summer of 2000. Twenty-six integrated samples were collected from the Middle Truckee River at the same time as grab samples. Analysis of both integrated and grab samples shows insignificant differences in SSC concentration between the collection methods. Therefore, grab samples were added to the integrated samples to develop the relationships described below.

The difference between the SSC and the TSS analyses is that the SSC method measures the entire sediment mass as the analysis is performed on the entire sample. The TSS analysis is usually performed on an aliquot of the original sample. Gordon and others (1999) demonstrated that it is very difficult to withdraw an aliquot from a sample that truly represents suspended material concentration, especially if the sample contains a substantial percentage of sand-size material. The authors also determined that results of the TSS analytical method are negatively biased by 25-34% with respect to SCC analyses collected at the same time and can vary widely at different flows at a given site. Moreover, TSS methods and equipment differ among laboratories. For all these reasons, the USGS cautions that load computations based on TSS data can result in errors as large as several orders of magnitude.

The USGS suggests that a relationship between SSC and TSS should be established for each site that TSS is to be used as a surrogate measurement of suspended material. To test this, the 26 integrated and grab samples collected during the summer of 2000 were analyzed by the DRI laboratory according to the SSC and TSS methods, respectively. Figure 8 indicates that no significant difference between the analyses methods could be detected.

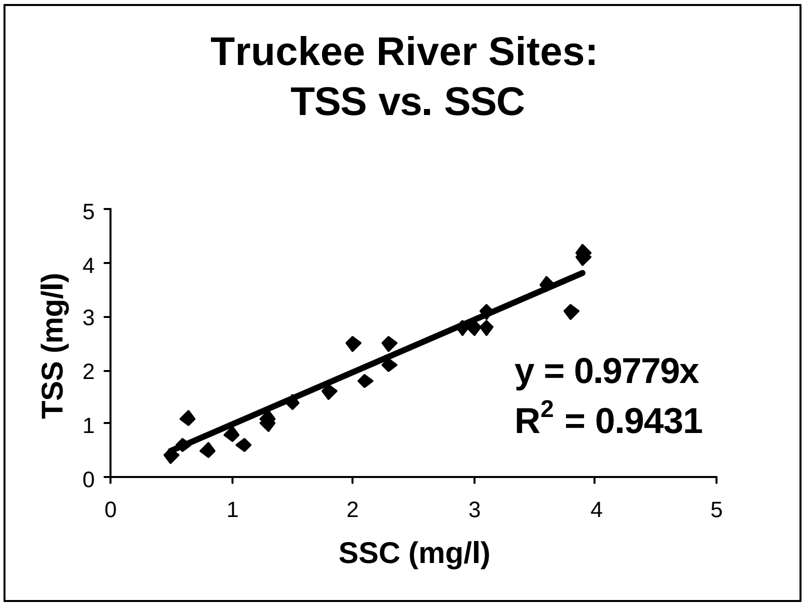


Figure 8. Relationship between total suspended solids (TSS) and suspended sediment concentration (SSC).

Because a nearly one-to-one relationship was reported, it was assumed that the data sets using each method could be directly compared and integrated. It should be noted that all samples were collected at flows less than 500 cfs. Therefore, this assumption may not hold true for flows greater than this value. A more thorough comparison of the analysis methods, and for that matter the sampling techniques, at higher values may be warranted.

3.2.2.3.2 Sediment discharge calculations

The instantaneous suspended sediment transport rate is the product of concentration C and discharge Q. Therefore, the total load L past a particular cross section for any time period is defined by the integral:

$$L = K\int_0^T C(t)Q(t)dt \qquad (2)$$

where concentration and discharge are measured at time t, and K is a units conversion factor. The equation can only be applied if near continuous measurements of concentration and discharge are recorded. In this case, equation 1 can be approximated by the sum:

$$L = \sum_{i=1}^{T/dt} C_i Q_i dt \qquad (3)$$

with a fixed sampling interval dt that is shorter than the minimum time over which discharge or concentration can significantly change.

As is the case for this study, such data records are rarely available. Various restrictions usually limit monitoring efforts to infrequent sampling intervals, usually weeks or a month. Upon observing a linear relation between the logarithm of sediment concentration and the logarithm of discharge, Campbell and Bauder (1940) suggested that a sediment rating curve could be used to estimate suspended sediment concentrations based on water discharge. Equation 2 is then applied using the estimated concentrations derived from the rating curve.

One method to approximate sediment load in the absence of a detailed record, therefore, is to derive a relationship between concentration and discharge to estimate unobserved values of concentration. Although the rating curve lacks physical justification, the relative simplicity of the technique has warranted its widespread use in sediment load computations. It has been shown to be adequate for many purposes where lengthy sediment records are unavailable (Miller, 1951; Colby, 1955). Another advantage is that the method can be easily modified to account for variability associated with non-linear flow dependence and time trends (Cohn et al., 1992). For these reasons, computations based on this method are warranted for this study.

The rating curve is almost invariably the ordinary least squares (OLS) regression of log concentration against log discharge using the available data, resulting in an intrinsic linear model in the form of:

$$\log C(t) = b_0 + b_1 \log Q(t) \qquad (4)$$

where *log* is the base 10 logarithmic function, b_0 and b_1 are model coefficients. Applying equation 4 results in regression residuals that are commonly assumed independent and identically distributed (iid) normal random variables, with a mean of zero and variance denoted by s^2 (Cohn et al., 1992). To obtain a useful form that can be used to compute suspended sediment loads, equation 4 must be back-transformed into real space. The concentration for any discharge is then computed by:

$$C(t) = 10^{b_0} \log Q(t)^{b_1} \qquad (5)$$

Typically, average daily flow values (Q_a) are applied to equation 5 rather than instantaneous or continuous flow measurements. This allows for computation of daily average sediment loads (L_d). Daily sediment loads are thus estimated by:

$$L_d = 10^{b_0} \log Q_a^{\ b_1}. \qquad (6)$$

3.2.2.3.3 Water discharge estimates

To compute sediment loads using equation 6, average daily flows are required for each basin. Average daily flows were either obtained from USGS historic records or synthesized from watersheds that contained historic flow records. This brings up several discussion points. Although instantaneous flow values were used to calculate instantaneous values of suspended sediment discharge whenever possible, such flow data did not always exist. In such cases where the instantaneous flow values were not recorded at the time of sampling at gauged sites, average daily flows were substituted for instantaneous flows. This relates to the DRI grab sample data at Farad and possibly the LRWQCB data. The general good agreement between USGS sediment rating curves constructed from instantaneous flow measurements and the DRI rating curve using daily average flow values validates this procedure.

Currently, flow is continuously recorded only for those tributaries that contain impoundments. The only other tributary stream with a continuous flow record is Bronco Creek, which was gauged from April 1993 through October 1998. Due to limitations associated with SPPCo turbidity data (discussed later), it was decided that load calculations would be based on water discharge data obtained from the 1996 and 1997 calendar years. These years seemed to be good choices, because it allowed for the comparison of a wet year to an average one that contained an extreme event.

For the tributaries where no flow record was available, synthetic hydrographs were created. This was accomplished by correlating flow measurements in the ungauged tributaries to those watersheds containing flow records. Gauged watersheds were evaluated on the basis of proximity and similarity of watershed characteristics to those for which they were being used to construct a hydrograph. Instantaneous and/or daily flow values were then compared between the watersheds to observe if a significant correlation existed. Because water discharge typically follows a log-normal distribution, a power-law relation was developed between the tributaries. This was done by performing OLS regression between the flow data sets. If the regression demonstrated that a significant flow relation existed between the watersheds, the flow record contained in the gauged watershed was used to synthesize one for the ungauged location(s). Table 3 provides summary information on which tributaries showed a significant flow relation.

The r^2 measures the proportion of total variation about the mean $\overline{Y}$ explained by the regression. For example, a regression model yielding an r^2 of .85 means that the equation explains 85% of the variation in the data about the average $\overline{Y}$. MAE (mean absolute error) is the mean of the absolute value of the differences in the measured and predicted values. The RMSE (root mean squared error), or standard deviation, is the average of the squared differences in measured and predicted flows. In all cases, the model with the highest r^2 and the lowest MAE and RMSE was used to synthesize the hydrographs for the corollary tributaries.

Table 3. Flow correlations between tributaries.

Sub-watershed							Flow Range (cfs)	
(y)	(x)	N	Regression equation	r^2	MAE	RMSE	Low	High
Bear	Blackwood (x_1) Ward (x_2)	33	$Q_y = 0.84 (Q_{x1})-.36 (Q_{x2}) - 1.58$	0.76	12.2	21.5	2.1	192
Squaw	Blackwood	52	$Q_y = 0.9383 (Q_x)$	0.92	21.0	38.5	2.1	711
Trout	Sagehen	26	$Q_y = 0.24 (Q_x) + 2.6563$	0.71	23.0	42.6	2.8	228
Bronco	Blackwood (x_1) Ward (x_2)	1942	$Q_y = 0.15 (Q_{x1}) + 0.9 (Q_{x2}) + 6.79$	0.71	5.6	9.5	0.92 <1	607 672
Juniper	Bronco	11	$Q_y = 0.66 (Q_x)$	0.66	7.2	8.2	<1	35
Gray	Bronco	15	$Q_y = 1.81 (Q_x)$	0.73	16.3	18.4	6.1	44.3

The synthetic hydrographs created for Gray and Juniper creeks were based on the documented flow record of Bronco Creek. Although these correlations are based on very few observations, they are justified on the basis of watershed proximities and similarities in characteristics and land uses. For Gray Creek, the OLS regression seemed to produce reliable results. This is suggested by the strong correlation between the predicted and measured flow values, as displayed in Figure 9.

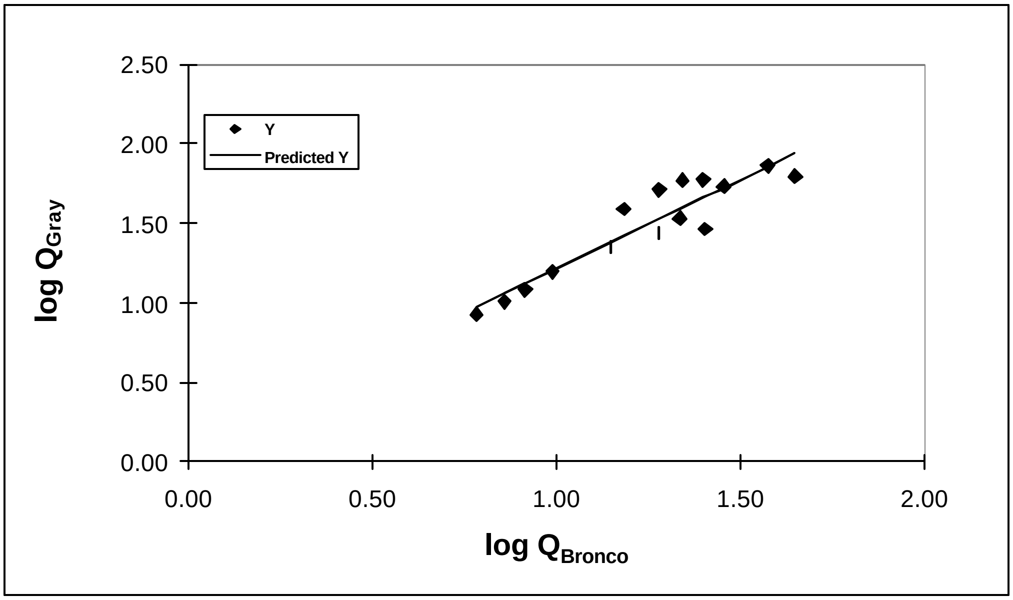


Figure 9. Correlation between flow in Gray and Bronco creeks.

Furthermore, a probability plot of the residuals confirms this conclusion, as the points appear to be normally distributed. When observing the same graphs for Juniper Creek (Figure 10), it can be seen that the OLS regression does a poor job in predicting flow. In fact, during the January 1997 flood event, flows were predicted to be larger in Juniper than in Bronco. This is suspicious since the Bronco watershed is approximately 1.5 times the size of that of Juniper. Therefore, instead of applying an OLS regression between the watersheds, a simple scaling factor computed as the ratio of the sizes of the watersheds was used to derive the hydrograph for Juniper Creek. Bronco Creek flow values were multiplied by a factor of 0.68 to obtain flow values for Juniper Creek.

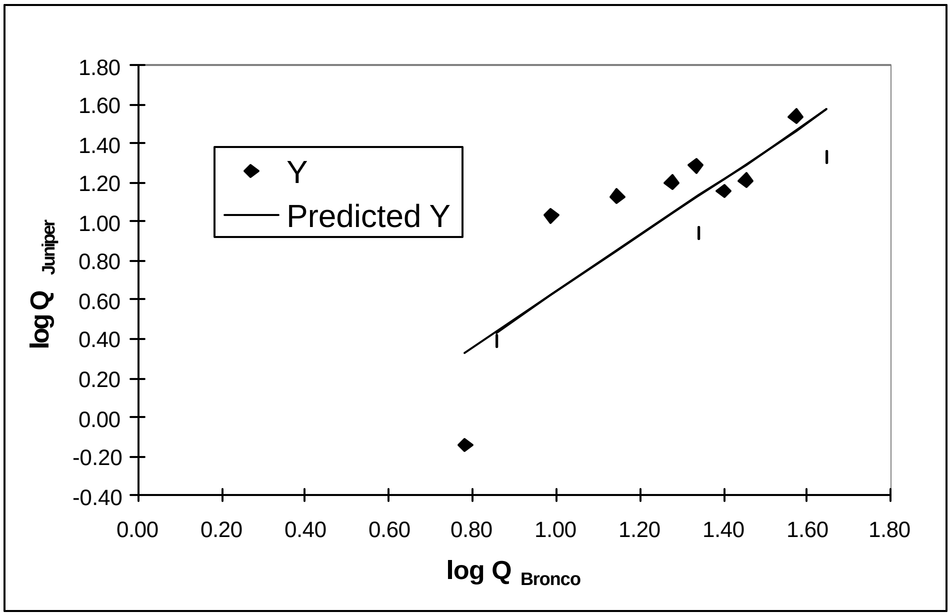


Figure 10. Correlation between flow in Juniper and Bronco creeks.

To summarize section 3.2 (Data Description), all relevant spatial data were collected. Most data were used to parameterize the AnnAGNPS model while some were collected for the Aerial Photography Analysis (section 3.3.4). Historic sediment data were collected and gaps in the data set were filled with recent data. Unfortunately, data did not exist for every location in the basin. To deal with the lack of data, correlations were developed between SSC, TSS, Tu and flow. Where flow data do not exist, correlations were developed between basins with historic flow data and those without. Using this method of correlation, an estimate of yearly suspended sediment load can be calculated for each major sub-basin to the Truckee River.

3.3 Assessments

The next step after collecting all the appropriate data is to assess the watershed. According to EPA protocol (1999a), the first step of source assessment is to compile an inventory of all sources of sediment to the waterbody. As mentioned previously, the watershed was assessed in three ways: 1) assessment by historic and new data, 2) assessment by watershed model, and 3) assessment by aerial photo analysis. The assessment by historic and new data is limited to those sub-basins where adequate data or correlations exist. The results of that assessment are then used to calibrate and validate the model. Because the model is discretized to elements smaller than the major sub-basins (e.g., Bronco Creek comprises 39 model elements), it is possible to estimate loads at a much smaller scale, thus revealing more variability in sediment production within the basin.

EPA protocol also states that after an inventory has been compiled, monitoring, statistical analysis, modeling, or a combination of methods should be used to determine the relative magnitude of source loadings. In this study, a statistical analysis of historic and new data was performed. Because data do not exist for the entire watershed, a watershed model was developed to estimate sediment processes where no data exist. The results of the statistical analysis were used to calibrate and validate the model. Then, using the historic aerial photos, the watershed was assessed with respect to landscape sensitivity and potential for sediment production resulting from disturbance.

3.3.1 Assessment by Historic and New Data

Using historic and new data, the sediment load can be estimated using flow, turbidity, or a combination of the two. This assessment will result in estimates of the annual sediment load for selected basins for 1996 and 1997. The prediction intervals are also reported with the estimates to provide a measure of confidence in reported values.

3.3.1.1 Sediment Load Estimate Using Flow

Using the average daily flow hydrograph in equation 5 allowed for average daily sediment loads to be computed for individual sub-basins and for the total loads exiting the California portion of the watershed (Farad/Floriston). Spreadsheets were used to facilitate these calculations and enabled prediction intervals to be incorporated. All prediction intervals were calculated at the 95% confidence limit using the t-test provided by the statistical package in Microsoft Excel ®. Computed daily average loads with prediction intervals were then summed to provide a total annual load for each site.

When the transformation from log to real space is completed by equation 5, error associated with the regression residuals is introduced into the computation, resulting in a significant bias of concentration values (Ferguson, 1986). In general, results obtained from this equation are systematically biased downward. Studies using field data (Walling et al., 1981; Ferguson, 1987) have demonstrated that this error may exceed 50%. To correct for underestimation of sediment loads, Ferguson (1987) suggests adjusting equation 5 to include an estimator, defined as the exponential function of 2.65 multiplied by the standard error of the model in $\log_{10}$ units. Unbiased estimation of the annual suspended sediment loads (L_{ub}) was obtained by:

$$L_{ub} = L_d \exp(2.651 s^2) = 10^{b_0} \ \log Q(t)^{b_1} \exp(2.651 s^2) \qquad (7)$$

where s is the standard error of the sediment rating curve in $\log_{10}$ units.

3.3.1.2 Sediment Load Estimate Using Turbidity

Estimation of suspended sediment loads has conventionally been done using water discharge and sediment rating curves. Obtaining records of sediment concentration data is a time consuming and expensive endeavor, making continuous sampling difficult. However, recent developments have shown that turbidity, the amount of light that is scattered or absorbed by a particular water, is generally a much better predictor of suspended sediment concentrations than water discharge (Lewis, 1996). The advantages of using turbidity as an estimator of suspended load are that it is cheaper and easier than sampling specifically for suspended sediment. Furthermore, battery- or solar-powered turbidimeters have made it so that near continuous records can be obtained easily. For these reasons, many studies have focused on using turbidty as an estimator of suspended loads (Lewis, 1996; Barber, 1996; Truhlar, 1976).

The relation between suspended sediment concentration and turbidity varies over time due to changes in sediment sources, organic loading or sensor calibration. Thus, greater error will be encountered when using a single curve to estimate long-term suspended sediment loads. Nevertheless, Lewis (1996) maintains that turbidity is probably more useful than water discharge as a long-term predictor of suspended sediment loads. A near-linear turbidity-suspended sediment relation will yield nearly unbiased load estimates when a continuous turbidity record is available. The detailed turbidity record often contains a signature of sediment inputs to the channel from erosion, mass wasting, or other newly created sediment sources. Such temporal variations in sediment concentrations are overlooked when using the sediment rating curve approach. Thus, these methods are subject to larger errors (Walling and Webb, 1988).

For this study, load computations based on turbidity were limited to one location. A near continuous record of average daily turbidity at Farad was acquired for the years 1996-1999. To compare calculations based on the sediment rating curve method, calculations were restricted to 1996 and 1997. It should be noted that part of the reason for choosing these years was that they contained the fewest number of gaps in the data set. Temporary fouling of the instrument often resulted in negative or zero values. In such cases, interpolated values were substituted into the record.

The relation between turbidity and suspended sediment concentration was derived by combining the data sets of DRI, LRWQCB and the USGS. Although different laboratories and instruments (all nepholometric) were used to analyze the samples, the reported turbidity values represent a comparable data set because analysis methods were consistent. Furthermore, to expand the number of observations, thereby reducing model prediction error, turbidity and suspended sediment concentration data obtained from Farad were integrated with those from Floriston.

The resulting relation of turbidity to suspended sediment concentration found by performing linear regression on the data sets is displayed in Figure 11. The following stepwise procedure was then completed to obtain suspended sediment load estimates:

- Average daily SSC was calculated by applying the regression equation;
- Average daily SSC was multiplied by average daily flow recorded at Farad and a conversion factor to obtain average daily load;
- Prediction intervals were calculated at the 95% confidence interval according to regression statistics. A value of zero was replaced for the cases where the lower prediction limit returned a negative value; and
- Summation of daily loads yielded annual load within a lower and upper range.

3.3.1.3 Results

A summary of load calculations by the sediment rating curve method with prediction intervals is presented in Table 4. Sub-basins were then ranked according to the total amount of suspended sediment that each yielded to the main stem of the Truckee River (Table 4). This was completed for individual years for which computations were completed.

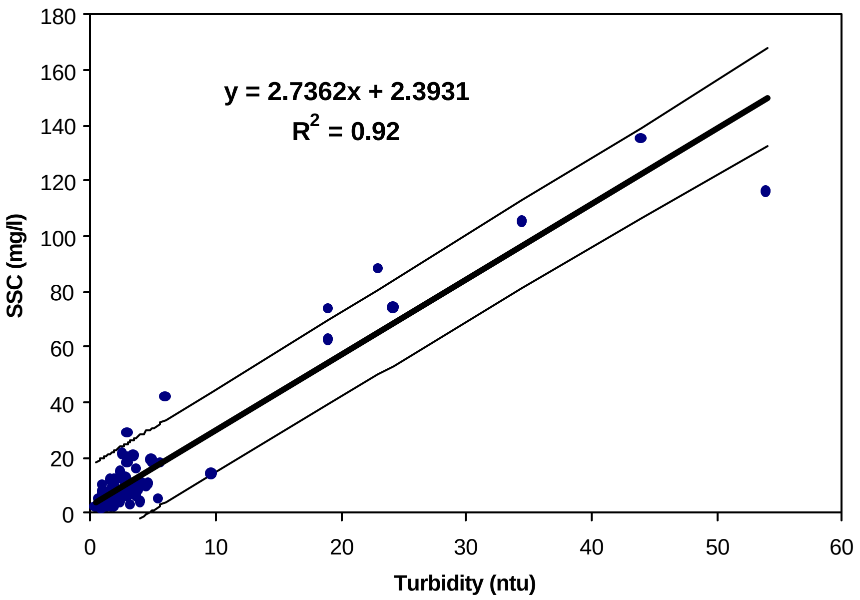


Figure 11. Relationship between suspended sediment concentration (SSC) and turbidity.

Table 4. Suspended sediment load predictions, 1996 and 1997.

1996 LOAD CALCULATIONS				1997 LOAD CALCULATIONS			
Site	Predicted Sediment Load (tons)	Lower Prediction Limit (tons)	Upper Prediction Limit (tons)	Site	Predicted Sediment Load (tons)	Lower Prediction Limit (tons)	Upper Prediction Limit (tons)
Donner Ck	2481	313	20034	Gray Ck	6567	1660	27121
Gray Ck	1418	548	3759	Squaw Ck	3640	680	19498
Squaw Ck	1402	273	7219	Donner Ck	3001	387	23660
Little Truckee R	1385	205	9398	Little Truckee R	1535	230	10296
Prosser Ck	1228	214	7786	Prosser Ck	1467	301	8373
Martis Ck	513	182	1453	Bear Ck	884	61	13015
Bear Ck	511	35	7842	Martis Ck	498	174	1435
Bronco Ck	206	59	826	Bronco Ck	448	130	1643
Juniper Ck	195	44	888	Juniper Ck	360	82	1614
Trout Ck	123	6	2645	Trout Ck	149	7	3065

It stands to reason that sediment yield increases proportionally with basin size. The USGS (1991) found this to be the case for sub-basins of Lake Tahoe. Although not strictly the case in this study, evaluating the restoration potential of watersheds based on total loads may result in a bias toward selection of larger sub-basins. An alternate approach is to normalize the suspended sediment yield of each sub-basin according to size. Dividing the total load of each sub-basin by the area gives units of load per unit area. This method allows the evaluation of watersheds without bias associated to basin size. If a small basin produces a relatively large amount of sediment, then it is a good candidate for restoration efforts. Table 5 and Figure 12 display suspended sediment loads of the basins after they have been normalized for drainage area. Figure 12 represents the average normalized loads for 1996 and 1997.

Table 5. Suspended sediment load predictions, normalized by area.

Site	Area (mi^2)	1996 load ($tons/mi^2$)	Site	Area (mi^2)	1997 load ($tons/mi^2$)
Squaw Ck	8.38	167	Squaw Ck	8.38	434
Bear Ck	5.29	96	Gray Ck	17.63	372
Donner Ck	30.03	83	Bear Ck	5.29	167
Gray Ck	17.63	80	Donner Ck	30.03	100
Trout Ck	4.89	25	Juniper Ck	11.28	32
Prosser Ck	52.9	23	Trout Ck	4.89	30
Juniper Ck	11.28	17	Prosser Ck	52.9	28
Martis Ck	40.4	13	Bronco Ck	16.46	27
Bronco Ck	16.46	12	Martis Ck	40.4	12
Little Truckee R	173	8	Little Truckee R	173	9

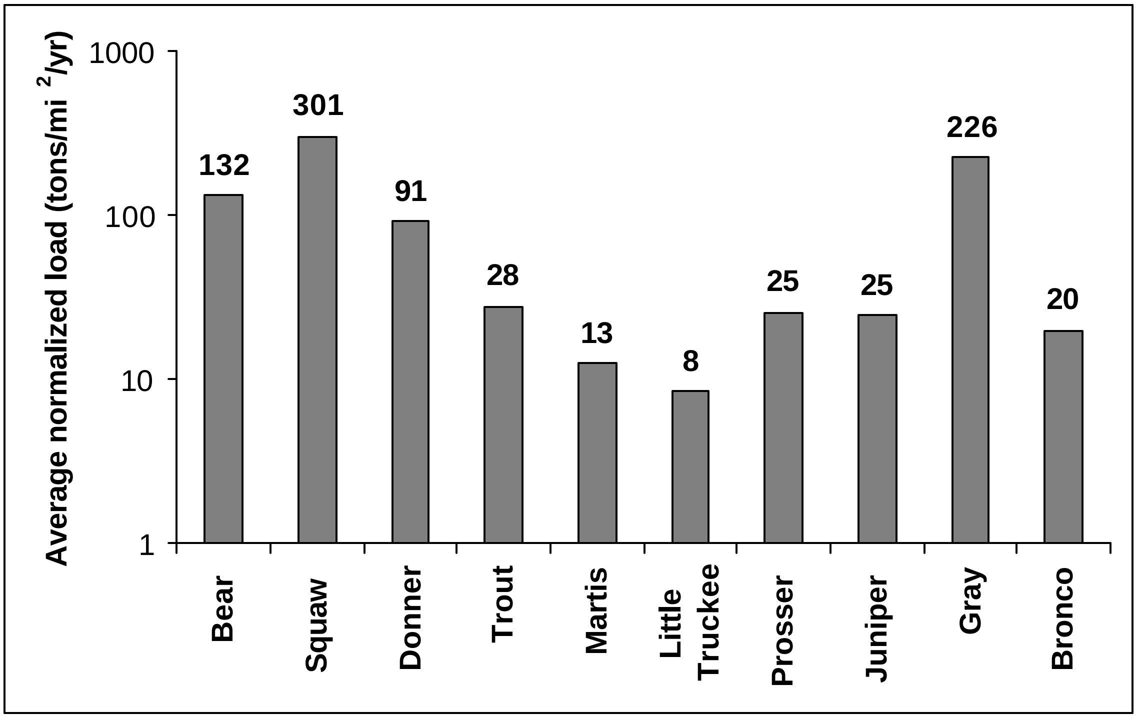


Figure 12. Average annual suspended sediment load predictions, normalized by area.

To summarize section 3.3.1 (Assessment by Historic and New Data), sediment loads from 10 sub-basins in the Truckee River watershed were estimated for the years 1996 and 1997. Estimates were based on a wealth of historic data as well as detailed recent data. To assist in potential restoration or land management decisions, the load for each basin was normalized by area. Ranking of these basins by load per area may give an indication of candidate restoration sites. Assuming cost of restoration varies with area, there is more benefit in restoring a basin with a high load-to-area ratio.

The assessment by historic and new data gives information at the sub-basin scale. Even a cursory look at figures 5 (land cover), 6 (canopy cover), and 7 (soil) suggests a large degree of variability at the sub-basin scale. It is reasonable to assume that variability within a basin yields variability in sediment production. Therefore, to address the variability at a smaller scale, a watershed model was developed.

3.3.2 Assessment by Watershed Model

As noted above, EPA protocols for TMDL source assessment enumerate watershed, or, erosion models, as one of the recommended methods for estimating sediment loads. Watershed models are common and very useful tools to help simulate behavior where no data exist, as well as predict system response under a variety of stresses. There are many models that simulate watershed processes and as many computer programs to facilitate the use of those models. Most models estimate erosion as a function of several parameters, including soil characteristics, topography, vegetation characteristics, and precipitation (USEPA, 1999a).

A desired function of a watershed model is the ability to accurately estimate runoff and sediment derived from landscape units within the watershed. To account for spatial variability in water and sediment production within the watershed, the model requires input parameters that reliably represent actual and projected conditions within the basin. As discussed above in the Data Description section, all available spatial data were explored and were used if data sets proved satisfactory for the model.

A watershed model should be considered a tool, one whose utility increases as new information is added. We anticipate that additional data will be collected in the future and, using that data for additional calibration and validation, model results will change. Notwithstanding future model enhancements, current model results can still provide valuable information to the reader. A review of the *rank* of sediment-producing areas can indicate which locations may need treatment. This will hold true regardless of the quality of the calibration (within reason). For example, a high sediment-producing area in a calibrated model will still likely be a high-sediment producing area in an updated model. The results of the calibration will show that the model is accurately reproducing suspended sediment loads; therefore, the relative productions rates of different areas of the basin should be valid.

3.3.2.1 Model Selection

For this study, only those models supported in the public domain were considered. Public-domain models have the advantage of undergoing peer review and, usually, a long history of use and evaluation by a large number of users. Many sediment models are based on the Revised Universal Soil Loss Equation (RUSLE). Though this equation was originally developed for annual prediction of erosion from shallow-sloped agricultural areas, it has been used with varying degrees of success on steeper slopes. Models do exist that were intended for steep slopes; however, they are either not in the public domain or their application to a basin the size of the Truckee is not compatible with the scale at which the model operates.

A number of watershed models are available either publicly or commercially. However, most were developed for the assessment of runoff and erosion from agricultural lands. None is appropriate for alpine forested watersheds where erosion is caused by surface runoff generated from snowmelt. In addition, these models do not adequately address management and operational practices on forested land.

After careful review of many candidate models, the newly developed AnnAGNPS (USDA, 2000) was selected to study the non-point source sediment load from the Truckee River watershed.

3.3.2.2 Overview of AnnAGNPS

Most of the description of AnnAGNPS is taken directly from documentation available at the AGNPS website (http://www.sedlab.olemiss.edu/agnps.html).

The AGNPS 98 (Agricultural NonPoint Source) model was developed by the Agricultural Research Service (ARS) in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service (SCS, hereafter the Natural Resources Conservation Service (NRCS)). It is a distributed parameter, event-based model that simulates the processes of runoff, sediment, and nutrient transport from watersheds under short-duration rainfall or snowmelt events. It was designed as a tool for evaluating watershed responses to different management practices.

The AnnAGNPS model is a batch-process, continuous-simulation, pollutant loading computer model developed as an upgrade to AGNPS 98. In contrast to AGNPS 98, AnnAGNPS is not restricted to event-based simulations; rather, it provides an annual continuous simulation of runoff, sediment, and pollutant transport. The capabilities of the Revised Universal Soil Loss Equation (RUSLE), adopted by USDA-NRCS to quantify erosion on agricultural lands and to guide the development of conservation practices for erosion control, have been incorporated into AnnAGNPS. This provides a watershed scale aspect to conservation planning.

Erosion analysis using AnnAGNPS requires three steps: data Preparation; simulation; and output processing.

Data preparation generates climate input data from daily precipitation data, delineates watershed and sub-watershed boundaries, maps soil and land management data to each AnnAGNPS cell, and determines flow hydraulic parameters (e.g., roughness, concentration time) for each sub-watershed and channel segment. Additional efforts are made to select the appropriate model options for the study watershed. Since the Upper Truckee River Basin is a forested watershed, the simulation options related to the agricultural lands were not activated for this study.

Output data include flow, sediment, and pollutant load from each event and the annual accumulated load from each sub-watershed. Average annual output evaluates variable accumulations over the simulation period at downstream reach locations to determine contributions from specific user-selected components (cell, feedlot, gully, point source, or reach). Variables analyzed are user selected from input source accounting flags or global source accounting flags.

3.3.2.2.1 Input Data Preparation: Watershed Topographic Characterization

The AnnAGNPS Input Data Preparation Model (AIDPM) (USDA, 2000) is used to calculate the slope, drainage area and elevation of these sub-basins. The AIDPM requires digital elevation data. The digital elevation data of a 150-m x 150-m resolution were used to generate the sub-basins as well as the channel network. Visual inspection confirms that the generated watershed adequately follows the natural drainage pattern. Figure 13 shows the 869 sub-basins generated by the model.

3.3.2.2.2 Input Data Preparation: Climate Data

There are three climate stations in the study basin. However, the current version of AnnAGNPS allows the use of only one climate station. The climate station at the town of Truckee was used for this assessment. Temperatures throughout the basin were modified from the Truckee station and are inversely proportional to elevation. The climate data are organized into two files: monthly.dat and prep.inp. The monthly.dat file contains the data of monthly averaged dew point (deg C), sky cover (%) and wind speed (m/sec). The prep.inp file contains daily precipitation, maximum and minimum temperature and solar radiation. The daily precipitation is the rainfall plus the water equivalent from snow melting. The radiation energy is calculated according to Stefan's Law:

$$R_a = sT^4 \qquad (8)$$

where R_a is the total radiation, s is Stefan's constant, and T is temperature $\left[0.813\times10^{-10}\ langley/(\min - K^{-4})\right]$.

The expression for hourly short-wave radiation snowmelt can be calculated as

$$M = \frac{H_m}{203.2Q_t} \qquad (9)$$

where H_m is the net absorbed radiation (langleys) and Q_t is the thermal quality of the snowpack.

3.3.2.2.3 Input Data Preparation: Soil Data

There are 17 soil groups according to the STATSGO database, and each soil group consists of 3 layers. The depth, bulk density and particle size distribution varies in different layers. However, the specific gravity, K factor, and reconsolidation half-life is the same for a single soil group.

STATSGO is a geo-referenced soil database developed for many uses. For this study, the following parameters were of primary importance: Soil ID, sequence number, erodibility factors, soil texture, rock percentage, bulk density, alkalinity, depth to impervious layer (bedrock), and hydrologic soil group. All of these parameters are found in STATSGO. However, the soil ID (called map unit ID or MUID in the database) is the smallest unit that is geo-referenced. Each MUID actually consists of five to 20 similar soils (or sequences), each with its own set of characteristics. Unfortunately, these individual sequences are not geo-referenced; that is, there is no way to identify the exact location of a sequence number within an MUID. Therefore, to develop one set of parameters for the smallest geo-referenced data set (at the MUID level), the characteristics of the soil sequences were averaged and assigned to the MUID.

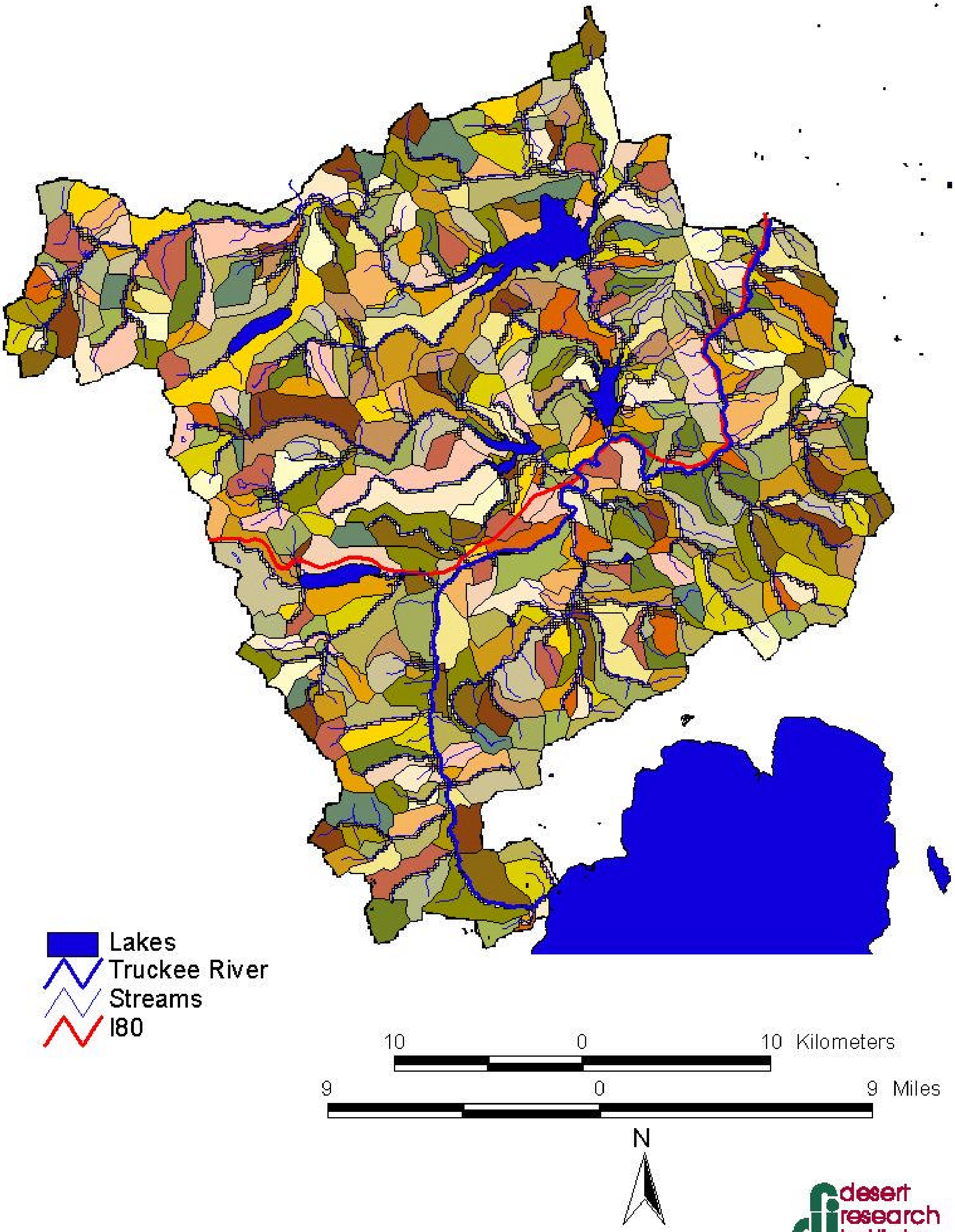


Figure 13. Sub-basins used in AnnAGNPS.

Also, the characteristics were averaged vertically and assigned to consistent layers. The layers used in the AnnAGNPS model are: layer 1, 0 to 12 inches; layer 2, 12 to 24 inches; and layer 3, 24 to 48 inches. Table 6 summarizes the input parameters for each soil.

Table 6. STATSGO soil parameters.

Soil ID	layer	soil erodibility factor (with rocks)	soil erodibility factor (without rocks)	sand + very fine sand (%)	silt (%)	clay (%)	rock fragments, 3 to 10 inches (%)	bulk density (g/cc)	caco3 (%)	depth to bedrock (inches)	hydrologic soil group
NV008	1	0.19	0.35	36.67	17.46	17.87	10.67	1.26	0	60	B
NV008	2	0.18	0.35	29.75	8.18	23.99	16.33	1.33	0	60	B
NV008	3	0.33	0.6	59.67	12.91	43.09	33	2.7	0	120	D
NV014	1	0.18	0.36	27.59	20.65	19.68	24.92	0.91	0	35.31	C
NV014	2	0.14	0.3	20.17	11.68	25.32	19.83	0.86	0	34.63	B
NV014	3	0.15	0.29	31.33	12.69	23.48	50.75	1.2	0	57.52	C
NV015	1	0.17	0.3	33.25	12.65	15.77	14.83	0.3	0	49.35	C
NV015	2	0.21	0.32	23.92	8.38	20.12	8.08	0.3	0	49.3	B
NV015	3	0.33	0.52	28.33	8.7	52.72	17	0.44	0	92.57	D
NV016	1	0.15	0.3	28.25	20.84	9.91	18.17	1	0	41.1	C
NV016	2	0.13	0.29	20.83	11.38	13.29	17.92	0.94	0	39.35	B
NV016	3	0.31	0.52	33	18.16	27.67	45.5	1.81	0	74.8	D
CA028	1	0.14	0.2	51.33	13.18	8.49	8.83	0.69	0.12	39.73	B
CA028	2	0.12	0.17	40.08	10.26	8.99	10.5	0.55	0.2	38.35	A
CA028	3	0.2	0.27	65.75	15.28	13.39	17.75	0.58	0.17	69.17	B
CA414	1	0.1	0.17	37.08	10.87	5.88	31.83	0.73	0	58.2	B
CA414	2	0.08	0.16	37.25	9.42	6.33	40.75	0.75	0	58.2	B
CA414	3	0.16	0.26	63.67	16.13	11.7	91.33	1.53	0	114	D
CA415	1	0.17	0.3	33.25	12.65	15.77	14.83	0.3	0	49.35	C
CA415	2	0.21	0.32	23.92	8.38	20.12	8.08	0.3	0	49.3	B
CA415	3	0.33	0.52	28.33	8.7	52.72	17	0.44	0	92.57	D
CA416	1	0.15	0.21	32.16	21.87	7.55	15.75	0.9	0	25.64	C
CA416	2	0.09	0.12	16.42	6.45	9.13	15.5	0.78	0	22.46	B
CA416	3	0.1	0.12	19.75	7.79	11.88	25	0.98	0	31.2	B
CA417	1	0.13	0.18	53.92	14.72	8.03	3.42	1.22	0	60	C
CA417	2	0.13	0.19	51.41	12.9	10.02	4.67	1.26	0	60	C
CA417	3	0.28	0.37	100.34	20.49	22.34	9.42	2.67	0	120	D
CA853	1	0.16	0.21	32.67	14.91	11.67	14.17	0.82	0	33.3	B
CA853	2	0.13	0.2	24.42	7.49	11.59	20.17	0.85	0	32.92	B
CA853	3	0.13	0.23	30	8.86	13.81	35.83	1.36	0	49.08	C
CA854	1	0.2	0.26	35.83	23.48	14.44	3	0.74	0	57.3	B
CA854	2	0.16	0.3	22.83	13.67	22.5	11.42	0.7	0	57.3	B
CA854	3	0.24	0.52	36.16	8.86	39.06	28.83	1.51	0	113.05	D
CA856	1	0.19	0.35	36.67	17.46	17.87	10.67	1.26	0	60	B
CA856	2	0.18	0.35	30.08	7.38	23.12	17.67	1.38	0	60	B
CA856	3	0.33	0.6	61.25	9.11	38.97	39.58	2.94	0	120	D
CA858	1	0.18	0.36	27.59	20.65	19.68	24.92	0.91	0	35.31	C
CA858	2	0.14	0.3	20.17	11.68	25.32	19.83	0.86	0	34.63	B
CA858	3	0.15	0.29	31.75	11.4	21.93	53.75	1.29	0	57.52	C
CA860	1	0.1	0.15	34.83	16.84	9.16	31.17	1.28	0	48	C
CA860	2	0.11	0.15	33.33	16.84	9.16	32.67	1.31	0	48	C
CA860	3	0.19	0.25	60	27.7	17.47	59.17	2.75	0	96	D
CA864	1	0.15	0.22	28.59	12.79	14.04	17.58	0.9	0	48.35	B
CA864	2	0.18	0.25	24.25	10.21	16.79	17.5	0.93	0	48.34	B
CA864	3	0.35	0.49	34.92	16.08	35.75	34.17	1.72	0	88.92	C
CA866	1	0.19	0.27	29.09	20.57	16.26	12.67	0.71	0	30.98	B
CA866	2	0.2	0.3	23	17.57	20.01	12.92	0.67	0	30.5	B
CA866	3	0.22	0.34	29.83	19.47	21.78	25.33	1.04	0	44.65	C
NOTE:											
	layer 1 is from depth=0 to 12 inches										
	layer 2 is from depth=12 to 24 inches										
	layer 3 is from depth=24 to 48 inches										

The soil erodibility factor, with and without rocks, is a dimensionless measure of the erodibility of the top layer (layer 1) and is used directly in the RUSLE. The soil textures (sand and very fine sand, silt, and clay) are based on the USDA soil texture classification system. The hydrologic soil group (HSG) is a classification of the runoff potential of a soil. Four values are possible, ranging from high infiltration capacity/low runoff (HSG A) to low infiltration capacity/high runoff (HSG D).

3.3.2.2.4 Input Data Preparation: Road Density

The density of dirt roads affects the conservation factor (C) used in the RUSLE and is calculated by the data provided by USGS and the U.S. Forest Service (USFS). The USGS provided a digital line graph (DLG) of all roads on the Nevada side of the basin. This information was compared with the most recent aerial photos available and it was determined that nearly all the roads in this area were dirt. The USFS provided dirt road data for the California portion of the basin. Unfortunately, the data were many years old and required updating. The coverage was compared to the most recent aerial photos and updated. Significant updating occurred in the Glenshire and Donner Lake areas.

The effect of road density is reflected in the C factor in the universal soil erosion equation. Dirt roads are assigned a C factor of zero, representing bare land. The percentage of land cover and the cover type are also factors that affect C and the runoff curve number and, thus, runoff and sediment yield. Since the concepts of practice and conservation factors were originally developed for different land cover types on agricultural lands, the practice factor is calculated as follows,

$$C = \frac{r_{road} B}{A} \qquad (10)$$

where r_{road} is the density of dirt road (miles/acre), B=20 ft is the average width of a dirt road, and A is the drainage basin area. C varies from 0.1 to 0.5 in this study area, which is consistent with the C factor that has been used in forested watersheds in North Carolina (Sun and McNulty, 1999). Figure 14 shows the dirt road network used in the model.

3.3.2.2.5 Input Data: Road Sand

Road sand is a management practice designed to improve automobile traction on snow- and ice-covered roads. When traffic grinds this sand into smaller particles it can become suspended in urban runoff, transported off-site, and deposited in streams. Sand is applied to the more heavily-used roads in the Truckee watershed, such as Interstate 80, Highway 89 North and South, Highway 267, Northstar at Tahoe, Squaw Valley, Alpine Meadows, and in the Town of Truckee. Though much of the applied sand is collected at the end of the winter, the fate and transport of road sand during the sanding season is still uncertain. Few data exist on the quantity of road sand collected. However, application rates are well documented.

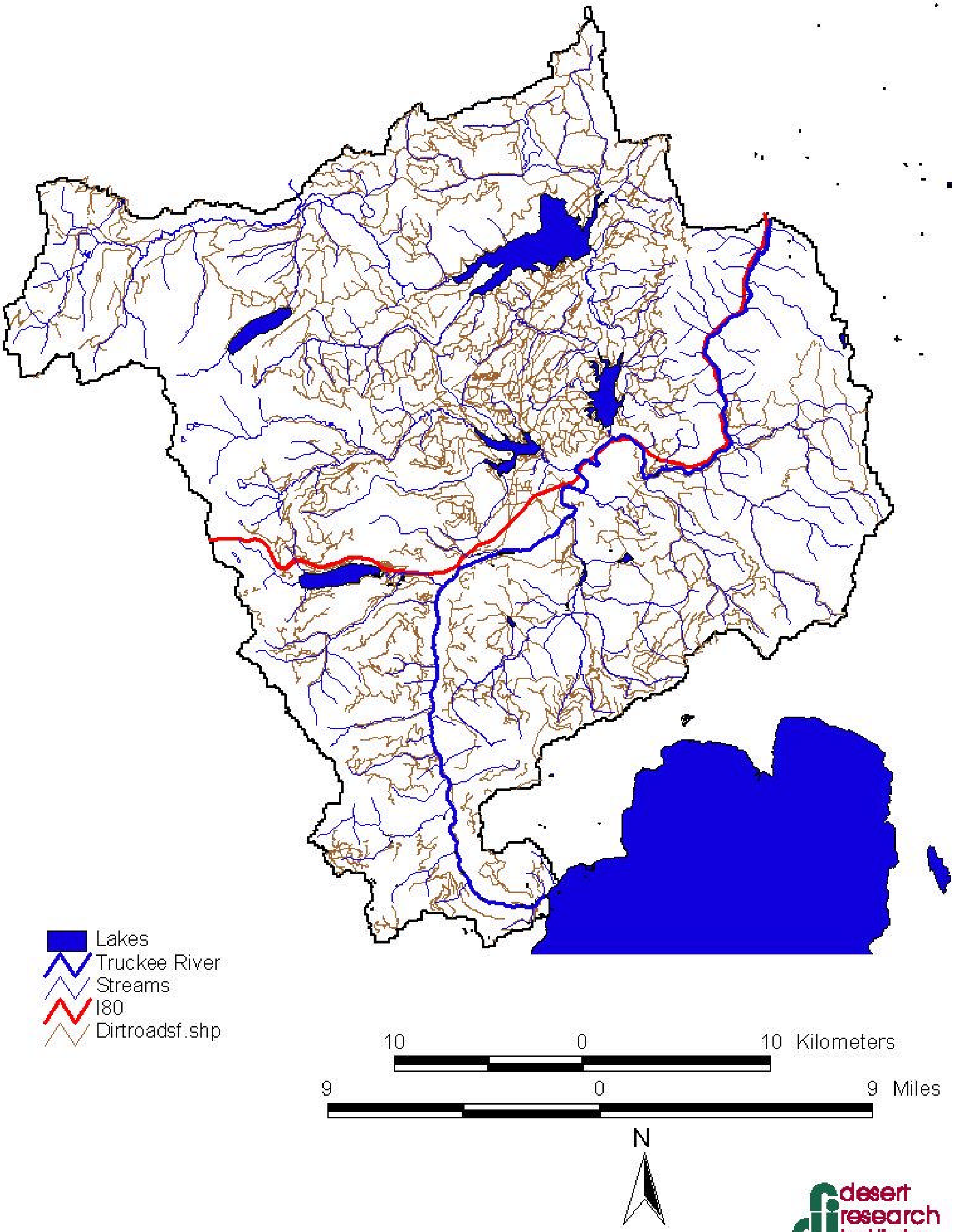


Figure 14. Dirt road network in study area.

Road sand was added to the model; however, several assumptions were required. Conversations with LRWQCB staff (Erlich, 2001) revealed that, in the past five years in the Lake Tahoe basin, the California Department of Transportation (CalTrans) recovered between 27% and 61% of the applied sand. Similar cleanup rates were assumed for the Truckee River Basin. For this study, it was assumed that 50% of the applied sand was recovered. Of the 50% remaining, it was assumed that 50% remained as sand, 30% was ground to a fine sand, and 20% was ground to a silt or clay. These fractions were then added to the model as line sources for the reaches described below.

The quantities used in the model were acquired from Nevada County, Placer County, and CalTrans and are the average of the 93-94 and 94-95 seasons. Table 7 shows the average mass of sand applied to the roads.

Table 7. Mass of sand applied to roads.

			Tons of Sand		
Route #	Route Description	Roadway miles	93-94	94-95	2-year avg.
267	Town of Truckee to Nevada/Placer County Line	2.8	651	848	750
267	Brockway summit to Nevada/Placer County Line	6.6	1096	1353	1224
89	Town of Truckee to Nevada/Sierra County Line	8.7	1016	1463	1240
89	Tahoe City to Squaw Valley	3.5	942	1366	1154
89	Squaw Valley to W. River St., Truckee	8.0	1719	2122	1920
I-80	Donner Summit to Donner Lake	3.4	11538	10413	10976
I-80	Donner Lake to Nevada State Line	22.6	20680	24285	22482
	Alpine Meadows Road	8.0	n/a	960	960
	Squaw Valley Road	7.0	n/a	700	700
	Cabin Creek Road	2.0	n/a	440	440
	Northstar at Tahoe		n/a	1500	1500
	Town of Truckee		n/a	6800	6800
	Nevada County		n/a	673	673

3.3.2.2.6 Flow Model: Rainfall-Runoff

In AnnAGNPS, runoff is derived using the standard SCS (Soil Conservation Service) TR55 method (USDA, 1986). The 24-hr rainfall intensity, daily precipitation, daily maximum and minimum temperature, monthly dew point temperature, monthly sky cover, and monthly wind speed are input parameters. In this model, both the peak runoff and a runoff hydrograph are predicted by the graphical peak discharge method and the tabular hydrograph method. The tabular hydrograph method uses prerouted hydrographs from specified sub-basins to produce the estimated runoff hydrograph. Flow paths are composed of overland sheet flow, shallow concentrated flow, in-cell concentrated flow and stream flow.

The runoff model calculates the concentration time t_c that is used to calculate the time-to-peak t_p in TR55 (USDA, 1986):

$$t_c = t_i + t_t \qquad (11)$$

$$t_i = 1.8(1.1 - K)L_0^{\frac{1}{2}} / S^{\frac{1}{3}} \qquad (12)$$

where t_i is the initial or overland flow time; K is the resistance coefficient, which is expressed as $K = 0.0132CN - 0.39$; CN is the curve number; L_0 is the length of overland flow; S is the averaged basin slope; and t_t is the travel time in the channel and is computed as

$$t_t = L / V \qquad (13)$$

where L is the longest travel length and V is the travel velocity that is determined empirically. The CN is used to compute excess precipitation, which depends on soil type and land cover.

The study area includes 11 different land and canopy cover types. An exhaustive literature search revealed no CNs specific to the species in the forest. Therefore, several assumptions were necessary. The CN of "Woods-grass Combination (orchard or tree farm)" in Table 2-2c of USDA (1986) was used in this study for Lodgepole Forest, White Fir and Ponderosa, and Red Fir. The CNs for meadows are found in Table 2-2d of USDA (1986). Woody shrubs are regarded as bare land without mature trees and dense understory. The CN for "Brush-brush-weed-grass Mixture" with brush as the major element in USDA (1986) was employed. The CNs for "bare soils and clear-cut areas" are obtained from Table 2-2b of USDA (1986). Since the Truckee River Basin is in the semi-arid land area, the CNs of "desert shrub" are used for the plantation type of land cover. The urban area in the town of Truckee consists of both the commercial district and the residential area. Therefore, the CNs for "Western Desert Urban Area," which takes into account both residential and commercial districts, were employed. The miscellaneous hardwood is assumed to consist of saltbush, greasewood, creosorte bush, blackbrush, *etc.*, therefore, "Desert Shrub" in Table 2.2b of USDA (1986) was used for this type of land cover.

The 11 sets of CN employed for the upper Truckee River Basin are shown in Table 8.

The peak discharge is calculated as

$$q_p = q_u A Q F_p \qquad (14)$$

where q_u is the unit peak discharge; A is the drainage area; Q is runoff depth; and F_p is the pond and swamp adjustment.

AnnAGNPS provides a set of unit hydrographs for the region that are empirically derived from an extensive database of values. The unit hydrograph is selected based on location of the centroid of the basin.

The final hydrograph was determined by the following equation:

$$\mathrm{Q} = \frac{P - 0.2(\frac{1000}{CN} - 10)^2}{P + 0.8(\frac{1000}{CN} - 10)} \qquad (15)$$

Table 8. Curve numbers for various land and canopy covers.

	Name	Percentage	Hydrologic Soil Groups A	B	C	D
1	Lodgepole, Forest	50%	57	73	82	86
	(woods-grass)	50% ~ 70%	43	65	76	82
		>70%	32	58	72	79
2	White Fir, Ponderosa	50%	57	73	82	86
	(woods-grass)	50% ~ 70%	43	65	76	82
		>70%	32	58	72	79
3	Red Fir	50%	57	73	82	86
	White Pine	50% ~ 70%	43	65	76	82
	Forest (woods-grass)	>70%	32	58	72	79
4	Meadows		30	58	71	78
5	Woody Shrubs	50%	48	67	77	83
	(brush-weed-grass)	50% ~ 70%	35	56	70	77
		>70%	30	48	65	73
6	Barren & Rock-bare soil		77	86	91	94
7	Water Bodies		100	100	100	100
8	Plantations (desert shrub)	50%	63	77	85	88
		50% ~ 70%	55	72	81	86
		>70%	49	68	79	84
9	Bare ground and Clear cuts areas		77	86	91	94
10	Urban developed (western desert landscaping)		63	77	85	88
11	Micellaneous hardwoods	50%	45	66	77	83
	(woods)	50% ~ 70%	36	60	73	79
		>70%	30	55	70	77

The 24-hour peak discharge is determined as follows:

Step 1: P_{24} is the spatially averaged total 24-hr rainfall amount plus the water equivalent snowmelt,

Step 2: Q_{24} is the spatially averaged runoff volume for the 24-hr event covering the drainage area to the cell outlet.

$$\mathrm{Q}_{24} = \frac{[\mathrm{P}_{24} - 0.2(\frac{1000}{\mathrm{CN}} - 10)]^2}{P_{24} + 0.8(\frac{1000}{CN} - 10)} \quad (16)$$

Step 3: Calculate I_a. $\frac{I_a}{P_{24}} = \left[(P_{24} + 2Q_{24}) - (5Q_{24}P_{24} + 4Q_{24}{}^2)^{0.5}\right] / P_{24}$. (17)

Step 4: Find 24-hr unit peak discharge by,

$$Q_{p24} = 2.78 \cdot 10^{-3} P_{24} A \left[\frac{a + ct_c + et_c^2}{1 + bt_c + dt_c^2 + ft_c^3} \right] \quad (18)$$

in which a, b, c, d, e, f are regression coefficients.

Step 5: Calculate discharge.

Flow paths are composed of overland sheet flow, shallow concentrated flow, in-cell concentrated flow and stream flow. Hydraulic parameters include flow velocity, depth, channel widths and roughness of the formed flow paths (estimated empirically). For example, assuming a rectangular channel, depth and velocity are computed as follows:

$$d_t(Q_t, W, n, S_0) = \left(\frac{nQ_t}{W\sqrt{S_0}}\right)^{\frac{3}{5}} \qquad V(Q_t, d_t, z, W) = \frac{Q_t}{Wd_t} \qquad (19)$$

The average roughness varies for each cell and reach; typical values are 0.15 for overland flow and 0.04 for the channel. For channels with a large longitudinal slope, channel width can be expressed as follows:

$$\text{width} = aD_a{}^b \qquad (20)$$

where $a = 0.25$ and $b = 0.39$. The coefficients were obtained from data collected at the Upper Salmon River, Idaho. AnnAGNPS provides a limited number of reference watersheds from which to choose the coefficients. From the available reference watersheds, it was determined that the steep, forested, Upper Salmon River was the most comparable to the Truckee River watershed.

3.3.2.2.7 Sediment Transport Model: Sheet and Rill Erosion

The three primary categories of erosion are: sheet and rill erosion, stream bank erosion and stream bed erosion. Sheet and rill erosion is calculated by the RUSLE (Theurer, 1991).

$$S_y = \{aQ^b * (q_b)^c * (D_a)^d * KLSCP\} + \{e * Q^f * (q_p{}^g) * (D_a{}^h) * C_f KLS\} \qquad (21)$$

where s_y is sediment yield; Q is surface runoff volume; q_p and q_b are peak and base rate of surface runoff; D_a is the total drainage area; and K, L, S, C, P are soil erodibility, slope length, surface slope, cover-management factor and supporting practices factors, respectively. The soil erodibility is determined by the soil type and particle size composition. In this model, the K factor is determined based on the STATSGO database, using the value of soil erodibility factor with rocks. Drainage area, flow discharge, slope, and overland flow length are calculated by the TOPAZ model. The operation C factor is determined by the dirt road density. The operation factor C equals 1 for an undisturbed watershed. It is assumed that no supporting practice exists in this basin and thus the P factor also equals 1. S_y strongly depends on soil composition, land conservation practice, and runoff.

3.3.2.2.8 Sediment Transport Model: Gully and Stream Erosion

When overland flow converges into channel flow, erosion will occur at the channel bed and banks. Sediment load in the stream is calculated as

$$q_s = c_s q_w = \frac{S}{W} q_w \qquad (22)$$

where q_s is the sediment transport rate, c_s is the concentration of sediment; S is the slope of the channel; W is the width of the channel; and q_w is flow discharge. Flow depth and velocity are estimated as follows:

$$d_w = A/W,\ V_w = (\frac{1}{n})d_w^{\frac{2}{3}}S_0^{\frac{1}{2}} \quad (23)$$

where A is the cross-sectional area and n is Manning’s coefficient. The sediment transport capacity is calculated as follows,

$$h = 0.322[(g_p - g_w)/(t / D_p)]^{1.626} \qquad q_{sc} = hktV_w^2 / V_f \qquad (24)$$

If $q_s > q_{sc}$, sediment will deposit on the bed. Otherwise, erosion occurs.

3.3.2.3 Model Calibration

A critical step in developing a model is calibration. A calibrated model is one that, for a given set of parameters, can reproduce historic data. The process involves adjusting parameters within acceptable bounds, running the model, and comparing model output to observed data. A calibrated model will adequately reproduce observed values.

The model was calibrated to the 1996 calendar year. 1996 represented an extreme year with 210% of average precipitation recorded at the Tahoe City gage. An extreme year was chosen to ensure that all areas received stresses above their sediment-producing threshold. For example, a low-sloped area may need an above-average rainfall intensity to generate significant sediment. If that threshold is not reached and the calibrated model (accurately) predicts no sediment, then no sediment would also be predicted under twice as much rain.

As an example, fictitious Area 5 may have a sediment-producing threshold of 3 inches per hour rainfall (though that value may not be known). If a model is calibrated with a maximum intensity of 1 inch per hour, that area will not produce sediment at 1 inch per hour. In addition, assuming a linear response between stressor (rain intensity) and result (sediment), “x” times the stressor will predict “x” times the response; or, 4 inches per hour will predict 4 times the response, or zero. However, if a model is calibrated using a stressor above the threshold, the linearity assumption will still hold at those high stresses and, it is the *high* sediment responses that are negatively impacting the beneficial uses. The extreme year 1996 was chosen to minimize the probability that the threshold was not yet reached during calibration.

Model simulation starts with model calibration using 1996 data. The calibrated model is then verified by 1997 data. Parameters used in calibration are cell surface roughness, the soil erodibility factor, and the coefficient for rill and interrill erosion. The verified model was then used to predict sediment reduction under various land management scenarios.

Table 9 and Figure15, below, show the comparison between historic predictions (with prediction interval) and model predictions.

Table 9. Model calibration results (1996 load calculations).

	Historic Data			
Site	Predicted Sediment Load (tons)	Lower Prediction Limit (tons)	Upper Prediction Limit (tons)	AnnAGNPS Model (tons)
Donner Ck	2481	313	20034	2342
Gray Ck	1418	548	3759	1403
Squaw Ck	1402	273	7219	1602
Prosser Ck	1228	214	7786	2104
Martis Ck	513	182	1453	1151
Bear Ck	511	35	7842	107
Bronco Ck	206	59	826	945
Juniper Ck	195	44	888	264
Trout Ck	123	6	2645	41

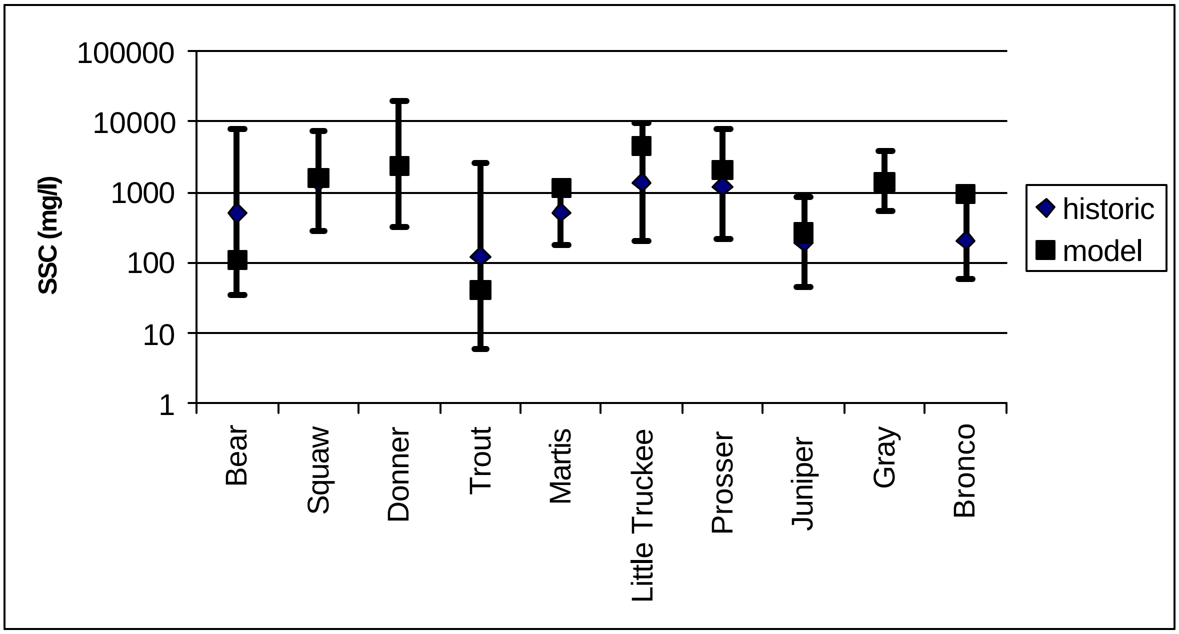


Figure 15. Predicted sediment load to the Truckee River--historic and model, 1996.

3.3.2.4 Model Validation

The next step in model development is validation. Validation is the process of using the calibrated model to estimate sediment load under a different set of stresses. The model itself is the same as that used for calibration but the precipitation and temperature (stresses) are different. The difference between calibration and validation is that the parameters are held constant in validation.

The model was validated to the average year of 1997. Though 1997 saw the extreme New Year’s Day flood, total precipitation for the year was 100% of the average. 1997 was also chosen because of the availability of a large dataset. Unfortunately, the New Year’s Day flood was so extreme that it caused landslides into the Truckee and most tributaries. Landslides were not modeled and are therefore not included in the predictions. It is also important to note that "landslide sediment" was not used to develop the rating curves, which were, in turn, used to develop the load predictions. To oversimplify, the rating curves were developed as a relation between flow and "in-stream sediment as a result of precipitation." There were no sediment samples taken during the flood event; therefore, the rating curves were not used to predict in-stream suspended sediment resulting from landslides. Table 10 and Figure 16 show the model validation results.

Table 10. Validation of model, 1997 load calculations.

	Historic Data			
Site	Predicted Sediment Load (tons)	Lower Prediction Limit (tons)	Upper Prediction Limit (tons)	AnnAGNPS Model (tons)
Gray Ck	6567	1660	27121	1011
Squaw Ck	3640	680	19498	892
Donner Ck	3001	387	23660	1678
Little Truckee R	1535	230	10296	3081
Prosser Ck	1467	301	8373	1592
Bear Ck	884	61	13015	59
Martis Ck	498	174	1435	635
Bronco Ck	448	130	1643	579
Juniper Ck	360	82	1614	147
Trout Ck	149	7	3065	58

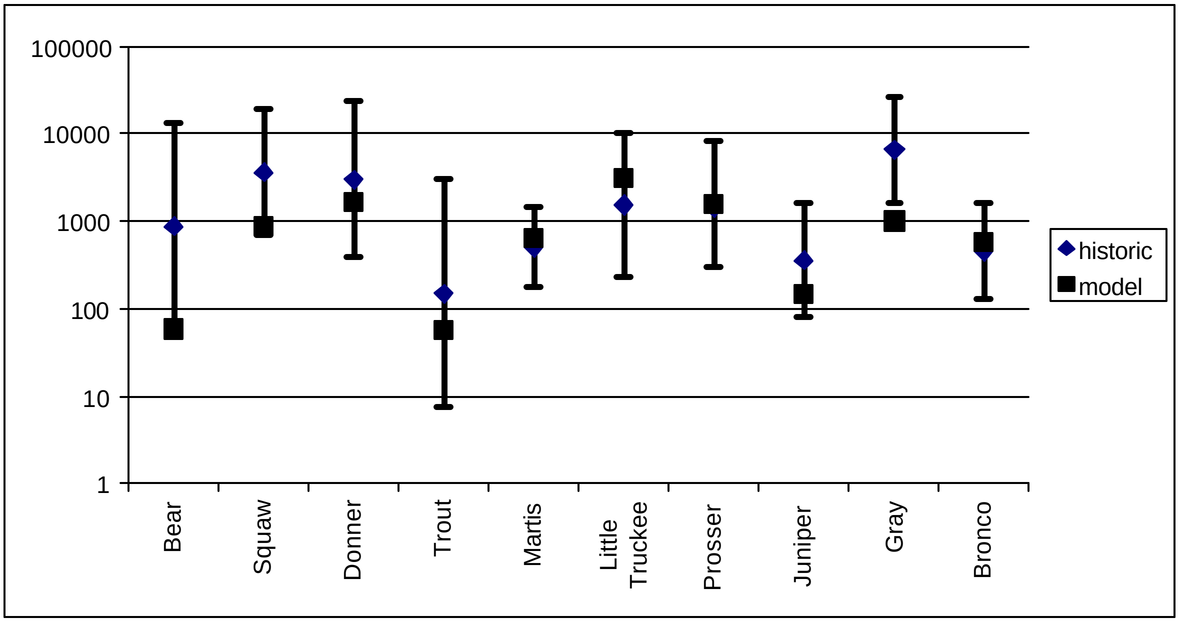


Figure 16. Predicted sediment load to Truckee River--historic and model, 1997.

3.3.3 Summary of Assessment by Watershed Model

The watershed model is one of the three methods used for source assessment in this study. The main strength of a watershed model is its ability to predict loads where no data exist. Historic and new data were used to develop correlations between abundant data (e.g., flow) and rare data (e.g., SSC). These correlations were then used to characterize the sediment load from major basins in the watershed. Then, the watershed model was used to predict sediment loads in more detail than is possible using historic or recent data. Acceptable model performance is illustrated through calibration and validation.

3.3.4 Aerial Photography Analysis

An aerial photo analysis was performed to complement the previous two watershed assessment methods. While the assessment by historic and recent data and assessment by watershed model approaches yielded an estimate of sediment production, the aerial photo analysis will not. Instead, it will produce an 'erosion vulnerability,' or sensitivity of certain areas to future disturbance. EPA protocols place aerial photo analysis in the Index category of source assessment. Indices do not provide load estimates but do provide a guide for the TMDL. The theory underlying this approach is that it is more efficient to target future erosion sources for remedial action than to evaluate past erosion locations, which are probably not amenable to productive treatment (USEPA, 1999a).

3.3.4.1 Purpose

The principal purpose of the aerial photo analysis was to identify sediment sources, assess the distribution of sediment sources, and infer the sensitivity of differing surficial geologic materials to surface disturbance. The goals were to:

- Perform a reconnaissance level geomorphic and Quaternary geologic assessment of the watershed to estimate natural variability in surficial geologic units.
- Identify obvious active sources of sediment and key soil and landscape variables controlling sediment availability.
- At a reconnaissance level, interpret satellite imagery and delineate areas of sensitive landscapes that may be deemed as potential sediment sources.
- Delineate portions of the landscape that may be susceptible to erosion either naturally or enhanced and/or accelerated by activities that may disturb the land surface.

Spatial differences in geomorphic processes, geologic materials, and weathering result in differing ages of a land surface throughout a watershed. Spatial differences in landscape age can be distinguished by the relative degree of soil development, in particular development of increasingly thicker, clay-rich B horizons with increasing soil age and an accompanying decrease in permeability of subsurface soil horizons. Thus, the heterogeneous nature in surficial deposit properties can have pronounced effects on surface runoff and erodibility of surficial units.

Because a desired function of the watershed model is the ability to accurately estimate runoff and sediment derived from landscape units, it is helpful to characterize the geologic deposits at or near the surface. In general, watershed models assume homogeneous hydrologic conditions throughout watersheds, although more advanced models are able to accommodate spatial differences in variables such as vegetation, topography, slope, and soil cover.

However, as a landscape evolves, the progressive change in properties of surficial units contributes to the surface hydrology characteristics of a watershed. These changes in variables can influence rates and magnitudes of sediment production within the watershed as well as the distribution of ages of landscape units, soil development, and soil-geomorphic relationships. To help account for the spatial differences in characteristics of surficial geologic materials and sediment production in the watershed, it is beneficial to identify and map the various surficial geologic units.

3.3.4.2 Methods and Techniques

A variety of common geomorphic techniques were used to assess landscape condition. This included relative soil development as it relates to landscape stability and sensitivity to erosion, geomorphic processes operating in the landscape and the general evolution of the landscape.

The study was structured to be a reconnaissance-level investigation at a regional scale. The reconnaissance approach was deemed appropriate for the level of detail sought by the watershed model.

The study emphasized aerial photographic interpretation in combination with limited field checking in selected sub-basins. Interpretation of aerial photography also took into consideration published soil information available through the USFS and Soil Conservation Service surveys (Soil Conservation Service, 1974, 1983, 1994) and existing regional geologic information (Birkeland, 1961; Burnett and Jennings, 1962; Harwood, 1981; Saucedo and Wagner, 1992). Critical to the assessment is knowledge of landscape evolution and geomorphic processes that helps to distinguish between short-term (decade to century) and longer-term (hundreds to thousands of years) geomorphic processes and responses of the natural system.

Important note on scale: The coarseness in scale of available geologic maps (1:250,000) and incomplete map coverage at scales larger than approximately 1:62,500 precludes extracting reliable information for use at very large scales (e.g., 1:500 to 1:15,000). Additionally, the scale of aerial photographs and resolution of imagery for mapping purposes, even when combined with limited spot checks, imposes a limit on the practical utility of these mapping products. The scale of the project is such that products (e.g., identification of potentially sensitive landscape areas) are not intended as definitive works for enforcing or dictating policy. Rather, the regional scale identifications are best used as a general guide to areas that may be sensitive to disturbance. At the regional scale of mapping, the uncertainty in identification of mapping units makes it impractical to assign an estimate of error for either contacts or extent of areas mapped without additional detailed field investigations. The thickness of contact lines may be larger than the finest resolution (15 m) on the DEM. On maps, the width of contact lines could represent tens of meters.

3.3.4.2.1 Aerial Photography

Current and historical aerial photography was acquired for much of the watershed. The aerial photography was acquired through the USFS in Truckee and Nevada City, California. Scales of aerial photography range from approximately 1:15,000 to 1:30,000. Given the immensity of the Truckee River watershed and limited resources, it was not feasible to photomap the entire watershed.

Identifying sediment sources from satellite imagery and aerial photography was accomplished using standard techniques for interpreting photography and imagery (e.g., Ray, 1960; Siegal and Gillespie, 1980; Foster and Beaumont, 1992). Areas of sediment production typically have diagnostic photographic characteristics, for example, tonal quality, which can indicate areas of recent erosion and/or deposition. Tonal quality also aids in distinguishing the types and extents of surficial deposits, which help in developing a relative chronology for surficial geologic units.

3.3.4.2.2 Surficial Geologic Units

Mapping of surficial geologic units is an important part of the geomorphic analysis and helps to account for spatial variability in watershed characteristics. Familiarity with geomorphic process and response concepts and the morphology of landscapes and streams helps in landform identification and the processes associated with erosion, sediment transport and deposition.

Although beyond the scope of the project, extracting the long-term sediment storage and movement within a watershed from surficial geologic deposits and their ages is a very important component of future detailed studies. With this information, important questions concerning sediment transport and storage can be addressed. For example, is sediment from hillslopes flushed from the tributary basins or is sediment stored in valleys? Knowing the age of different landscape elements can provide clues to other important questions such as: How did the watershed and sub-basins respond to historic logging? Have the fluvial systems adjusted to changes brought about by logging, or do they continue to respond to disturbance?

3.3.4.2.3 Identification and Characterization of Landscape Units

The mapping of landscape units was based on geomorphic and geologic criteria that take into consideration hydrologic properties of units, sedimentology, and geomorphic processes. A geomorphic approach provided logical and convenient units for mapping and assessment of their distribution. Delineation of geomorphic units (e.g., hillslopes, fluvial terraces, alluvial and debris fans, etc.) included limited field observation of selected Quaternary geologic characteristics, such as landscape elements (slopes, fluvial terraces), depositional units, and the relative degrees of soil development.

Quaternary geologic units were distinguished and mapped from aerial photographs and satellite imagery and focused on three principal areas as test cases: Martis Creek and lower portions of Gray and Bronco creeks. Careful mapping of surficial geologic units based on texture, tonal quality, and stratigraphic and cross-cutting relationships resulted in a reconnaissance-level surficial geologic map. Units identified in this manner were assigned relative ages.

The mapping was useful for determining that detailed, ground-level studies of soil-geomorphology and landscape history are warranted for the development of more realistic watershed sediment models. This conclusion derived in part from assessing the general distribution of the different types and ages of landscape units.

Typical mapping units included bedrock exposures (R), landslides (Qls), hillslope (Qc), fluvial (Qal), and glacial (Qg) deposits. A simple classification scheme for landscape units, sediment production, and relative sensitivity to disturbance was then developed (Table 11). For example, hillslopes can be identified and characterized according to slope angle and process type (e.g., transport limited or weathering limited), which can provide an estimate of stability and sediment production. An important consideration is surface disturbance, which can readily and significantly alter dominant geomorphic processes, surface hydrology, and sediment yield.

3.3.4.2.4 Predicting Sensitivity and Potential Sediment Sources

Sensitivity of the landscape is related to its history and conditions antecedent to natural and/or anthropogenic disturbances. The sediment that is derived from any particular source region will be a function of the surficial geology, climate, vegetation, position in the landscape, weathering characteristics and geomorphic processes. Predicting points of sediment input to streams can be derived to a certain degree from the surficial geologic mapping and by assessing the geomorphology and geomorphic processes.

3.3.4.2.5 Relationships Between Runoff and Surficial Geology

Because runoff and sediment yield are functions of rainfall intensity and infiltration capacity of surficial deposits, the characteristics of underlying soils and bedrock are important. Studies have shown that the texture of soils plays a role in infiltration and runoff characteristics (Meyer, 1986). Therefore, the nature of Quaternary surficial deposits should have an influence on infiltration and runoff. For example, coarse-grained unconsolidated slope deposits and young landscape units (e.g., fluvial terraces) will typically be permeable in contrast to certain types of clay-rich glacial deposits, finer-grained deposits on lower slopes, and older landscape units. Thus, it is important not only to determine the distribution of landscape units, but also to determine the nature of deposits and relative ages of the units.

Predicting potential sediment sources and yield can also be made based on slope angle and aspect (e.g., Abrahams and Parsons, 1991). High slope angle does not always correspond to high runoff and sediment yield because of surface roughness that can be associated with very steep slopes (e.g., Yair and Klein, 1973). Underlying bedrock units also play a role in terms of infiltration characteristics and erodibility. Well known morphometric relationships among watershed geomorphology parameters exist, such as those between basin area, basin relief, relief ratio and sediment yield (Hadley and Schumm, 1961; Schumm, 1963) (Figures 17 and 18), and can be used as a first estimate of sediment yield. From these relationships, potential sensitivity or susceptibility to surface disturbance can be inferred.

3.3.4.2.6 Importance of Soil Geomorphology in Understanding Landscape Processes

It is generally accepted that a relationship exists between the relative ages of landscape units and the relative degree of soil development (e.g., thickness, relative clay content of the B horizon; Figure 19). Investigations of soils have demonstrated that soil age (hence, degree of development) plays a role in the infiltration characteristics of surficial geologic units, hillslope processes, and drainage network evolution (e.g., Wells et al., 1983; Wells et al., 1985; Wells and Dohrenwend, 1985; Dohrenwend et al., 1987; Birkeland, 1990, 1999; Tonkin and Basher, 1990; McDonald 1994). Thus, the age of soils developed on the landscape can be expected to have a bearing on runoff characteristics. Figure 19 is a composite graph illustrating conceptual relationships between infiltration, soil development, and runoff.

Table 11. Landscape classification.

Landscape Element	Typical surficial materials	Soil Charcteristics	Type of Sediment Produced	Typical Relative Stability	Dominant Processes	Relative Sensitivity to Disturbance
Steep Hillslopes (barren)	Coarse debris	Little to none	Primarily coarse-grained, but abundant fines trapped in coarse debris	Stable	Slow and rapid mass wasting, creep	Moderate - if disturbed, large quantities of fines can be released; surface infiltration properties may change
Steep Hillslopes (covered)	Thin mantle of soil	Thin, weakly developed	Fine silts and clay	Stable	Slow and rapid mass wasting, creep, debris flows	High - if mantle disturbed, large quantities of fines can be released
Moderate Hillslopes	Thin to moderately thick soils, colluvium	Thin to moderately thick; variable degree of development	Fine silts and clay	Stable	Slow mass wasting, creep, debris flow	Moderate to high - if surface mantle is disturbed, large quantities of fine sediment may be released
Gentle Slopes	Moderately thick soils formed on colluvium	Range of soil development from none to thick, well-developed soils	Fine silts and clays	Very stable	Overland flow, slow mass wasting	Low to moderate depending on relative degree of soil development
Valley Floor	Young, mixed fine- and coarse-grained deposits	Little to no soil development	Coarse sand and gravel, fine silt	Moderately to unstable	Fluvial erosion	Low to moderate
Fluvial Terraces	Coarse-grained with texturally fine near surface horizons	Range from no soil development to extremely thick, clay rich soils	Coarse sand and gravel to fine silt and clay	Very stable to moderately stable	Overland flow, fluvial erosion	Low to high depending on relative degree of soil development, position in the landscape
Glacial Deposits	Heterogeneous mix of coarse- and fine-grained sediments	Typically moderately to well-developed soils	Primarily fine-grained silt and clay	Moderately stable	Mass wasting, fluvial	Moderate to high - heterogeneous nature makes these sensitive to disturbance

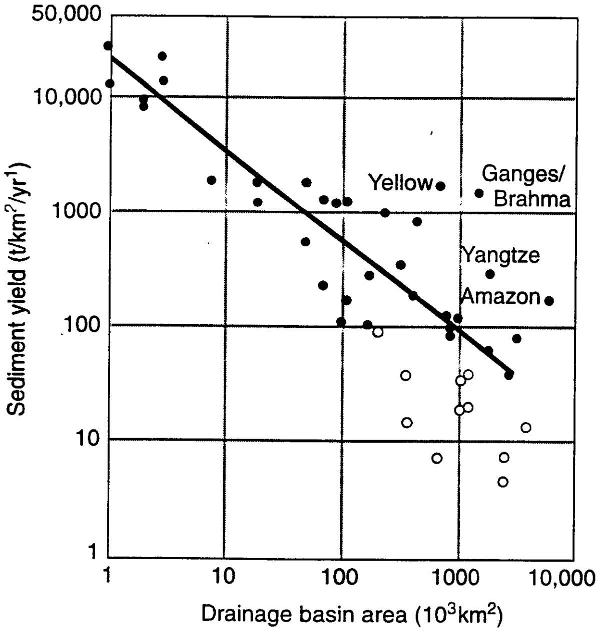


Figure 17. Relationship between sediment yield and basin area.

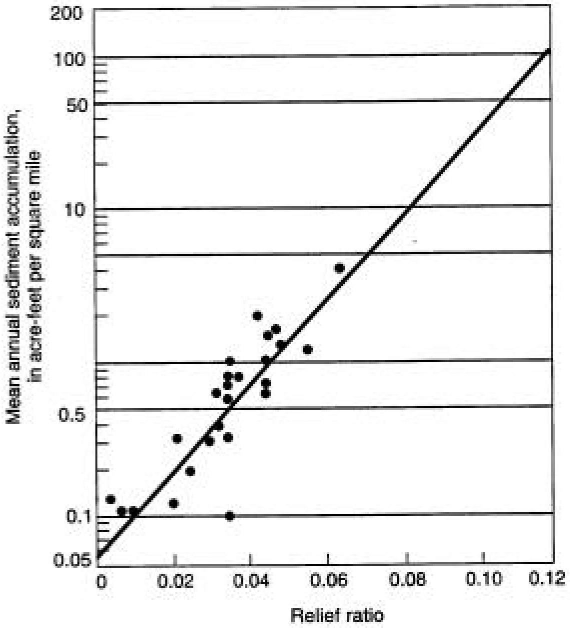


Figure 18. Relationship between sediment accumulation and relief ratio.

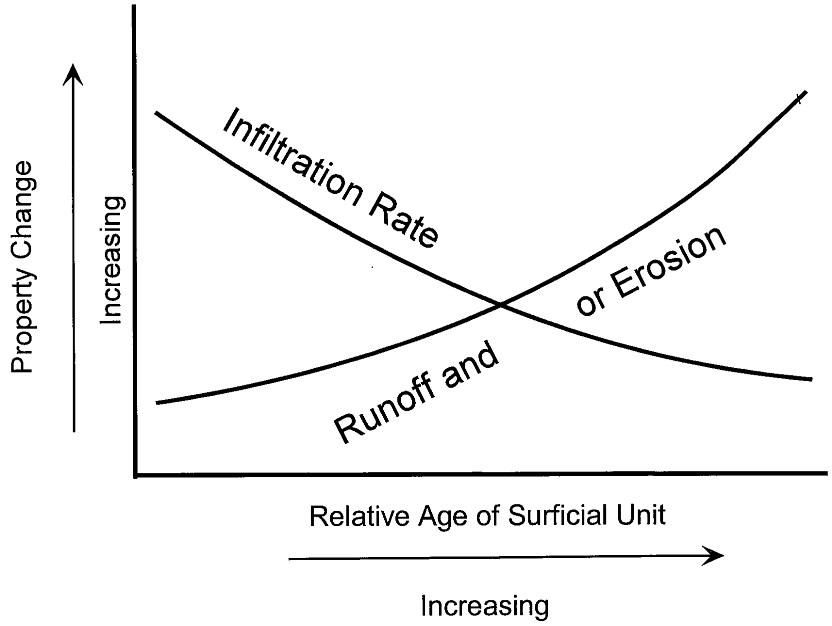


Figure 19. Relationship between runoff, erosion, infiltration rate and age of landscape unit.

Typically, those parts of the landscape with well-developed soil profiles and thick, clay-rich B horizons are indicative of a landscape that has been stable over long periods of time. Commonly, but not exclusively, these landscapes have very low surface relief and occupy relatively flat parts of the landscape. Despite having soil properties with low infiltration capacity, and hence inherently sensitive to changes in surface cover, the older surficial units have remained unaffected by erosion. These types of landscape elements may be highly susceptible to erosion if the surface is disturbed by either natural process or modification by humans. Disturbance of the upper, permeable A horizon has the effect of exposing the underlying low permeability B-horizon to direct precipitation. Thus, the older stable surface may be highly sensitive if even gentle slopes are disturbed or if disturbance occurs near the edges of the surfaces where the greatest relief may exist.

3.3.4.2.7 Geomorphic responses and sediment discharge

Alluvial system response to extrinsic basin changes, such as climate, natural events, or human disturbance may be asynchronous throughout the watershed and dependent upon intrinsic basin characteristics. Responses to these types of events may lead to exceedence of thresholds intrinsic to the fluvial system throughout the watershed and initiate a cascading sequence of geomorphic adjustments throughout the watershed. This cascading effect is referred to as a complex geomorphic response (Schumm, 1973a; Wells and Rose, 1981). The result can be erosion, transport and deposition of sediment that differ in space, time, and intensity. Commonly, there are disparate alluvial chronologies in adjacent drainages and correlation of geomorphic events within a watershed may be difficult (e.g., Schumm, 1973b; Bullard, 1985). The dynamic nature of the geomorphic system and complex geomorphic response is particularly important with respect to burn areas, relationships between forest fire and geomorphic processes, and the routing and storage of sediment within fire-affected areas (e.g., Laird and Harvey, 1986; Morris and Moses, 1987; Florsheim et al., 1997; Meyer et al., 1992).

3.3.4.3 Field Checking

Limited, site-specific field checking of key landscape units and Quaternary geologic deposits was conducted in parts of several sub-basins. Watersheds checked included Martis Creek, Squaw Creek, lower Coldstream Creek, parts of Sagehen Creek, Little Truckee River, and in the vicinity of Boca and Stampede reservoirs. This provided some independent field checking of landscape units, weathering characteristics, and geomorphic processes. The field observations offered added confidence in assessing the sediment and water contribution from those units.

3.3.4.4 Results

The following section describes the general geomorphic process/landscape element associations within the study area. A general stratigraphy of surficial geologic units is provided with a brief description of general characteristics, their distributions, sources for sediment, and potential sensitivity to disturbance activities. Finally, a case example is given for the lower parts of Martis Creek and Gray and Bronco creeks.

Note on the geology of the area: The geology and geologic history of an area can have a marked influence on the production of sediment, geomorphic processes, stability of slopes, and evolution of the landscape. In the Truckee River watershed, there are three basic bedrock lithologic units that are distributed throughout much of the region: two igneous and metamorphic rock units (granitic, volcanic, metavolcanic) and a sedimentary unit (lacustrine). Younger, unconsolidated Quaternary fluvial, slope, glacial, and lacustrine deposits are found throughout the watershed.

Granodiorite and granite comprise most of the higher peaks and ridge crests, particularly along the crest of the Sierra Nevada (Birkeland, 1961; Burnett and Jennings, 1962; Harwood, 1981; Saucedo and Wagner, 1992). These igneous rock units are medium to coarse grained and are relatively homogeneous and massive units. A large, north-trending shear zone is located on the western margin of the watershed, which for the most part separates granitic terrane from volcanic terrane. The rocks along the shear zone are highly fractured and enhanced weathering-related phenomena are common. An isolated metavolcanic unit outcrops northeast of Stampede Reservoir (Saucedo and Wagner, 1992; Burnett and Jennings, 1961).

Volcanic rock units in the watershed comprise a heterogeneous mix of andesitic lava flows and intercalated volcaniclastics, lahars, breccias and some associated lacustrine deposits. The lava flows typically form resistant beds that stand out in relief from the less resistant, less consolidated lahars, breccias, and debris flow deposits.

Sparse exposures of lacustrine deposits are exposed around Boca Reservoir and are associated with basalt flows that dammed an ancestral Truckee River. These units are fine-grained and generally have low permeability relative to coarser-grained fluvial deposits.

Principal Quaternary geologic units include fluvial, glacial, lacustrine, and mass wasting deposits. Fluvial deposits are found along most streams and comprise many of the terraces along the Truckee. In the area from the confluence of Martis Creek upstream to the Town of Truckee, fluvial terraces are composed of glacial outwash deposits derived from Pleistocene alpine glaciations in the higher elevations.

At least three glaciations are recognized in this part of the Sierra Nevada. The Sherwin (pre-Wisconsin), the Tahoe (early Wisconsin), and the (late Wisconsin). Glacial outwash deposits are found in the larger drainages that head near the crest of the Sierra Nevada. These are typically coarse-grained gravel and heterogeneous mixes of gravel, sand, and fluvio-lacustrine sediments.

In the higher elevations, glacial moraines are preserved along valley margins, near the mouths of Bear, Squaw, Pole, Deep, Cold, Donner, and Prosser creeks and near cirque basins. The glacial geology has not been mapped in sufficient detail to identify specific deposits in the upper parts of the Little Truckee River, although the drainages were glaciated (Birkeland, 1963) and shown on regional geologic maps (Burnett and Jennings, 1962; Saucedo and Wagner, 1992).

Lacustrine deposits are relatively isolated in the watershed and are associated with the Lousetown and Hirschdale basalt flows that dammed the Truckee River (Birkeland, 1963). A number of fluvial units are mapped by Birkeland (1963) and interpreted to be the result of aggradation by a higher base level caused by these flows (e.g., Prosser Creek alluvium, Juniper Flats alluvium).

Mass wasting deposits consist of dry rock slides, translational debris slides, some rotational slumps, creep, and debris flows. Most of the steep slopes in the headwater regions are affected by some form of mass wasting, most commonly by creep.

3.3.4.4.1 Landscape Elements, Geomorphic Processes, and Characteristic Surficial Units

The predominant landscape elements within the Truckee River watershed include high and low relief slopes, valley floors, glacial landforms (moraines), fluvial landforms (terraces), and the stream channels. Within each type there are commonly several subcategories.

Hillslopes: Hillslopes in the watershed are characterized according to relief and approximate slope angle. Very steep slopes are considered to be greater than 35 degrees, steep slopes 15 to 35 degrees, moderate slopes 5 to 15 degrees, and gentle slopes less than 5 degrees. Relief is an important variable because of the influence of gravity, microclimatic weathering influences, and potentially greater area of exposed slope. Hillslope cover ranges from barren to heavily forested to scrub brush and grasses. Barren slopes are not restricted to the steepest category because of fire impacts on lower-angle slopes, but, typically, steep bedrock outcrops are associated with steep to very steep slopes.

Steep to Very Steep Slopes: The steep to very steep slopes are generally found on the upper elevation extremes of watersheds, particularly along the Pacific Crest of the Sierra Nevada and higher elevation areas. Resistant beds within volcanic units can also be associated with very steep slopes. Smaller, lower relief (<50 m) steep and very steep slopes may be found along some reaches of the Truckee River and larger tributaries.

Geomorphic processes operating on the steep and very steep slopes predominantly are gravity controlled. Rock falls and a range of slow (creep) to rapid (rock slides) mass wasting processes are common. Depending on saturation and precipitation, these processes may be represented by shallow debris flows of variable thickness.

Dependent upon lithology and geologic structure, the composition of very steep and steep hillslopes can be of two general types: 1) bare rock outcrops and coarse, angular piles of cobble- and boulder- size debris, derived from volcanic rocks, at or near the angle of repose, or 2) finer-grained sand to angular gravel grus, a weathering product of granitic rocks. Both types of deposits tend to form steep slopes near the angle of repose because of interlocking rock particles. The interlocking coarse, angular rock fragments tend to form relatively stable slopes. The debris-covered slopes also provide natural traps for fine-grained dust and precipitation, which enhance chemical weathering and further production of fine sediment bound in the interclast spaces. Percolation of precipitation and snowmelt can enhance transport of the fine sediment deep into the slope deposits where it may form a relatively thin, unconsolidated layer. In some areas, vegetation provides an additional measure of stability to the slopes.

The soil cover on the steep slopes is generally very thin and weakly developed to non-existent. However, the slope deposits are relatively stable and the coarseness of deposits are probably not a factor in sediment water quality. However, because of the entrapment of fine sediment within the coarse deposits, disturbance of debris-covered slopes could cause release of fine sediment into streams.

Intermediate and Gentle Slopes: These slopes typically are found on the lower slopes, at valley margins at the toes of slopes, along some broader ridge crests at higher elevations, in much of the area in the vicinity of Truckee, and in the large areas north of Interstate 80. Relief typically varies from a few to several hundred meters.

The deposits that mantle theses slopes are also dependent upon underlying rock types. Additionally, in some cases the rock types higher up on the steeper parts of the slope may deliver detritus to the lower slope areas.

Geomorphic processes occurring on these slopes include slow mass wasting (creep), some shallow landsliding and debris flow activity, Hortonian flow, and channelized flow.

Valley Floors: Valley floors are most prominent along the higher order streams in the intermediate and lower parts of the Truckee River watershed. These may be on the order of a few tens of meters to several hundred meters or more in width. The valley floors are commonly associated with glacial features and fluvial terraces. They are typically covered with riparian and wet meadows vegetation.

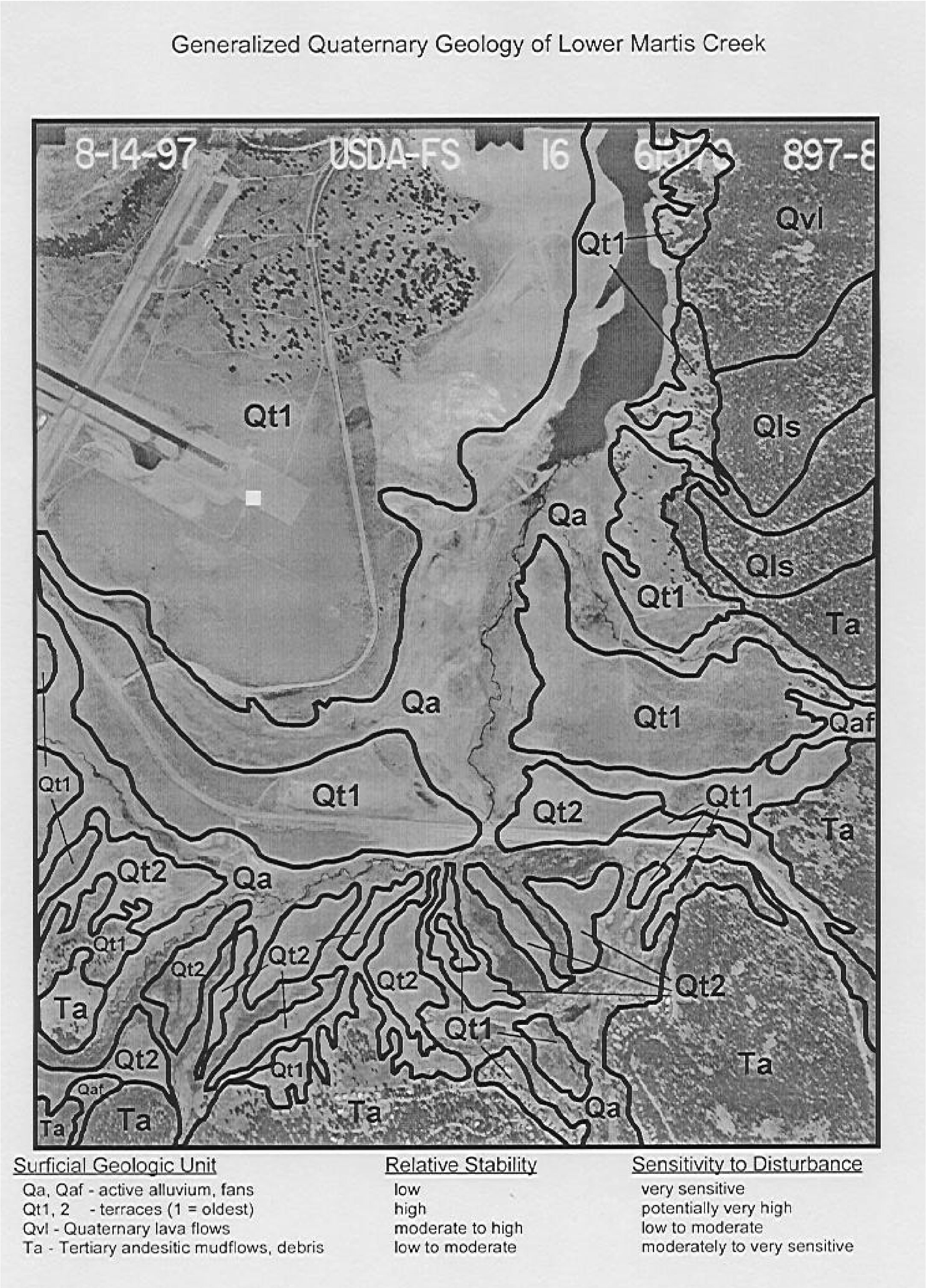
Fluvial Terraces: Fluvial terraces are common along the larger tributary watersheds and along the length of the Truckee River. They are typically coarse-grained alluvium that may be relatively stable depending on their landscape position relative to the Truckee River or incised streams that may cross the terraces. Older terraces have well-developed soils and may be sensitive to surface disturbance along edges of the terraces where relief is greatest.

3.3.4.4.2 Results: Martis and Gray Creeks

Figure 20 shows a generalized surficial geologic map for the lower reaches of Martis Creek. In this region, the principal units mapped are fluvial terraces and colluvial units, including alluvial/colluvial fans along side slopes. The map also summarizes the relative sensitivity to erosion and, hence, sediment production of the different mapped units.

The Martis Creek area contains moderate to steep, high relief slopes on the south and east sides of the watershed. Slopes covered by forest appear to be stable. Extensive areas of exposed bedrock are not apparent. However, the underlying bedrock, which consists of a heterogeneous mix of andesitic volvanic rocks, has a thick weathering profile that is susceptible to erosion and the release of fine-grained sediments to streams. North of the mountains on the south side of the watershed, Martis Creek crosses a low-relief, broad valley mapped as Sherwin outwash by Birkeland (1961).

The fluvial and glacial outwash deposits are typically a mixture of moderately sorted fluvial sand and gravel. Thin, discontinuous lenses of lacustrine and fluvio-lacustrine deposits are common, can be very fine grained, and be associated with low surface permeability.



Surficial Geologic Unit	Relative Stability	Sensitivity to Disturbance
Qa, Qaf - active alluvium, fans	low	very sensitive
Qt1, 2 - terraces (1 = oldest)	high	potentially very high
Qvl - Quaternary lava flows	moderate to high	low to moderate
Ta - Tertiary andesitic mudflows, debris	low to moderate	moderately to very sensitive

Figure 20. Quaternary geology of Lower Martis Creek.

Field observations confirmed the well-developed character of the soils in this area. Soils on the oldest surfaces are mapped as part of the Martis-Euer Variant Series (Soil Conservation Service, 1994) and have some of the thickest argillic B horizons of any soils in the region (Table

12). Surface horizons overlying the clay-rich B horizons are typically only a few centimeters thick. Many of the colluvial fans emanating from tributaries also have well-developed soils, however, their positions in the landscape make them subject to localized burial; hence, surface hydrology can differ across these units.

Table 12. Typical soils in the Truckee River Basin.

Soil Series	Taxonomic Class	Typical Profile	Thickness Bt-horizon (in)	Thickness Bt-horizon (cm)	Max Redness B-horizon or profile (d/m)
Ahart	Andic Xerumbrepts	A-C			10YR
Euer	Ultic Haploxeralfs	A-Bt-C	9	23	
Euer Variant	Ultic Haploxeralfs	A-Bt	58	147	10YR/7.5YR
Fugawee	Ultic Haploxeralfs	A-Bt-C	28	71	5YR/5YR
Fugawee Variant	Ultic Haploxeralfs	A-Bt	13	33	7.5YR/10YR
Jorge	Ultic Haploxeralfs	O-A-Bt-C	28	71	10YR/7.5YR
Kyburz	Ultic Haploxeralfs	A-Bt-Cr	28	71	5YR/5YR
Martis	Ultic Haploxeralfs	A-Bt	50	127	10YR/7.5YR
Meiss	Lithic Cryumbrepts	A-R			10YR
Tallac	Pachic Xerumbrepts	A-C			10YR
Tahoma	Ultic Haploxeralfs	A-Bt	40	102	7.5YR/7.5YR
Tahoma Variant	Ultic Haploxeralfs	A-Bt	43	109	7.5YR/7.5YR
Tinker	Andic Haplumbrepts	A-B-C	12	30	7.5YR/7.5YR

Data and horizon nomenclature is from Soil Survey of the Tahoe National Forest Area (USDA, 1974, 1994). In maximum B-horizon or profile redness column, (d/m) represents dry and moist Munsell colors, respectively.

The terraces and outwash plains having well-developed soils represent long periods of landscape stability and little surface erosion. However, these land surfaces have great potential for accelerated erosion if disturbed, especially along their margins or adjacent to incised streams where relief may be greater. The younger terraces and fan units, also with well-developed soils, presently appear to be stable. As noted by recent evidence of deposition of fine-grained sediments over these younger surfaces, disturbance can have an impact on sediment derived from these areas.

The youngest fluvial deposits, those comprising the small floodplains and lowest terraces, are the least consolidated and, therefore, are susceptible to entrainment during dominant and extreme discharge events. Where Martis Creek and/or tributaries impinge on the older terraces, the potential for undercutting and erosion is greater. These cases represent natural fluvial processes, but it should be noted that disturbance of the landscape in another part of the watershed can impact the fluvial system and potentially provoke fluvial responses that could result in increased erosion.

In the higher relief areas to the East, the landscape appears to be relatively stable. Resistant lava flows have prevented deep incision and headward extension of the streams, hence, the land surface has remained intact. Colluvial mantles on the side slopes may be susceptible to increased sediment yield if disturbed.

Near the reservoir on Martis Creek and farther to the north along the side slopes, the underlying rock units consist of lava flows intercalated with breccias, tuff, volcanic debris flows and fluvio-lacustrine deposits. If the protective surficial mantle becomes disturbed some of these hillslopes may be prone to accelerated erosion.

In the southern part of the Martis Creek watershed, the bedrock consists of mixed andesitic debris flows, breccias and tuffaceous deposits. In general, the unit weathers rapidly and likely is capable of producing significant amounts of sediment. If the stabilizing vegetation and colluvial mantle on the surface are disturbed, the unit may be capable of generating greater runoff and erosion and sediment yield from both the surficial mantle and the underlying bedrock.

3.3.4.4.3 Results: Lower Gray and Bronco Creeks

Gray and Bronco creeks are characterized by nearly 1,000 m of relief that is only a few kilometers from the Truckee River base level. The drainage area is underlain by large areas of friable andesitic volcaniclastic rocks and can be conducive to high rates of sediment production. Tonal qualities on aerial photographs indicate large areas of exposed bedrock and there appears to be little stabilizing vegetation throughout the watersheds.

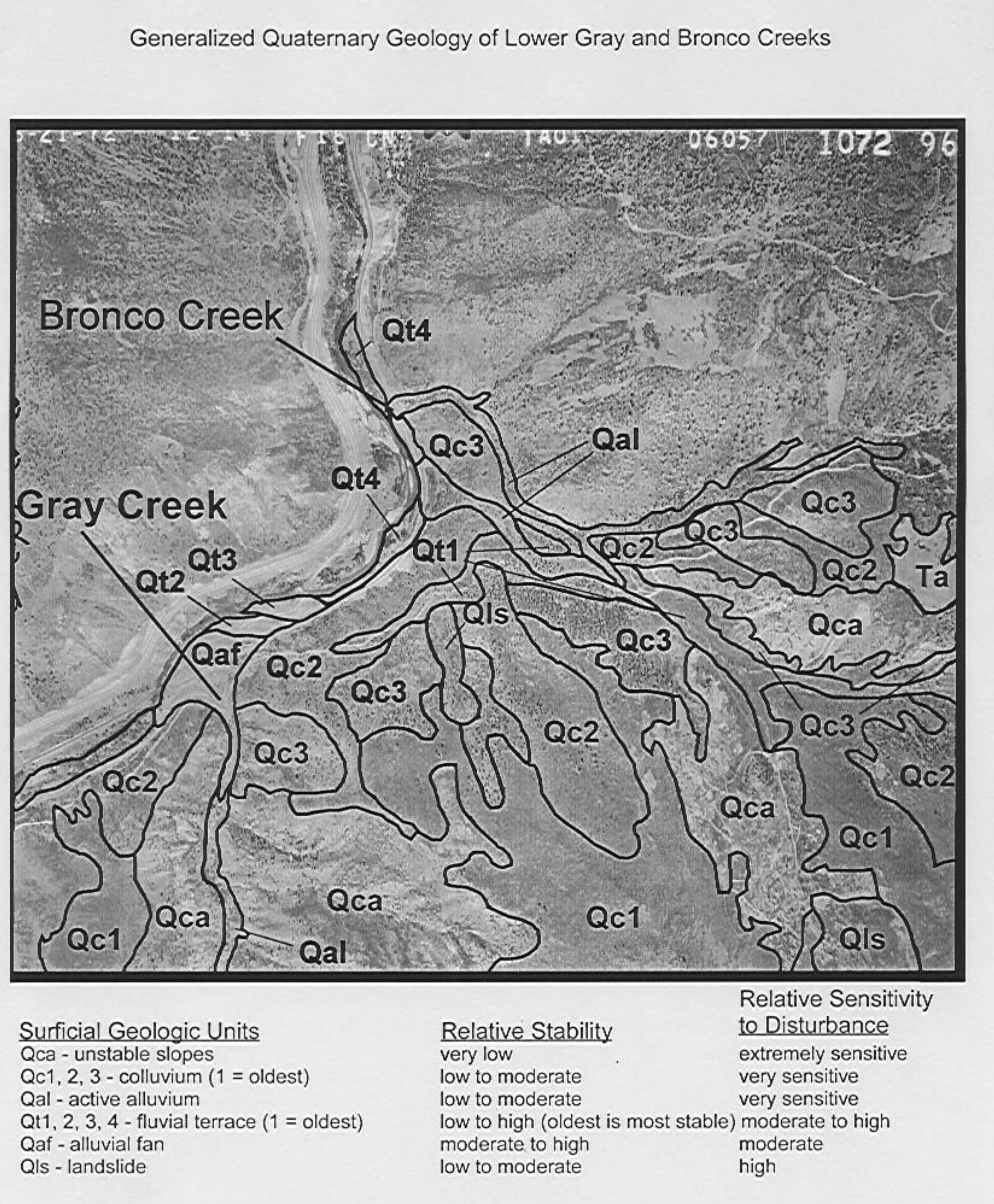
The two watersheds have steep side slopes and relatively narrow, alluvial valleys. Small tributaries in the lower part of the watershed have extremely high gradients and, despite having small capture areas, intense rain events may be capable of generating substantial runoff and erosion of the steep slopes.

The fresh appearance of colluvial deposits at the base of the slopes suggests high rates of active erosion (Figure 21). Active slopes have built colluvial aprons at the toe slope that act as temporary buttresses and trap sediment shed from the upper slopes. Disturbance of the colluvial aprons may be capable of provoking incision into the colluvium and reactivation of upper slopes. The result would likely be an increase in hillslope sediment production and delivery to the valley floor.

Tonal qualities also help to identify different stages of slope stability. Multiple past episodes of hillslope erosion followed by stability indicate that the process is ongoing. It is unknown if former surface disturbances (e.g., forest fires or logging activity) are solely responsible for the eroding slopes. The nature of surface mantle suggests that the protection afforded is minimal and that the slopes are inherently sensitive to disturbance. There may also be intrinsic threshold values for the stability of the slopes as a function, for example, of surficial mantle thickness, slope, vegetation, and climate.

In general, the lower part of both watersheds is extremely sensitive to disturbance, either from natural events or anthropogenic disturbance such as logging and road cutting. A large knickpoint exists near the mouth of the west fork of Bronco Creek and the east fork is essentially a hanging valley. Valley-fill sediments may be highly unstable and disturbances in the watershed could result in rapid headcutting and removal of the fill and further destablization of hillslopes by undercutting the toe slopes. Natural or anthropogenic disturbances that destabilize the hillslopes could impact the volume and type of sediment reaching the Truckee River.

Alluvial and colluvial fans have formed at the mouths of Gray and Bronco creeks. The fan at the mouth of Gray Creek either has built onto an older terrace (Qt2 on Figure 21) or fluvial terraces have been cut on the alluvial fan (Qt2 and Qt3). The fan probably provides some degree of stability for the watershed in terms of a temporary local base level that may inhibit deeper incision of the trunk stream and tributaries. The location of the fans likely reflects high sediment discharge relative to water and could reflect the behavior of watershed responses to changing environmental conditions.


Generalized Quaternary Geology of Lower Gray and Bronco Creeks

Surficial Geologic Units	Relative Stability	Relative Sensitivity to Disturbance
Qca - unstable slopes	very low	extremely sensitive
Qc1, 2, 3 - colluvium (1 = oldest)	low to moderate	very sensitive
Qal - active alluvium	low to moderate	very sensitive
Qt1, 2, 3, 4 - fluvial terrace (1 = oldest)	low to high (oldest is most stable)	moderate to high
Qaf - alluvial fan	moderate to high	moderate
Qls - landslide	low to moderate	high

Figure 21. Quaternary geology of Lower Gray and Bronco creeks.

The oldest terrace (Qt1) in this area is preserved between Gray and Bronco along the Truckee River. It is possibly a remnant of glacial outwash deposits. The valleys of Bronco Creek formerly graded to Qt1; however, the East fork of Bronco Creek has incised and appears to have adjusted its gradient to the Truckee River base level. Relative to the East fork of Bronco Creek, the West fork appears to have more sediment stored in its valley. This may be in part a result of relative drainage capture areas and discharge capable of transporting the sediment supply. The alluvial valley of the West fork is less incised, although the Truckee River base level is now transmitting upstream into the valley.

3.3.4.4.4 Basin-wide analysis

A general assessment of the Truckee River watershed was made, primarily based on interpretation of satellite imagery. The basis for the interpretation was largely from extrapolation of results of aerial photo mapping. The accompanying image (Figure 22) shows areas interpreted to have either currently high sediment production or characteristics of areas that may be sensitive to disturbance and susceptible to erosion.

Because of the reconnaissance nature of this study, the vast majority of the areas have not been field checked. With this in mind, the map is not intended for use as a document to dictate land use. Rather, it should be used as a guide for areas to investigate in greater detail before determining actual sensitivity to controllable disturbance activities.

As noted previously, relief ratio is a morphometric property of drainage basins related to sediment discharge (Figure 18). The relief ratio is the ratio of drainage basin relief to the length of the basin. Table 13 shows relief ratios for nine sub-basins. The relief ratios range from 0.04 (Prosser Creek) to 0.17 (upper Prosser Creek basin). The lowest values are for the watersheds with very long basins, and the higher ratios are relatively short and high relief basins. In a general sense, the watersheds with the highest relief ratios might be expected to be high sediment producers. In the case of Prosser Creek, the high relief ratio in an upper tributary suggests high sediment yield. Overall, the low relief ratio for the entire Prosser Creek watershed may be misleading because the area is very large and middle and lower parts of the drainage may be capable of absorbing sediment supplied by upper tributaries. Field observations indicated that large amounts of sediment are stored in the lower reaches of Prosser Creek.

In general, disturbance of vegetation and the land surface in areas underlain by well-developed soils could lead to potentially higher rates of erosion and sediment yield. Large areas of impermeable surfaces could be expected to generate greater runoff, sediment yields, and have an impact on fluvial system behavior.

Table 13. Relief ratios for watersheds within the Truckee River watershed.

Watershed	Maximum Elevation (ft)	Minimum Elevation (ft)	Relief (ft)	Watershed Length (mi)	Relief Ratio
Bear Creek	8450	6200	2250	3.8	0.11
Squaw Creek	9000	6100	2900	4.4	0.12
Pole Creek	8550	6000	2550	3.4	0.14
Deep Creek	8750	6000	2750	3.8	0.14
Cold Creek	8800	6000	2800	5.7	0.09
Martis Creek	8750	5500	3250	6.5	0.09
Prosser Creek	8400	5700	2700	11.8	0.04
Prosser Creek trib	8400	6300	2100	2.3	0.17
Juniper Creek	8600	4850	3750	6.8	0.10

Note: measurements taken from 1:24000 – scale topographic maps.

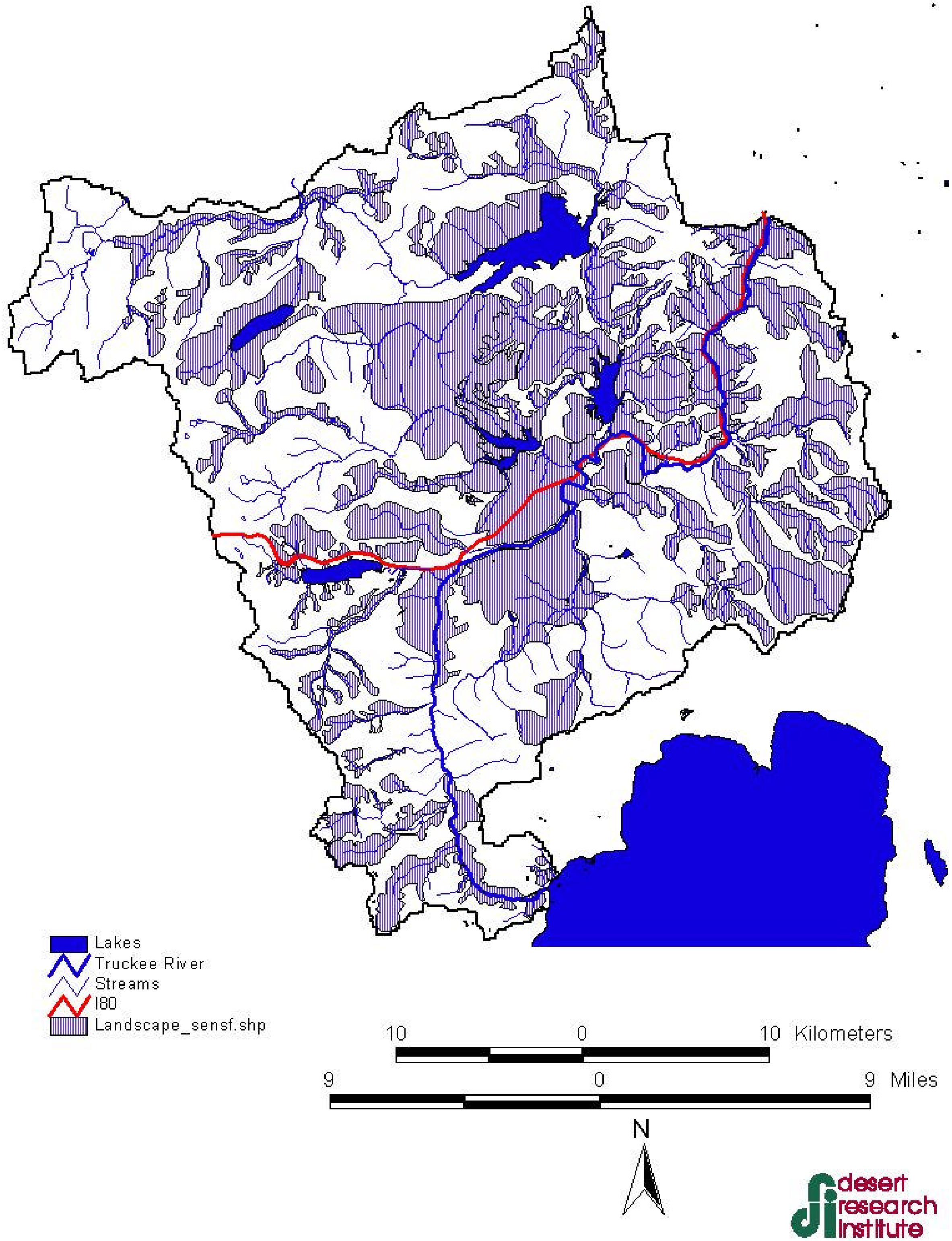


Figure 22. Landscape units susceptible to erosion.

High relief areas that are disturbed by logging, road building, or recreational facilities might be expected to produce elevated sediment yields if the stabilizing vegetation and surface soil are disturbed. Similarly, areas of lower relief along trunk streams may be subjected to increased fluvial erosion during high discharge events.

3.4 Synthesis of All Assessments

The Truckee River watershed was assessed in three ways: 1) review and analysis of historic data; 2) watershed model; and 3) aerial photo analysis of sensitive landscapes. The following is a review of all assessments with a discussion of specific conclusions, strengths and weaknesses of the approach, and recommendations.

3.4.1 Review of Suspended Sediment Loading Estimate by Historic and New Data

One important task in completing a TMDL is to gather all relevant data. There is a wealth of TSS, SSC, and turbidity data available at various locations within the basin. Upon review of that data, however, it was discovered that the most useful data for this method, continuous SSC with flow measurements, were rare. Collection of very detailed SSC and flow data for a wide range of flows during the spring snowmelt season proved to be a crucial task to thoroughly analyze loads in the basin.

Even with the abundance of historic and new data, it was still necessary to fill data gaps. To do this, relationships were developed between flow and sediment measurements taken in adjacent or nearby basins. Comparison to reference sites is a recommended method in the EPA protocols (USEPA, 1999a) and an excellent way to increase the amount of relevant data. The development of correlations allowed estimates of annual sediment load to be made at most of the major sub-basins to the Truckee River.

The strength of this method is its use of actual data. In general, more confidence can be derived from real data than from estimates or models. The main weakness of this method is that data collection, at the level necessary for in-depth analysis of the entire basin, is expensive. Also, it is nearly impossible to collect an adequate quantity of data in a basin the size of the Truckee River Basin.

Though this method is very detailed, there are still improvements or additions that can be made. First, data should be collected during snowmelt and rain events. As discussed below in the Proposed Monitoring section (4.2), high loads and high variability in loads over time can be expected during these events. Snowmelt and rain events in the Sierra Nevada occur very quickly; as a result, mobilizing field crews in time to capture the event is difficult. The most efficient way to collect this information is through remote data collection of turbidity. Use of this information requires development of SSC-Tu rating curves; but the benefit of collecting detailed data far outweighs the cost.

Also, grain size distribution of suspended sediment is almost never obtained. Results from such an analysis may yield insight into the source of sediment as well as its effect on streambed conditions.

As mentioned above, collecting data to characterize all areas in a large basin is impractical. Ideally, location of data collection efforts would isolate land-use practices to isolate their effect on sediment load. One very useful way to overcome this lack of information is to develop a watershed model to simulate the sediment-generating processes occurring in the basin.

3.4.2 Review of Source Assessment by Watershed Model

The AnnAGNPS watershed model (USDA, 2000) was chosen to simulate sediment processes in the basin. The main strength of a watershed model is its ability to simulate behavior where no data exist. To lend confidence in the model's ability to simulate the processes, it was calibrated to measured sediment load in a wet year (1996) and validated to an average year (1997). Results of model runs can show spatial variation in sediment load in greater detail than is realistically possible with data collection alone.

Results of the modeling exercise show the SSC in the Truckee River is affected more strongly by those model elements closest to the stream. Runoff, and associated sediment, from adjacent areas are deposited directly in the stream, whereas sediment with a longer overland distance to travel before reaching a stream has a greater chance of deposition in downhill elements.

Areas of potential concern can be identified by high values of sediment per unit area. Further investigation is needed to determine the source of these high sediment generators. As stated above, the Truckee River Basin is a highly variable system. The natural variation found in canopy cover, soils, and land use can be assumed to be found with sediment load, as well.

As with any modeling effort, data quantity and quality are a concern. Future work in this area includes investigation of soil data requirements. For example, the STATSGO data set is very coarse—each map unit is actually a compilation of five to 15 distinct soils. Though many will say that more detailed soil data are necessarily better, it has not yet been proven for basins the size of the Truckee River. It is possible that accuracy in sediment prediction is hindered not by soil detail, but by the accuracy or scale of the digital elevation model, the canopy cover data, or climate conditions. Better knowledge of data requirements is, therefore, required to improve the model and to provide direction in data collection.

3.4.3 Review of Aerial Photography Analysis

The aerial photo analysis was performed to complement the previous two assessments. Though this assessment did not provide a load estimate, EPA protocols (1999a) state that, "it is more efficient to target future erosion sources for remedial action than to evaluate past erosion locations, which are probably not amenable to productive treatment." The aerial photo analysis identified areas of erosion vulnerability (or sensitivity) in the basin.

Erosion vulnerability was determined primarily by the relative degree of soil development, or soil age. Older soils have undergone more weathering and, as a result, contain more fine-grained particles. The particle size has a direct effect on the infiltration rates and, therefore, affect runoff. Areas of high runoff will potentially erode at higher rates.

Aerial photos of the basin at scales ranging from 1:15000 to 1:30000 were used to identify geologic units. A detailed analysis was performed in Martis, Gray, and Bronco creeks. A coarser, basin-wide analysis was performed using the Landsat image from August 1999.

The strength of this analysis lies in the ability to identify areas that, while currently stable, may become significant sediment producers if disturbed. An important benefit to establishing a TMDL is the ability to make educated decisions on future land-use activities. The collection of historic data gave information at a sub-basin scale, the model took that information a step further and identified smaller areas already producing high sediment, and the aerial photo analysis complements this information by identifying potential future areas of concern.

The weakness of this section is the resources required to draw useful conclusions. An analysis at the scale performed for Martis, Gray, and Bronco creeks is an excellent resource but impractical at a basin-wide scale. Using the basin-wide analysis (Figure 22) will give a general indication of sensitive areas but any land-use decisions will require further investigation.

In hindsight, it might have been a better use of resources to use the aerial photos to develop a disturbance layer. Knowledge of disturbance locations and type would allow a more thorough correlative analysis to be performed relating disturbance type and sediment yield. This would also make better use of model results and would allow for a more directed BMP analysis, all of which would improve the forthcoming TMDL.

3.4.4 Summary

The three assessment methods outlined above form a family of tools used to provide a thorough watershed assessment. Each has its own strengths and weaknesses but, performing all three, with a comparison of each, lends greater confidence in the assessments as a whole.

The three methods also provide a stepwise strategy for future TMDLs, with the recommendations listed above. The Truckee River Basin is a large basin with a great deal of variability. No one method can reasonably yield the insight into the complex processes of the basin that a combination of three, complementary methods can.

3.5 Suspended Sediment Loading Under Various Best Management Practices and Land-Use Scenarios

3.5.1 Summary of Best Management Practices and Restoration

An important element in the eventual development of a sediment TMDL in the Truckee River Basin is the identification and evaluation of relevant best management practices. Best management practices (BMPs) are those practices designed to mitigate the effects of disturbance on the landscape. They can be as simple and non-destructive as retiring an area from particular activities or as complex as a heavily engineered treatment facility.

Sediment stemming from anthropogenic sources can be controlled by prevention, interdiction and/or restoration (Waters, 1995). Of the three, prevention at the source of erosion is the preferred choice. Interdiction involves capturing and retaining sediment between the site of origin and the stream. Removing sediment from the stream by bringing physical conditions back to their original state is restoration.

This section focuses on preventative actions that can be taken to minimize erosion/sedimentation production from a variety of management activities. It should be noted that many of the actions that are taken as preventative measures may also act to help in restoring the land to a more natural state.

3.5.1.1 Livestock Grazing

Livestock are attracted to the riparian zone for drinking water and more abundant foliage, especially in semi-arid to arid climates. Negative impacts include trampling and destabilizing streambanks, which cause channel widening, reduction of stream depths, alternating current velocities and extensive sediment deposition. The most effective way to inhibit sediment production due to livestock overgrazing is fencing; use of these structures, also known as “cattle exclusion,” prohibits livestock access to the riparian zone (Waters, 1995).

However, fencing can be economically impractical if miles of streams are included within the grazed area. Fencing is used as part of the general strategy, but not the only one. General alternatives for grazing management include:

- Designing a system of resting pasture units, including the riparian zones and rotating stock among these units;
- Giving complete protection to selected fisheries of high value and sensitive areas such as springs; and,
- Developing watering areas away from streams and springs.

3.5.1.2 Forestry

Control measures to prevent erosion from logging roads remains a primary concern. There is much literature on sediment production from dirt logging roads. For the purposes of this review only the general conclusions will be presented, but the reader is referred to Waters (1995) and Weaver and Hagans (1994) for more extensive literature reviews. The following general methods will help in reducing erosion from logging roads:

- Near stream locations, steep slopes and inner valley gorge areas should be avoided to reduce sediment delivery and mass soil wasting potential.
- As few roads as possible, as short as possible, should be used.
- The road width should be as narrow as possible; less excavation reduces the probability of the occurrences of mass failures.
- To avoid runoff concentration on roads, grades should range from 5-15%, with a minimum of 3% to allow for drainage. Switchbacks and sharp turns require culverts or other measures to prevent rills and/or gully formations.
- Covering the road surface with gravel or crushed rock will reduce direct erosion of the roadbed.
- Vertical or near vertical road cuts should be completed to reduce excavation and erosion of the slope. Since vertical cuts may cause mass soil movement in unconsolidated materials, such areas should be avoided. If this is not possible, retaining structures are advisable.
- Because of the high probability of failure, fill slopes should be avoided. If they are used, they should be stabilized with vegetation, retaining structures, etc.
- To disperse drainage and reduce gully formation, an outsloping road drainage should be used for low grades. An inside drainage should be implemented for steeper grades.
- Inside drainage requires road ditches to carry runoff along the road. These features should be lined with gravel or crushed rock to minimize erosion of the ditch surface. Furthermore, cross drains should be incorporated into the design to disperse runoff. Underground pipes or log construction should be installed at the low point of the road for this purpose.
- Water bars may also be used to disperse drainage from roads. These are low earth humps or logs placed at a 30° angle downslope. These features should be spaced closer together on steeper grades.
- Stream crossings should be avoided since these are areas where sediment is delivered directly to the stream network. If unavoidable, culverts or bridges should be used to minimize sediment delivery. In such cases, riprap should be installed on the approaches to prevent these features from being washed out.

- Vegetation on road edges and cut and fill slopes will act to stabilize slopes and reduce erosion. Vegetation is also the major factor in minimizing erosion on abandoned roads.
- The canopy cover of trees and brush may be thinned adjacent to roads to permit sunlight to dry roadbed and fills.
- Access to abandoned roads should be closed to vehicles. Ideally, these roads should be reconstructed, and bridges and culverts removed to avoid subsequent use and maintenance. Reconstruction should include the installation of water bars and vegetation to stabilize reconstructed slopes.

The techniques used in tree harvesting affect erosion and sedimentation (Waters, 1995). Clear cutting reduces canopy cover and exposes bare soil to erosion. Selective harvesting should be employed. The method of skidding logs to access roads or yarding platforms is also a factor in erosion. Helicopter logging is preferred since it eliminates use of skid trails and the logging roads to a large extent.

Other techniques that may be useful are dispersing skid trails (as opposed to concentrating them by downhill skidding), constructing slash dams and cross ditches, installing water bars, scattering slash on trail surfaces, and later, seeding the trail. Streambank erosion may be increased by cutting or skidding directly in the riparian zone. Since this erosion is difficult to avoid, working in the riparian zone should be prohibited altogether. A buffer strip of 50-300 ft should be left uncut along the sides of streams in logged watersheds.

3.5.1.3 Urban Development and Construction

Generally, there are ten principles that summarize controlling the processes of erosion and sedimentation related to urban development and construction (Goldman et al., 1986):

- *Fit development to the terrain*. The best way to minimize the risk of creating erosion and sedimentation problems by construction is to disturb as little of the land surface as possible. Therefore, grading should be minimized.
- *Time grading and construction to minimize soil exposure.* Grading should be staged so that only small areas are exposed to erosion at any one time. Timing of the grading should coincide with the dry season.
- *Retain existing vegetation whenever feasible.* Vegetation is the most effective form of erosion control; little erosion occurs on a soil covered with undisturbed natural vegetation.
- *Vegetate and mulch denuded areas* as soon as possible after grading is completed. Mulch helps seedlings to become established and protects the soil until vegetation takes control.
- *Divert runoff from denuded areas.* Dikes or ditches may be used to divert upland runoff away from a disturbed area to a stable outlet.
- *Minimize length and steepness of slopes.* These factors are among the most critical in determining runoff velocities and, thus erosion potential. Terraces will slow runoff and provide a place for small amounts of sediment to settle out.
- *Keep runoff velocities low.* Channel velocities can be kept low by lining driveways with rough surfaces like vegetation or rip rap, by designing broad, shallow flow areas, and by constructing check dams at frequent intervals.

- *Prepare drainageways and outlets to handle concentrated or increased runoff.* Compacted or impervious surfaces created during construction increase runoff velocities and peak flows in drainages; therefore, drainages should be designed to account for these changes.
- *Trap sediment on site* using sediment retention basins/ponds, silt fences, straw bales. Remember vegetation and mulch is the best form of sediment control.
- *Inspect and maintain control measures at regular intervals.*

3.5.1.4 Streambanks

In controlling streambank erosion, two zones must be considered: the upper bank zone, which is influenced by high water flood events, and the lower bank zone, which is adjacent to normal stream water levels. The lower bank zone is most susceptible to erosion since it is always in contact with stream flow. The upper zone may require modification and/or structural protection if runoff is severe due to a steep slope. The following methods may be used to reduce streambank erosion in both zones:

- Surficial treatments, such as riprap and revegetation, may be employed to increase resistance to erosion.
- Slope reduction to the angle of repose will act to reduce slumping of bank materials.
- Water energy can be reduced through installation of instream deflectors, retards, or brush, logs, and rock barriers. These structures may not, however, be compatible with aesthetic, boating or fishery goals.
- Fencing will eliminate foot traffic and livestock grazing.

Erosion control in upland areas will limit downstream cumulative effects.

3.5.2 Erosion and Runoff Control Techniques in the Lake Tahoe Basin

Due to the similarities of their respective watershed processes, BMPs that have been implemented in the Tahoe Basin may also be applicable to the Truckee River watershed. A large number of erosion control and other water quality improvement projects have been implemented in the Tahoe Basin over the past 15 years (Murphy and Knopp, 2000). Much information has been learned from observing performance of projects on occasional site inspections. Information regarding BMP effectiveness, however, remains mostly qualitative and based on occasional site inspections and observations. At the time of this publication, efforts are underway to quantify BMP effectiveness within the Basin. Therefore, effectiveness of each specific BMP is largely unknown at this time.

The following BMP techniques have been or are currently practiced in the Lake Tahoe Basin. Each technique demonstrates promise as an effective BMP, but more research is needed to quantitatively determine the effects of each specific BMP. For information specific to design criteria related to each BMP the reader is referred to Chapter 4 of the Lake Tahoe Watershed Assessment (Murphy and Knopp, 2000).

- Snow and Ice Management practices
    - Road substance application (sand)
    - Mechanical removal
    - Traffic control

    - Construction
- Source control management practices
    - Acquisition of environmentally sensitive lands
    - Catch basins
    - Maintenance practices
    - Road reclamation
    - Curbs
    - Gutters and roadside channel stabilization
    - Retaining walls
    - Slope stabilization
    - Stormwater diversions
    - Vegetative erosion control
- Vegetated systems and constructed wetlands practices
    - Wetlands
    - Wet ponds
    - Buffer zones/stream environment zones (SEZs)
    - Filter strips
    - Grass swales
    - Spreading runoff across well-vegetated areas or meadows
- Infiltration management practices
    - Infiltration trenches
    - Infiltration basins
    - Exfiltration trenches (infiltration trenches with perforated pipe underdrains)
    - Drainage/dry wells
- Detention/sedimentation management practices
    - Wet detention ponds
    - Dry detention ponds

3.5.3 Simulation of Best Management Practices Using the AnnAGNPS Model

One way to simulate best management practice (BMP) effectiveness is to use the existing watershed model. Though the model is fairly detailed, most BMPs are implemented at a much smaller scale than the model elements. However, as stated above, conventional wisdom (as well as intuition) suggests that some of the more effective BMPs involve revegetation and removal or re-design of dirt roads. The resulting change in sediment load resulting from revegetation or removal/re-design of dirt roads can be quantified, at least on a coarse scale, using the model. All model runs are compared to model results using the 1997 conditions. Figures include both the total reduction in sediment mass as well as the reduction per unit area for each management practice.

Three management practices were evaluated with the model: increased canopy cover, decreased road sand, and decreased dirt road density.

3.5.3.1 Increased Canopy Cover

One of the major factors influencing SSC is raindrop energy. Sediment detachment is directly related to raindrop energy which is, in turn, a function of raindrop velocity. Once sediment is detached from the parent material, erosion is much more likely. However, erosion still requires overland flow. Increased canopy cover has the effect of reducing velocity by interception or deflection of the raindrops.

A review of Table 8 shows the different curve numbers for each category of canopy cover. A change in curve number indicates a change in runoff quantity. Note that an increased canopy cover percentage relates to a decrease in curve number—indicating a decrease in runoff and, therefore, a decrease in erosion. To model the effects of revegetation, the canopy cover percentage was increased by one level in the model. Elements with a canopy cover of less than 50% were modeled with a canopy cover of 50 to 70%. Elements with a canopy cover of 50 to 70% were modeled with a canopy cover of greater than 70%. Elements with a canopy cover of greater than 70% were not changed. Table 14 and Figure 23 show the results of the analysis by major basins. Figures 24 and 25 illustrate the basin-wide results.

Table 14. Modeled Reduction in SSC by Increased Canopy Cover—Major Basins.

Basin	Calibrated Model 1997 (tons)	BMP Canopy Cover (tons)	Percent Reduction
Bear	59	30	50
Squaw	892	507	43
Prosser	1592	1081	32
Donner	1678	1242	26
Trout	58	45	23
Little Truckee	3081	2439	21
Gray	1011	797	21
Bronco	579	493	15
Martis	635	629	1
Juniper	147	147	0

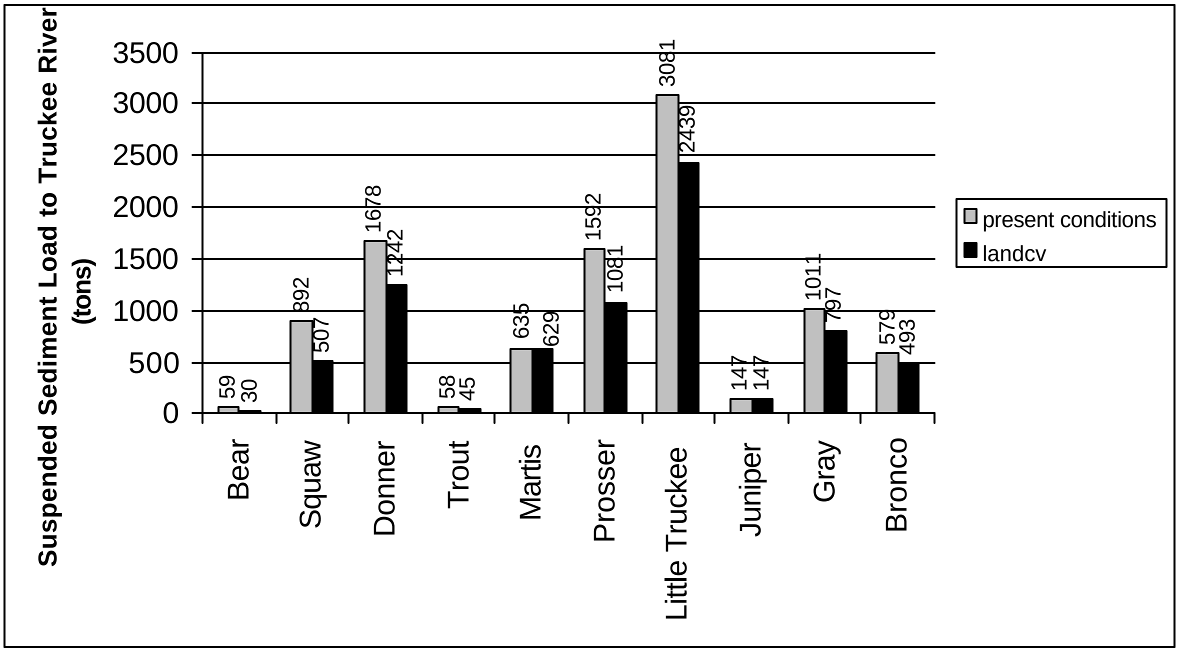


Figure 23. Suspended sediment load to Truckee River under increased canopy cover conditions—major basins.

While analyzing the results of this exercise and determining which basins should be revegetated, it is important to recognize the limitations. It has not yet been determined the reason a certain area exists under the reported canopy cover. Differences in canopy cover may be the result of natural variation, historic disturbances (e.g., fire, clearcutting, grazing), or present activities. If two areas produce high sediment loads, one under naturally low canopy cover, the other under low canopy cover as a result of present activities, the latter should be considered first for revegetation. In other words, the potential causes of sediment should be considered before implementation of BMPs or restoration

That said, model results suggest that an increase in canopy cover by one level over the entire Truckee River watershed will reduce SSC in the Truckee River by 26%. Therefore, revegetation should be considered an appropriate BMP for this watershed.

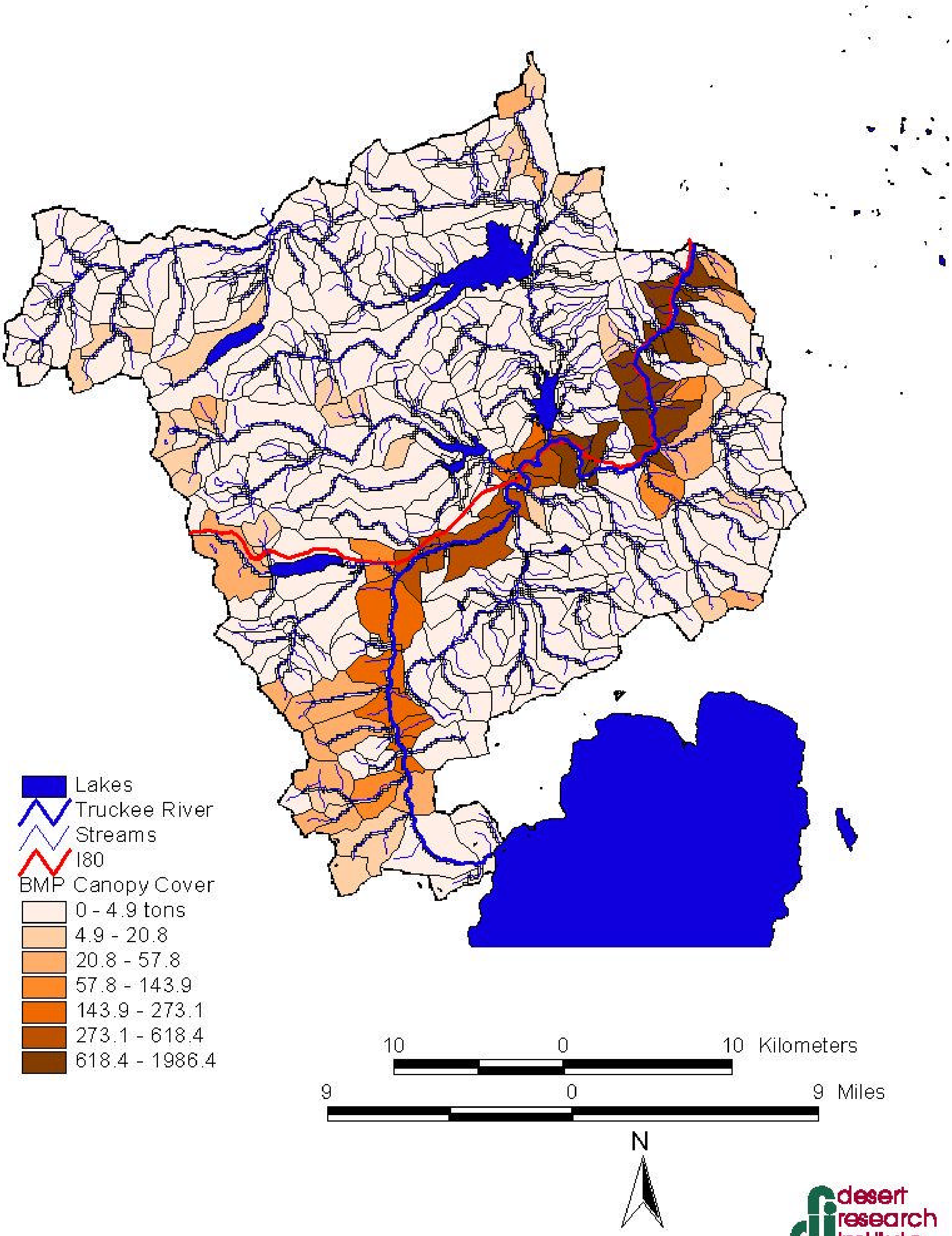


Figure 24. Decrease in suspended sediment load under increased canopy cover conditions.

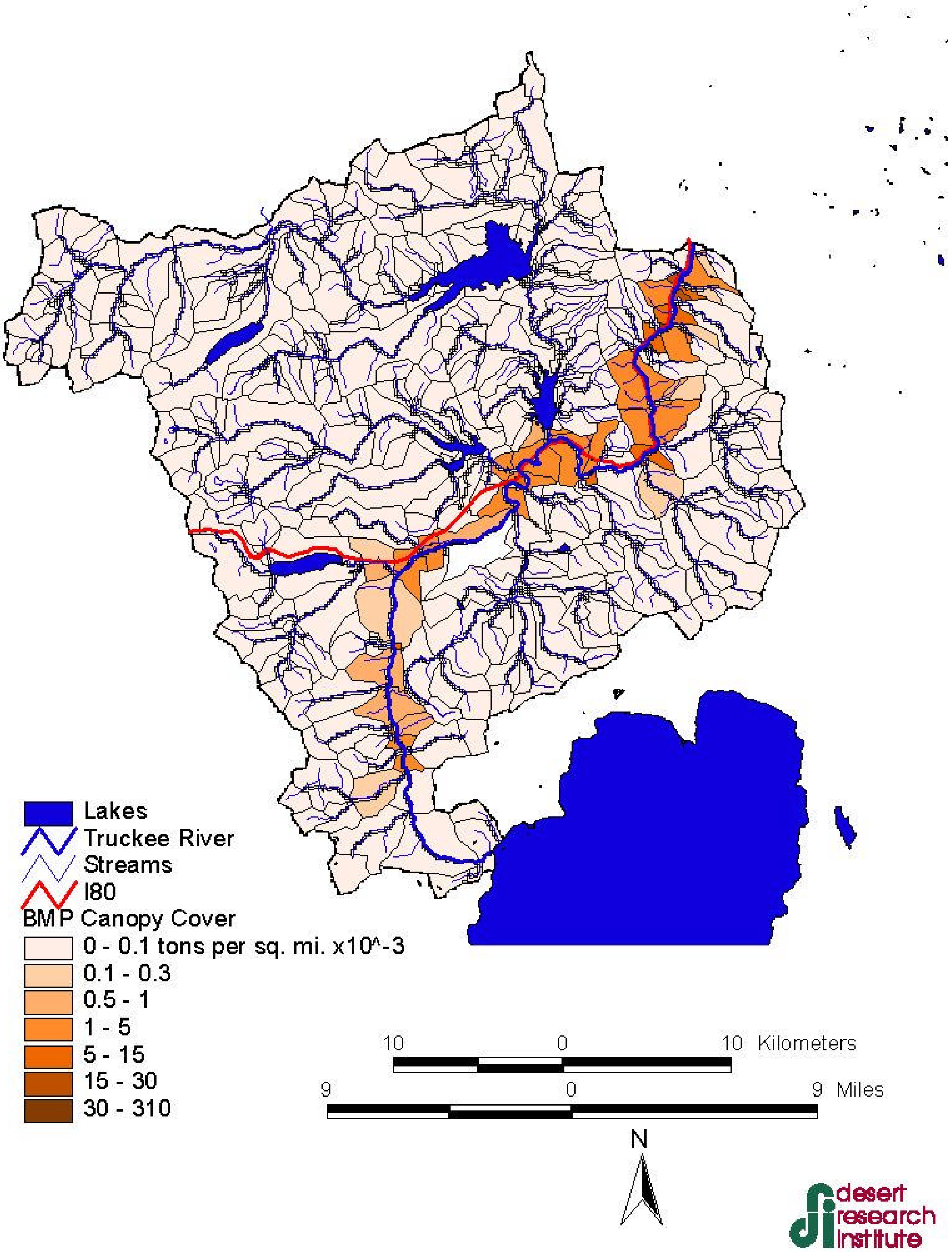


Figure 25. Decrease in suspended sediment load per unit area under increased canopy cover conditions.

3.5.3.2 Decreased Road Sand

The effect of decreased road sand was also modeled. As stated above, there were some simplifying assumptions required to include road sand to the model. All results should be viewed in light of those assumptions.

Recall that to simulate the impacts of road sand, it was assumed that a certain percentage of the applied sand was delivered to the downstream model element. This represents post-BMP sediment loads. An effective road sand BMP will reduce the amount of material leaving the road and entering the downstream element. The effect of the BMP was modeled by simply reducing the point source of sediment in the model.

Another limitation is the initial condition of the downstream model elements. The cumulative effects of road sand application over many years may result in a large reservoir of loose sediment immediately downhill from the road. This reservoir of antecedent sediment could become an additional source of sediment. This potential additional source was not considered in this analysis.

Table 15 shows the results of the analysis. Figures 26 and 27 show the basin-wide results.

Table 15. Modeled Reduction in SSC by Decreased Road Sand—Major Basins.

Basin	Calibrated Model 1997 (tons)	BMP Reduced Road Sand by 25% (tons)	Percent Reduction	BMP Reduced Road Sand by 50% (tons)	Percent Reduction
Trout	58	52	11	45	23
Bear	59	59	0	59	0
Squaw	892	892	0	892	0
Donner	1678	1672	0	1666	1
Martis	635	634	0	634	0
Prosser	1592	1592	0	1592	0
Little Truckee	3081	3081	0	3081	0
Juniper	147	147	0	147	0
Gray	1011	1011	0	1011	0
Bronco	579	579	0	579	0

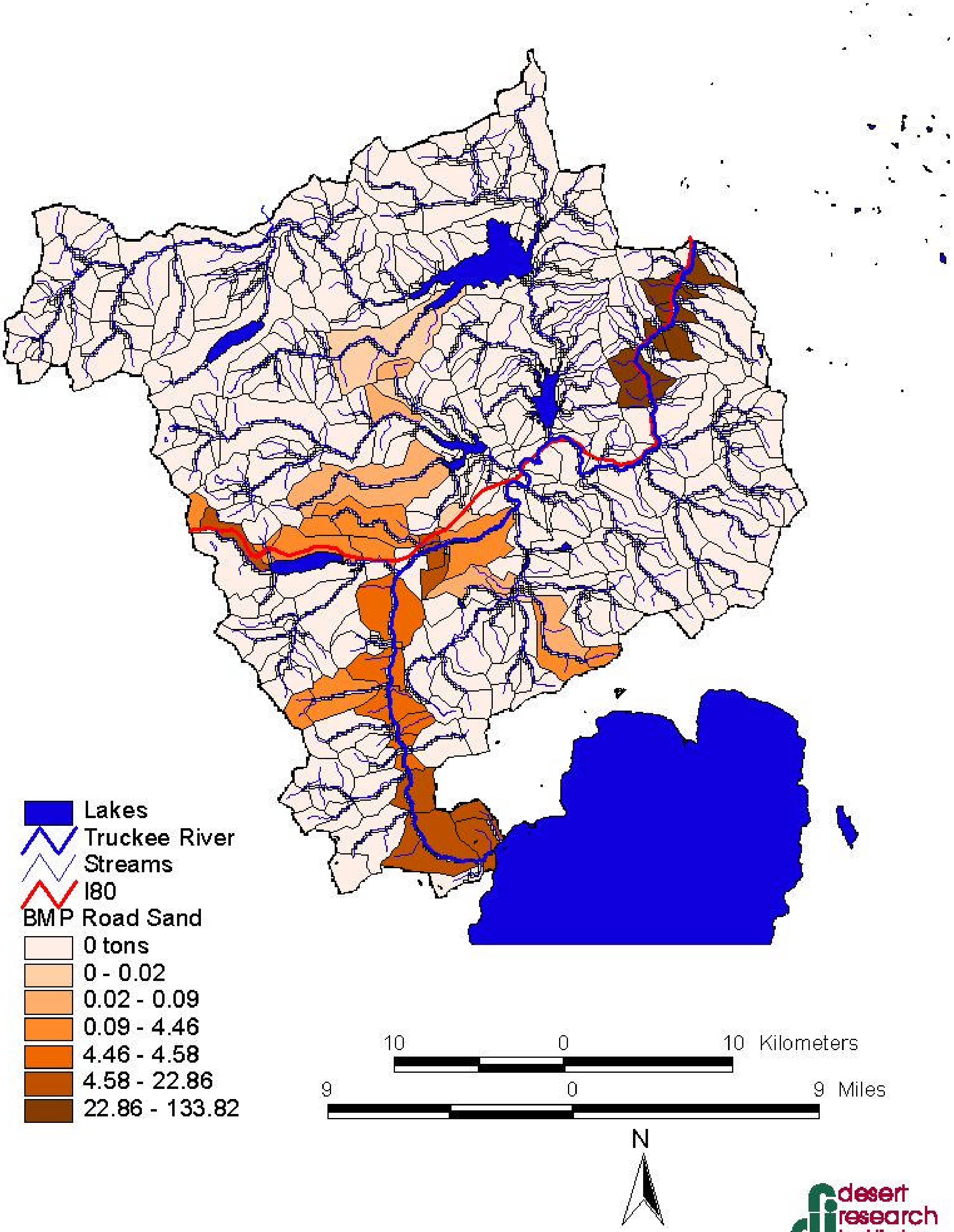


Figure 26. Decrease in suspended sediment load under decreased road sand conditions.

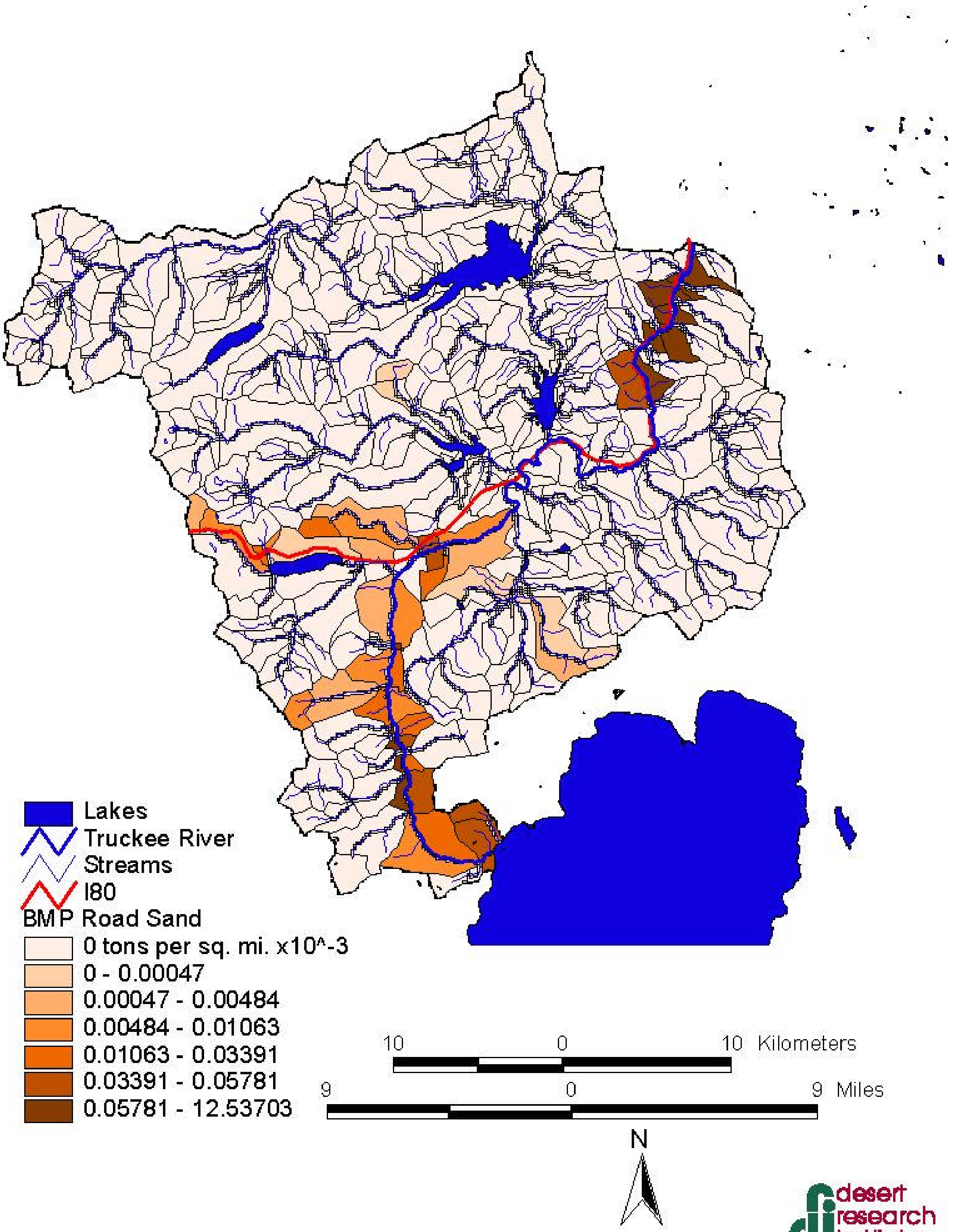


Figure 27. Decrease in suspended sediment load per unit area under decreased road sand conditions.

As shown in Table 15, the only major basin showing a significant decrease in sediment load to the Truckee River as a result of road sand reduction is Trout Creek. Inspection of the basin suggests that when the applied sand leaves the road, it has a short distance to travel before reaching a stream. Once in the stream, either Trout Creek or a tributary transport to the Truckee River is imminent.

Inspection of the entire basin, however, shows significant reductions in sediment load to the Truckee River along Highway 89 South and Interstate 80 and minor reductions along Highway 267. BMPs that result in a 50% reduction in the amount of sand that leaves the road generate a 0.8% reduction in SSC in the Truckee River. Figure 27 shows the estimated reduction in sediment load at each model element.

A second conclusion that can be drawn from the basin-wide analysis is that SSC in the Truckee River resulting from road sand application is inversely proportional to the distance from the River. Through deposition, the watershed has the capacity to absorb sources of sediment such as road sand. The longer a pulse of sediment has to travel overland to reach the stream, the higher probability that a portion of the load will be deposited. It can be expected, then, that sand application on roads relative to their proximity to streams is an important consideration when evaluating where to apply BMPs.

3.5.3.3 Decreased Dirt Road Density

Another potentially important contributor to SSC in the Truckee River is dirt roads, trails, and skid trails.

To assess the potential reduction in SSC to the Truckee River resulting from another BMP, the dirt road density was reduced in the model by 25 and 50%. This reduction manifests itself in the C factor of the RUSLE. Recall that dirt roads extend the channel network and increase the unvegetated area of the basin. Table 16 and Figure 28 show the effect of reducing the dirt road density in the major basins and over the entire Truckee River Basin. Figures 29 and 30 illustrate the basin-wide results.

Table 16. Modeled Reduction in SSC by Decreased Dirt Road Density—Major Basins.

Basin	Calibrated Model 1997 (tons)	BMP Reduced Dirt Road Density by 25% (tons)	Percent Reduction	BMP Reduced Dirt Road Density by 50% (tons)	Percent Reduction
Prosser	1592	1082	32	1000	37
Trout	58	41	30	40	32
Donner	1678	1215	28	1119	33
Gray	1011	748	26	687	32
Little Truckee	3081	2290	26	2106	32
Bronco	579	504	13	462	20
Bear	59	55	8	50	15
Squaw	892	825	7	758	15
Martis	700	648	7	596	15
Juniper	147	137	7	126	15

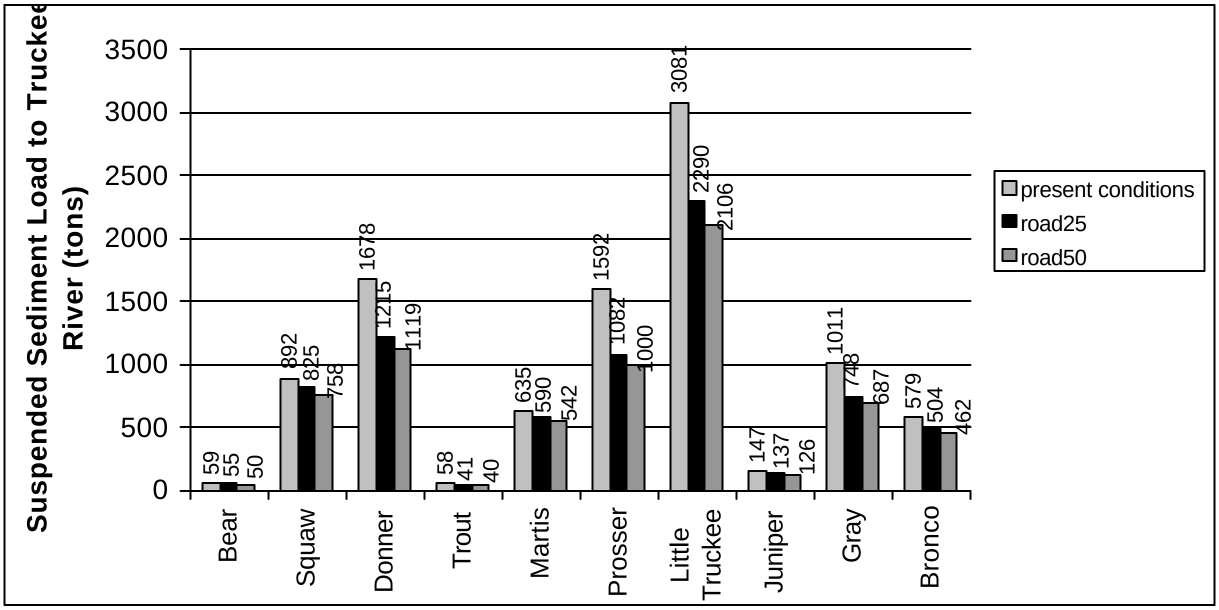


Figure 28. Suspended sediment load to Truckee River under decreased dirt road density—major basins.

Of the major basins, all benefit from a reduction in dirt road density. It is also interesting to note that, for many basins, a decrease in density of 25% is almost as beneficial as a decrease of 50%. Prosser, Trout, Gray, and Little Truckee River experience a large decrease in SSC by a 25% reduction in density but an incrementally small additional drop at a 50% reduction in density. All other major basins continue to exhibit the same rate of decrease in SSC regardless of the reduction in dirt road density.

The entire Truckee River basin experiences a 20% decrease in SSC for a 25% reduction in dirt road density and a 26% decrease in SSC for 50% reduction. From this limited analysis, it is clear that implementation of BMPs to limit the erosion from dirt roads has a significant effect on SSC in the Truckee river. It should also be noted that a 25% reduction in dirt roads (or, implementation of BMPs to eliminate sediment from 25% of the dirt roads) is nearly as beneficial to the SSC in the Truckee River as a 50% reduction in dirt road density.

3.5.3.4 Summary of Best Management Practice Analysis

Three management practices were evaluated with the model: increased canopy cover, decreased road sand, and decreased dirt road density. Conclusions made from this analysis should be viewed in context of the limitation of the model. Locations of disturbance in the basin are unknown; therefore, it is also unknown whether an existing condition (e.g., canopy cover) is a result of past disturbance or natural conditions. However, from this analysis, several conclusions can be made:

First, model results suggest that revegetation of the entire basin (simulated in the model by an increase in canopy cover) results in a 26% decrease in SSC in the Truckee River. However, there is almost no difference in SSC from Martis Creek or Juniper Creek and a 50% and 43% decrease in SSC from Bear Creek and Squaw Creek, respectively. Though variability is high, it is reasonable to expect a significant reduction in SSC to the Truckee River resulting from revegetation.

Though there was a very small improvement resulting from road sand reduction, it is reasonable to assume that appropriate BMPs are more critical in reaches near the stream.

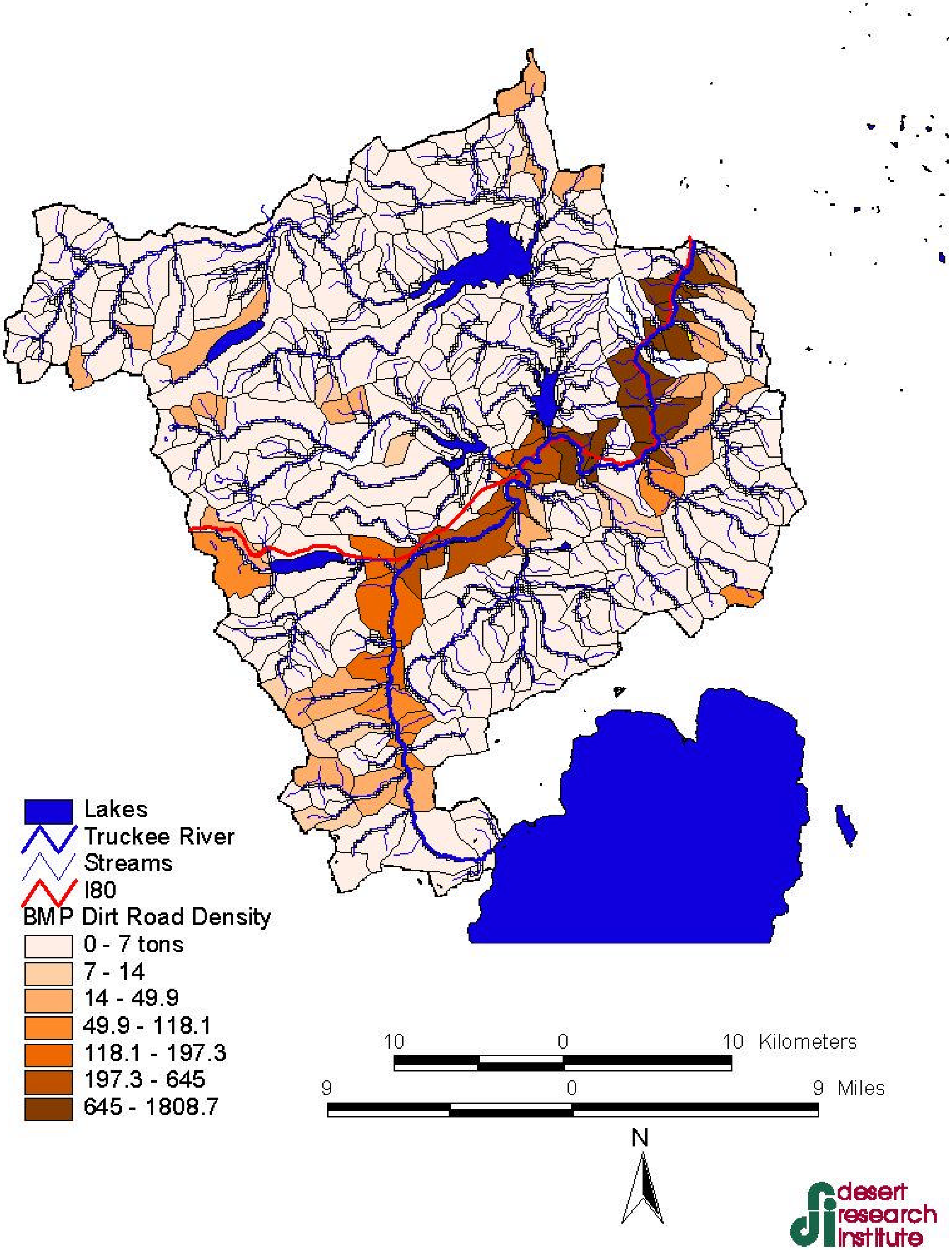
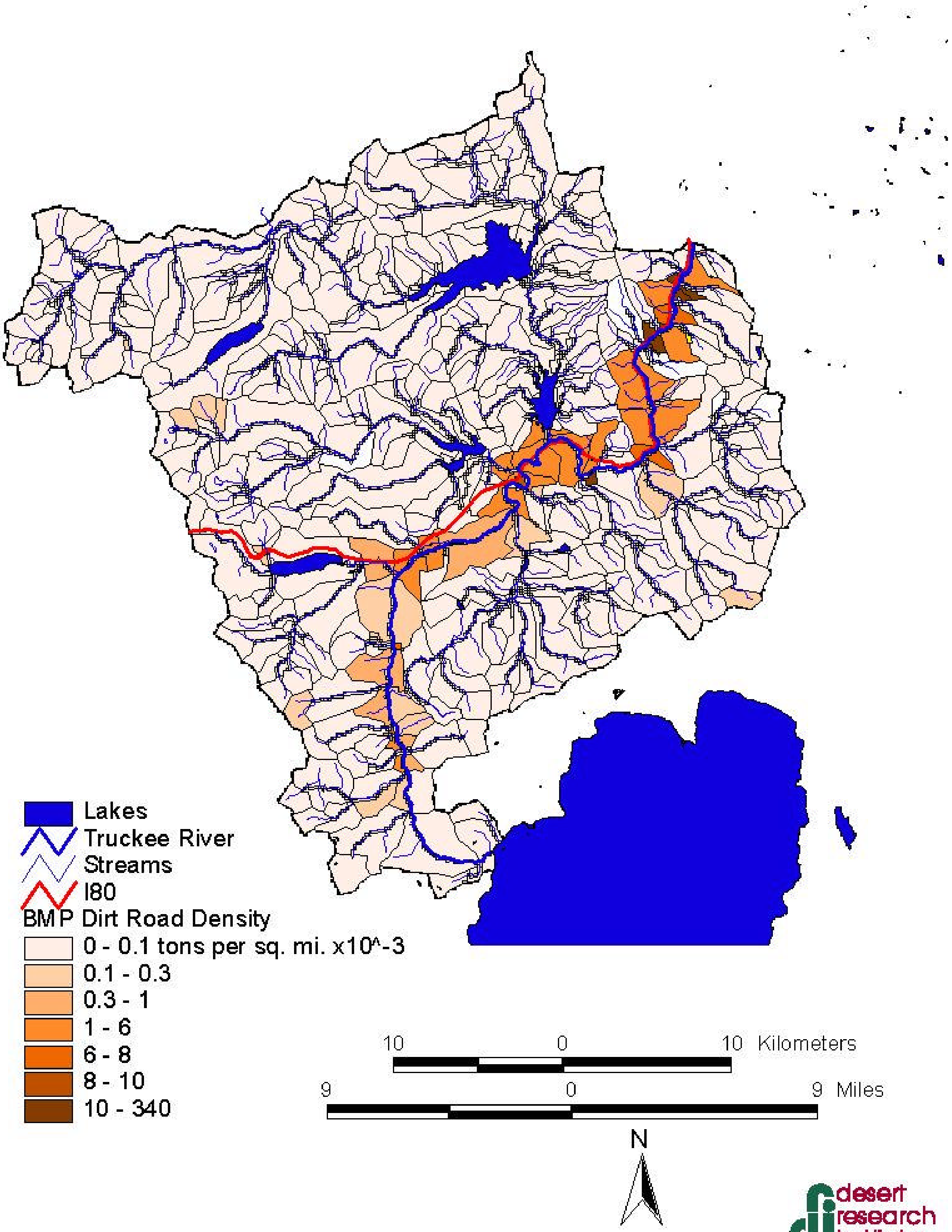


Figure 29. Reduction in sediment load resulting from 50% dirt road density reduction.



desert research institute

Figure 30. Reduction in sediment load per unit area resulting from 50% dirt road density reduction.

According to model results and literature review, all tributaries benefit from a reduction in dirt road density. For a 50% reduction in dirt road density (or, BMPs that reduce sediment from dirt roads), a 26% reduction in SSC in the Truckee River can be expected. However, nearly the same reduction (20%) can be achieved by a 25% reduction in dirt road density.

In addition to the conclusions listed above, it is clear that the relative importance of an area of the basin is inversely related to its distance from the stream. That is, those areas near the stream have a greater effect on SSC in the Truckee River than do those farther away. This phenomenon can be explained by the concept of a basin's sediment capacity. The farther sediment has to travel to reach the stream, the more likely it is to be deposited along the way. In other words, management practices on areas near the stream have a greater effect on SSC. Figure 31 illustrates this conclusion.

4. PROPOSED MONITORING PLAN

The objective of the proposed monitoring plan is to identify sites where additional or new monitoring will validate TMDL elements, assess the adequacy of control actions to implement the TMDL, and provide a basis for *reviewing* and *revising* TMDL elements or control actions in the future. The 'review' and 'revision' of a TMDL address the issue of adaptive management. Adaptive management provides the flexibility to update and modify a plan based on new information and should be an essential component to any monitoring plan.

The following is a discussion of existing monitoring occurring in the Truckee River watershed and a proposed monitoring plan. An effective monitoring plan needs to complement any existing monitoring and add value to the total data set. The proposed monitoring plan will attempt to fill in data gaps and add to or improve existing monitoring plans.

4.1 Existing Monitoring

The purpose of this section is to provide an overview of past and present monitoring activity - including frequency, constituents sampled, sampler, and method.

An examination of the constituents of the many historic monitoring efforts shows that the vast majority of parameters fall into one of five groups: Suspended Sediment (TSS and/or turbidity); Chemical Parameters (major organics, inorganics, and nutrients) Physical Parameters; Biological Parameters, and Discharge.

Historic and present monitoring efforts are described in the discussions, figures, and tables below. Each of the five categories includes a brief discussion of sample method, frequency, and general information concerning the usefulness of the data. The purpose is to provide the reader with the information necessary to make educated decisions about future monitoring plans.

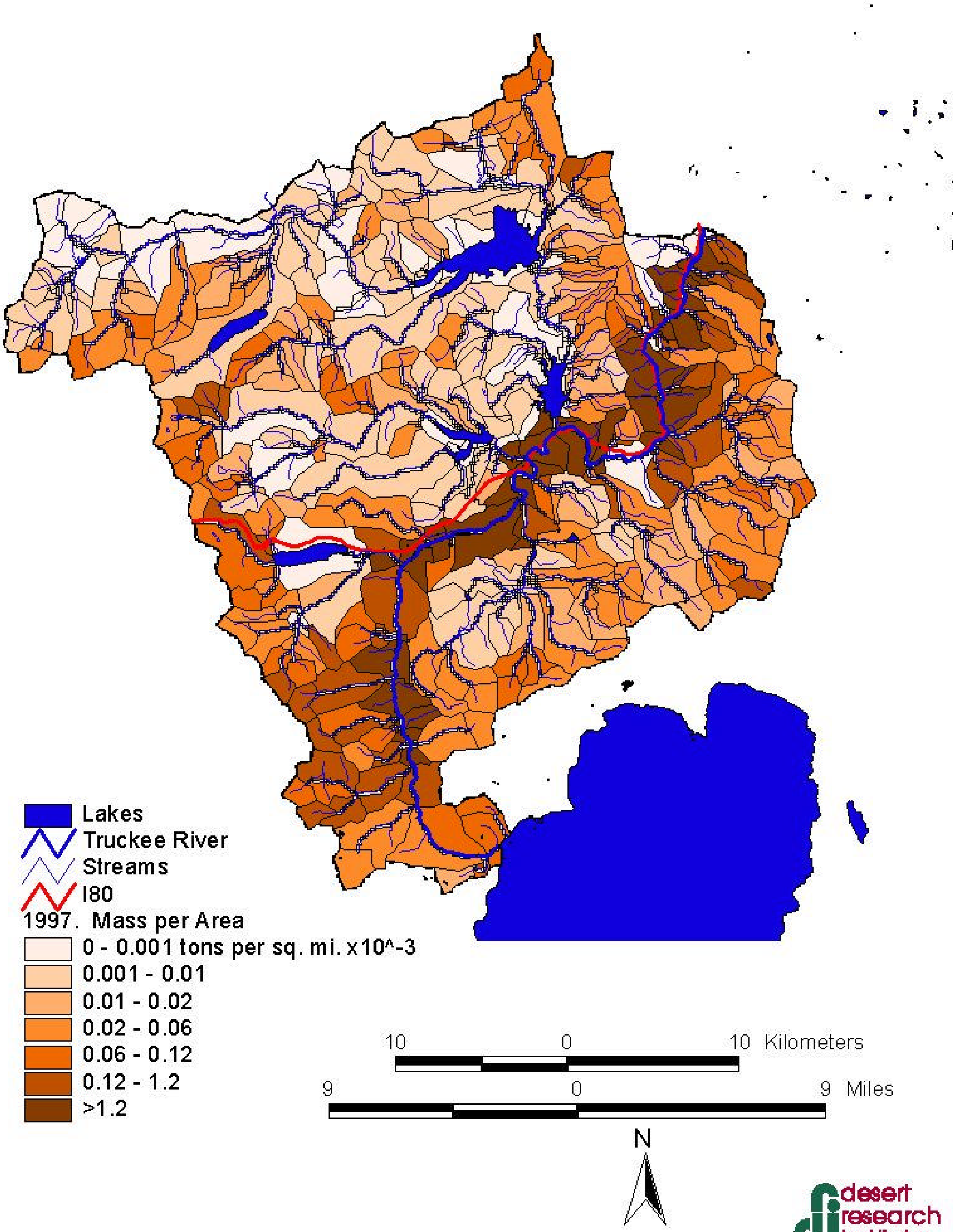


Figure 31. Sediment load per unit area—1997 calibration.

4.1.1 Suspended Sediment

Included in suspended sediments are total suspended solids (TSS); suspended sediment concentration (SSC); total suspended solids (TDS); and turbidity (Tu).

4.1.1.1 Total Suspended Solids (TSS)

Monthly grab samples collected by DRI have traditionally been monitored in the Truckee River for TSS. Most of the available data is that from *Farad*, having been collected since 1979. *Above Donner* and *below Martis Creek* have been analyzed for TSS since April of 1992. Newer locations *at Tahoe City*, *above Martis Creek*, and *above Juniper Creek* have been recorded since September of 1999. The DRI laboratory performs "Physical Properties: Residue, Filterable Gravimetric, Dried at 180°C," USEPA Method No. 160.1.

4.1.1.2 Suspended Sediment Concentration (SSC)

DRI collects "grab" samples as a part of their Truckee River Monitoring Program. The sampling method used by the USGS to collect the samples is the Equal-Discharge-Increment method discussed earlier.

USGS has collected relatively few suspended sediment samples in the Truckee River Basin. Suspended sediment data sets exist for the following locations and periods of record:

- Truckee River at Farad: 2/74- 10/77, 4/93 - 3/95; n=60;
- Sagehen Creek: 5/68 - 8/96; n= 803;
- Martis Creek: 8/73 - 8/95; n= 69.

For suspended sediment samples collected from fluvial waters, the USGS has traditionally analyzed for SSC. The SSC analytical method, ASTM D 3977-97, Standard Test Method for Determining Sediment Concentration in Water Samples (Gray, et al., 2000), is the USGS standard for determining concentrations of suspended material in surface water samples. The SSC analysis is performed on the entire sample, thus measuring the entire sediment mass. Another commonly used measurement of suspended material, the one used for analysis of DRI grab samples is the TSS analytical method. It has been widely used as a measure of suspended material in stream samples because it is mandated, or acceptable, for regulatory purposes and is an inexpensive laboratory procedure. The TSS analysis is usually performed on an aliquot of the original sample.

During the spring snowmelt runoff period, DRI collected integrated suspended sediment samples in the Truckee River at the same locations as the traditional monitoring sites. Samples were also collected in the major tributaries: Bear, Squaw, Donner, Trout, Martis, Juniper, Gray and Bronco Creeks. Samples were collected from March through October of 2000. Because of the problems associated with load computations based on TSS measurements, samples were analyzed for SSC. For the sites located on the Truckee River, both integrated and grab samples were collected for comparative purposes.

4.1.1.3 Turbidity (Tu)

Turbidity is measured continuously in the Truckee River by the SPPCo, the CalDWR, and intermittently by DRI and the USGS. To meet the water supply requirements of the

Reno/Sparks metropolis, SPPCo operates and maintains a water diversion at Farad, California. To provide an early warning signal that SSC might be reaching excessive levels, SPPCo monitors turbidity levels of river water at Farad.

CalDWR has set up a network of turbidimeters along the length of the Truckee River. Currently, data from three sites is available: Tahoe City, Bridge 8 (just north of the confluence of Squaw Creek with the Truckee River) and Farad. Three other proposed sites to install instruments are Squaw Creek, near the Trout Creek confluence with the Truckee, and on the Truckee River above Juniper Creek.

DRI laboratories analyzed for turbidity on the same samples that are collected as a part of their Truckee River Monitoring Program and the integrated samples collected for SSC analysis. Turbidity values for Farad have been collected since 1970. *Above Donner* and *below Martis Creek* have been analyzed for turbidity since October of 1998. Newer locations *at Tahoe City, above Martis Creek,* and *above Juniper Creek* contain a record since September of 1999. One turbidity value is available for each year from 1970-1975 for Bronco and Gray Creeks. Samples were also collected in the major tributaries during the snowmelt period of 2000: Bear, Squaw, Donner, Trout, Martis, Juniper, Gray and Bronco Creeks. Samples were collected from March through October of 2000.

The USGS sampled for turbidity at various locations in the basin in the Truckee River at Farad, in Martis Creek and Sagehen Creek. The most extensive of these is the Sagehen Creek data set, which extends from 1983 through 1996. Farad data extends from 1974 to 1983 and again from 1993 through 1996. Martis data extends from 1973 through 1995. The sample method was integrated; however, the sample analysis method is unknown.

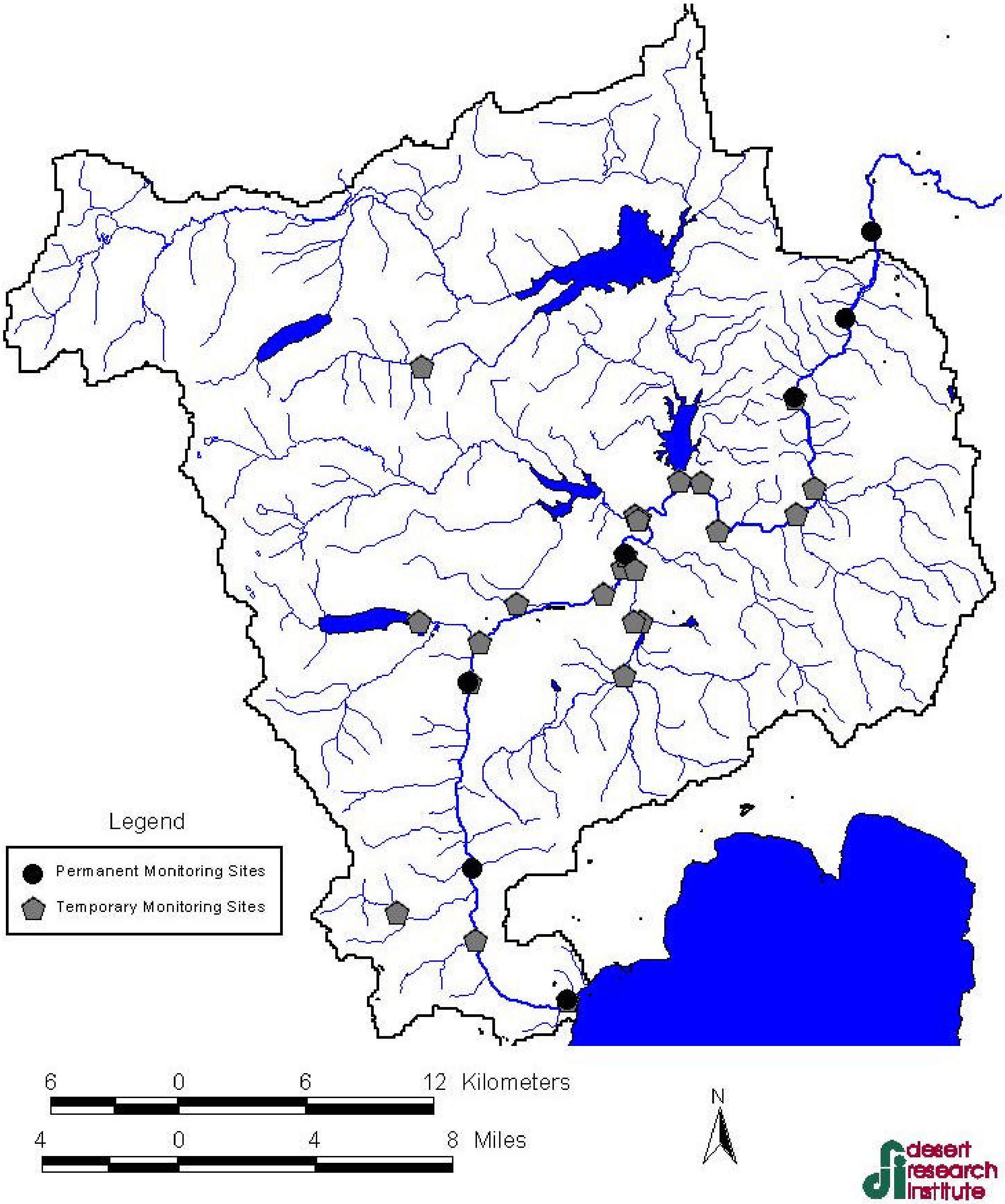


Figure 32. Existing sediment and turbidity monitoring sites.

Table 17. Truckee River basin watershed monitoring sites, sediment parameters.

Location	Sampled By	Constituent	Sample Freq.	Reported	Begin	End	Method
Truckee R. @ Tahoe City	DRI	TU, SSC			04/01/00	10/01/00	integrated
Truckee R. @ Tahoe City	Cal DWR	turbidity	hourly	hourly	2/18/00	present	point
Truckee R. @ Bridge 8	Cal DWR	turbidity	hourly	hourly	3/22/00	present	
Truckee R. above Donner Creek	DRI	TU, TSS	monthly	monthly	10/2/91	present	grab
Truckee R. above Donner Creek	DRI	TU, SSC			04/01/00	10/01/00	integrated
Truckee R. above Martis Creek	DRI	TU, SSC			04/01/00	10/01/00	integrated
Truckee R. near Polaris	TTSA	alk, Cl- , DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly			grab
Truckee R. below Martis Creek	DRI	TU, SSC			04/01/00	10/01/00	integrated
Truckee R. below Martis Creek	TTSA	alk, Cl- , DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly	1978	present	grab
Truckee R. Above Juniper Creek	DRI	TU, SSC			04/01/00	10/01/00	integrated
Truckee R. @ Farad, CA	DRI	TSS	monthly	monthly	1/9/80	present	grab
Truckee R. @ Farad, CA	DRI	TU	monthly	monthly	1/4/79	present	grab
Truckee R. @ Farad, CA	DRI	TU, SSC			4/1	10/1	integrated
Truckee R. @ Farad, CA	Sierra Pacific	turbidity	hourly	daily average	1996	present	point
Truckee R. @ Farad, CA	Cal DWR	turbidity	hourly	hourly	3/24/00	present	point
Near Stateline	TTSA	alk, Cl- , DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly	1978	present	grab
Truckee R. @ Farad, CA	USGS	Sediment					
Truckee R. @ Verdi, NV	Sierra Pacific	turbidity	hourly	ave dialy	1/1/96	present	point
Bear Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Squaw Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
North Fork Squaw Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Donner Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Trout Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Martis Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Martis Creek Lake near Truckee	USGS	Sediment			8/16/73	8/12/85	
Martis Creek Lake near Truckee	USGS	Sediment			8/16/73	8/14/95	
Martis Creek near Truckee	USGS	Sediment			8/16/73	8/14/95	
Sagehen Creek	USGS	Sediment			5/20/68	8/6/96	integrated
below Prosser Creek Dam	DRI	SSC, Tu			04/01/00	10/01/00	integrated
below Boca Dam	DRI	SSC, Tu			04/01/00	10/01/00	integrated
Juniper Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Gray Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Gray Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	approx. annual	approx. annual	05/17/68	24-Jul-75	grab
Bronco Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Truckee R. @ Tahoe City	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Bear Creek	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Squaw Creek	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Truckee R. above Donner Creek	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Donner Creek	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Truckee R. below Donner Creek near Truckee	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Trout Creek	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Truckee R below Prosser Creek, near Truckee	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Prosser Creek at mouth near Truckee	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Little Truckee River below Boca Dam	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Truckee R. @ Farad, CA	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Martis Creek at Mouth @ Truckee R. near Truckee	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	

4.1.2 Chemical constituents (dissolved and total)

Chemical constituents include nutrients, organics, and inorganics.

DRI has been collecting monthly grab samples to be analyzed for constituents since the mid 60’s *at Farad*, *above Donner Creek* since 1989, and *below Martis Creek* since 1991. Sites *at Tahoe City, above Martis Creek*, and *above Juniper Creek* have been monitored since September of 1999. These samples are analyzed for nutrients and major cations and anions at DRI. Results are returned to the Nevada Division of Environmental Protection.

The Tahoe-Truckee Sanitation Agency (TTSA) collects grab samples to be analyzed for certain constituents at three locals on the Truckee River above and below their sewage treatment facility. The sites are *near Polaris, below Martis Creek* and *near the Stateline*. Sample frequency varies from monthly to bi-monthly depending on the specific constituent. The record extends back to 1978.

USGS data is broken down into nutrients, organics, major inorganics, and minor and trace inorganics. All data was collected using the integrated technique. It should be noted that the USGS did not find elevated levels for any constituent for the Middle Truckee in the last NAWQA study.

Nutrients data collected on the Truckee River before 1980 was *at Tahoe City, at Highway 267 near Truckee, at the old US 40 Bridge below Truckee, at Boca Bridge near Truckee,* and *at Farad,* and at these other locations in watershed: Squaw Creek, Donner Creek, Prosser Creek and the Little Truckee River. More recent sampling was conducted on the Truckee River at Farad in the early 90’s as a part of the USGS’s NAWQA program. Martis Creek and Sagehen Creek also contain an extensive data set through the mid 80’s and 90’s, respectively.

The organics collected in the basin were analyzed primarily for volatile components. The small data set was collected generally before 1980 (except Sagehen, sampled in 1988).

Major inorganics have been sampled throughout the basin from 1960 (*near Truckee*) through the 90’s. Most samples were collected during the 1990 water year. However, extensive records exist for Martis and Sagehen Creeks. An extensive data set is available concerning minor and trace inorganics for the Truckee River *at Tahoe City, near Truckee* and *at Farad*, as well as Sagehen Creek, Martis Creek and Donner Lake.

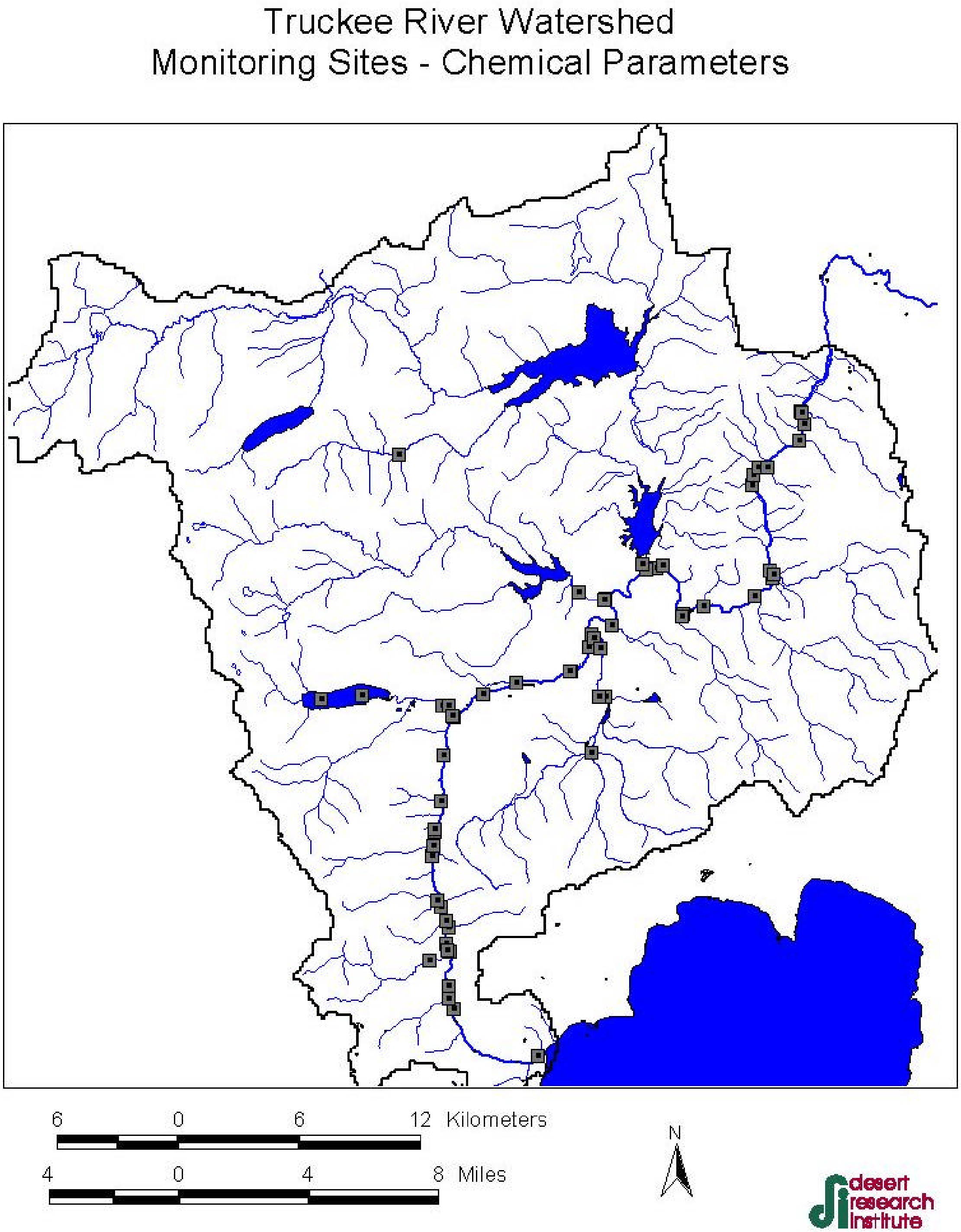


Figure 33. Existing chemical properties monitoring sites.

Table 18. Truckee River basin watershed monitoring sites, chemical parameters.

Location	Sampled By	Constituent	Sample Freq.	Reported	Begin	End	Method
Truckee R. @ Tahoe City	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO4	monthly	monthly	9/1/99	present	grab
Truckee R. @ Tahoe City	USGS	Nutrients			2/22/78	6/8/83	
Truckee R. @ Tahoe City	USGS	Organics			4/21/78	3/21/80	
Truckee R. @ Tahoe City	USGS	Major Inorganics			2/22/78	9/25/80	
Truckee R. @ Tahoe City	USGS	Minor and Trace Inorganics			2/22/78	9/25/80	
Truckee R above Bear Creek, near Alpine Meadows	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee River at HWY 89 Bridge near Squaw Valley	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee River above Squaw Creek near Squaw Valley	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee River below Squaw Creek near Squaw Valley	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee R Tr .4 mi above Pole Creek, near Squaw Valley	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee River above Rocky wash, near Truckee	USGS	Major Inorganics			11/19/90	10/30/91	
Rocky wash at mouth, near Truckee	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee R. near Truckee	USGS	Nutrients			5/1/61	5/9/66	
Truckee R. near Truckee	USGS	Organics			3/21/80	3/21/80	
Truckee R. near Truckee	USGS	Major Inorganics			10/5/60	5/9/66	
Truckee R. near Truckee	USGS	Minor and Trace Inorganics			10/5/60	5/9/66	
Truckee R. above Donner Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	monthly	monthly	10/4/89	present	grab
Truckee R. above Donner Creek near Truckee	USGS	Minor and Trace Inorganics			11/18/90	11/18/90	
Truckee R. below Donner Creek near Truckee	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee R at HWY 267 near Truckee	USGS	Nutrients			6/2/80	8/8/80	
Truckee R at HWY 267 near Truckee	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee R above Trout Creek	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee R. above Martis Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	monthly	monthly	9/1/99	present	grab
Truckee R. near Polaris	TTSA	alk, Cl- , DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly			grab
Truckee R. near Polaris	TTSA	alk, Cl- , DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly			grab
Truckee R. near Polaris	TTSA	NO3-	bimonthly	bimonthly			grab
Truckee R. at Polaris	USGS	Major Inorganics			11/19/90	10/30/91	
TruckeeR. below Martis Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	monthly	monthly	10/2/91	present	grab
TruckeeR. below Martis Creek	TTSA	alk, Cl- , DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly	1978	present	grab
TruckeeR. below Martis Creek	TTSA	alk, Cl- , DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly	1978	present	grab
TruckeeR. below Martis Creek	TTSA	NO3-	bimonthly	bimonthly	1978	present	grab
Truckee R at old US 40 Bridge below Truckee	USGS	Nutrients			6/2/80	8/8/80	
Truckee R at old US 40 Bridge below Truckee	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee R at Boca Bridge near Truckee	USGS	Nutrients			6/2/80	8/8/80	
Truckee R below Prosser Creek, near Truckee	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee R below little Truckee R near Truckee	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee R. Above Juniper Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	monthly	monthly	9/1/99	present	grab
Truckee R near Hirschdale Dump	USGS	Organics			3/25/80	3/25/80	
Truckee R below Juniper Creek near Hirschdale	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee R above Bronco Creek, near Floriston	USGS	Major Inorganics			11/19/90	10/30/91	
Truckee R. @ Farad, CA	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	monthly	monthly	8/11/66	present	grab
Near Stateline	TTSA	alk, Cl- , DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly	1978	present	grab
Near Stateline	TTSA	alk, Cl- , DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly	1978	present	grab
Near Stateline	TTSA	NO3-	bimonthly	bimonthly	1978	present	grab
Truckee R. @ Farad, CA	USGS	Nutrients					
Truckee R. @ Farad, CA	USGS	Organics					

Table 18. Truckee River basin watershed monitoring sites, chemical parameters (continued).

Truckee R. @ Farad, CA	USGS	Major Inorganics		
Truckee R. @ Farad, CA	USGS	Minor and Trace Inorganics		
Truckee R. below Farad Powerhouse @ Farad, CA	USGS	Nutrients	4/1/92	9/2/92
Truckee R. below Farad Powerhouse @ Farad, CA	USGS	Major Inorganics	4/1/92	9/2/92
Truckee R. above Fleish power diversion near Verdi	USGS	Major Inorganics	11/20/90	11/20/90
Dewme TSS Cave near Tahoe City	USGS	Nutrients	5/13/93	5/13/93
Dewme TSS Cave near Tahoe City	USGS	Major Inorganics	5/13/93	5/13/93
Dewme TSS Cave near Tahoe City	USGS	Minor and Trace Inorganics	5/13/93	5/13/93
Bear Creek at mouth, near Alpine Meadows	USGS	Major Inorganics	11/19/90	10/30/91
Squaw Creek at Squaw Valley Road at Squaw Valley, CA	USGS	Nutrients	8/8/80	8/8/80
Squaw Creek at HWY 89 near Squaw Valley	USGS	Major Inorganics	11/19/90	10/30/91
Deer Creek 200 fett above mouth, near Squaw Valley	USGS	Major Inorganics	11/19/90	10/30/91
Silver Creek at HWY 89 near Squaw Valley	USGS	Major Inorganics	11/19/90	10/30/91
Pole Creek at mouth near Squaw Valley	USGS	Major Inorganics	11/19/90	10/30/91
Unnamed Tributary upstream of Deep Creek, near Truckee	USGS	Major Inorganics	11/19/90	10/30/91
Deep Creek above Mouth, near Truckee	USGS	Major Inorganics	11/19/90	10/30/91
Cabin Creek at HWY 89, near Truckee	USGS	Major Inorganics	11/19/90	10/30/91
Donner Lake at Sample Point 1 near Truckee	USGS	Nutrients	11/28/72	12/6/73
Donner Lake at Sample Point 1 near Truckee	USGS	Major Inorganics	5/17/73	12/6/73
Donner Lake at Sample Point 1 near Truckee	USGS	Minor and Trace Inorganics	5/17/73	9/13/73
Donner Lake at Sample Point 2 near Truckee	USGS	Nutrients	5/16/73	12/6/73
Donner Lake at Sample Point 2 near Truckee	USGS	Major Inorganics	5/16/73	12/6/73
Donner Lake at Sample Point 2 near Truckee	USGS	Minor and Trace Inorganics	5/16/73	9/13/73
Donner Ck at Donner Lk	USGS	Nutrients	6/2/80	8/8/80
Donner Ck near Truckee	USGS	Organics	3/21/80	3/21/80
Donner Ck at mouth, near Truckee	USGS	Major Inorganics	11/19/90	10/30/91
Trout Creek at mouth, near Truckee	USGS	Major Inorganics	11/19/90	10/30/91
Martis Creek at HWY 267 near Truckee	USGS	Nutrients	8/16/73	10/16/85
Martis Creek at HWY 267 near Truckee	USGS	Organics	8/16/73	8/16/73
Martis Creek at HWY 267 near Truckee	USGS	Major Inorganics	4/23/80	10/16/85
Martis Creek at HWY 267 near Truckee	USGS	Minor and Trace Inorganics	8/16/73	10/16/85
Martis Creek Lake near Truckee	USGS	Nutrients	8/16/73	8/14/95
Martis Creek Lake near Truckee	USGS	Organics	8/16/73	5/1/74
Martis Creek Lake near Truckee	USGS	Major Inorganics	4/23/80	8/14/95
Martis Creek Lake near Truckee	USGS	Minor and Trace Inorganics	8/16/73	8/14/95
Martis Creek near Truckee	USGS	Nutrients	8/16/73	8/14/95
Martis Creek near Truckee	USGS	Organics	8/16/73	5/1/74
Martis Creek near Truckee	USGS	Major Inorganics	4/23/80	8/14/95
Martis Creek near Truckee	USGS	Minor and Trace Inorganics	8/16/73	8/14/95
Martis Creek at Mouth at Truckee R near Truckee	USGS	Organics	3/21/80	3/21/80
Martis Creek at Mouth at Truckee R near Truckee	USGS	Major Inorganics	11/19/90	10/30/91
Union Valley Creek at mouth near Truckee	USGS	Major Inorganics	11/19/90	10/30/91
Sagehen Creek	USGS	Nutrients	5/16/68	8/6/96

Sagehen Creek	USGS	Organics			2/22/88	2/22/88	

Table 18. Truckee River basin watershed monitoring sites, chemical parameters (continued).

Sagehen Creek	USGS	Major Inorganics			5/16/68	8/6/96	
Sagehen Creek	USGS	Minor and Trace Inorganics			5/16/68	8/6/96	
Prosser Creek below Prosser Creek Dam near Truckee	USGS	Nutrients			6/2/80	8/8/80	
Prosser Creek at mouth near Truckee	USGS	Major Inorganics			11/20/90	11/20/90	
Little Truckee River below Boca Dam	USGS	Nutrients			6/2/80	8/8/80	
Juniper Creek at mouth near Hirschdale	USGS	Major Inorganics			11/19/90	10/30/91	
Gray Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	Approx. annual	Approx. annual	05/17/68	24-Jul-75	grab
Bronco Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	Approx. annual	Approx. annual	06/02/67	07/24/75	grab
Bronco Creek at mouth, near Floriston	USGS	Major Inorganics			11/20/90	10/30/91	
Canyon 24 at mouth near Floriston	USGS	Major Inorganics			11/20/90	11/20/90	
Mystic Canyon at mouth near Floriston	USGS	Major Inorganics			11/20/90	11/20/90	
Puny Dip Canyon at mouth near Floriston	USGS	Major Inorganics			11/20/90	11/20/90	
Deep Canyon at mouth near Verdi	USGS	Major Inorganics			11/20/90	11/20/90	

4.1.3 Physical properties

Physical properties include temperature, specific conductance (field and lab), electoconductivity, dissolved oxygen and pH (field and lab).

As a part of the Truckee River monitoring program, DRI has been taking monthly temperature and DO measurements in situ *at Farad* since the mid 60's, *above Donner Creek* since 1989, and *below Martis Creek* since 1991. Sites *at Tahoe City, above Martis Creek,* and *above Juniper Creek* have been monitored since September of 1999. Measurements for electroconductivity and pH are completed on the grab samples in the laboratory.

Historic USGS data on the physical properties is available for the Truckee River and most of its major tributary waters. Data begins in 1960 (*near Truckee*) and runs through the mid-90's, although continuous data is atypical. Most samples were taken during the 1990 water year for the NAWQA study, however a long record exists for Sagehen and Martis Creeks.

TTSA collects grab samples to be analyzed for certain constituents at three sites on the Truckee River above and below their sewage treatment facility. The sites are *near Polaris, below Martis Creek* and *near the Stateline*. Sample frequency varies from monthly to bi-monthly depending on the specific constituent. The record extends to 1978.

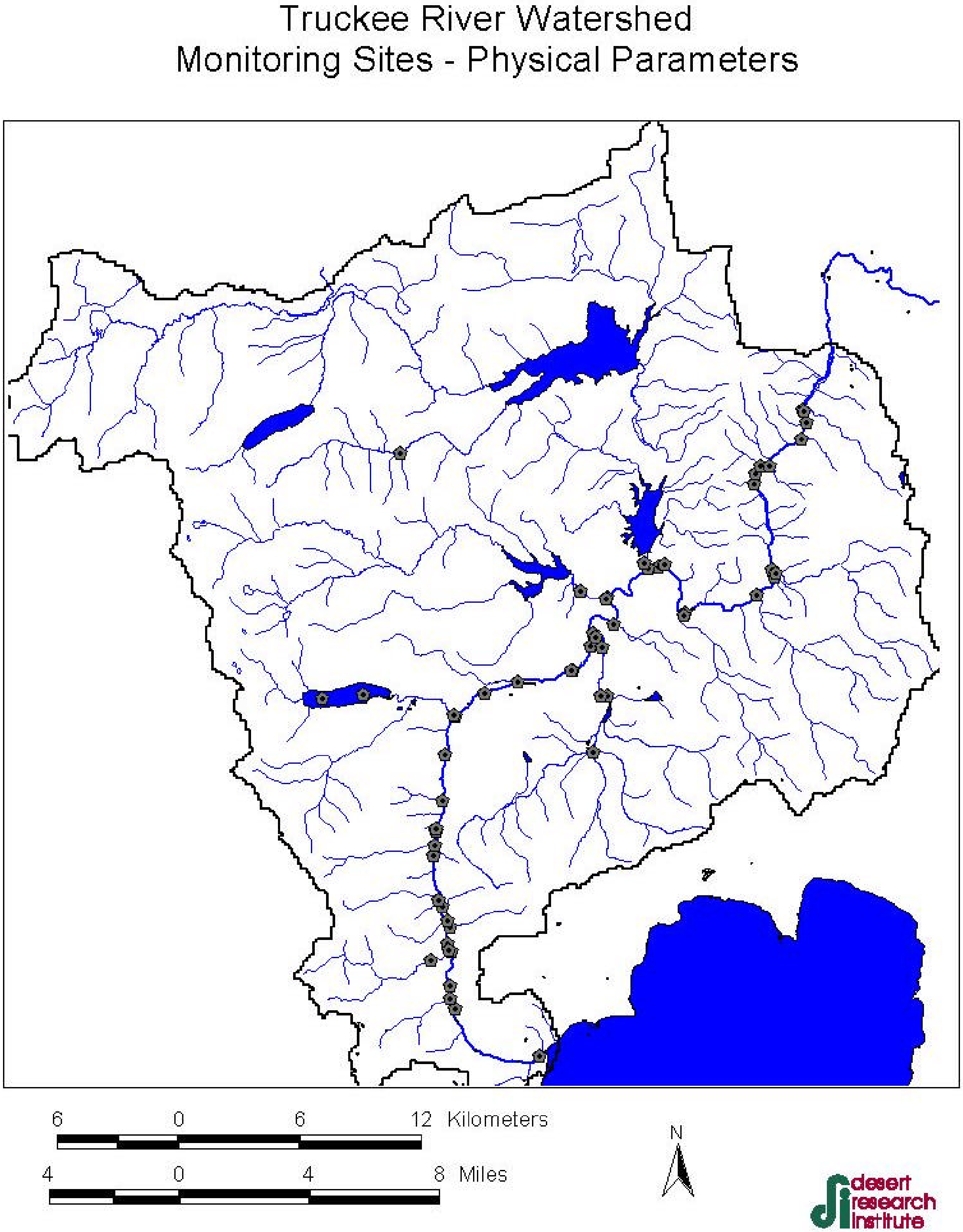


Figure 34. Existing physical properties monitoring sites.

Table 19. Truckee River basin watershed monitoring sites, physical parameters.

Location	Sampled By	Constituent	Sample Freq.	Reported	Begin	End	Method
Truckee R. @ Tahoe City	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO5	monthly	monthly	9/1/99	present	grab
Truckee R. @ Tahoe City	USGS	Physical Property			2/22/78	6/8/83	
Truckee R above Bear Creek, near Alpine Meadows	USGS	Physical Property			11/19/90	10/30/91	
Truckee River at HWY 89 Bridge near Squaw Valley	USGS	Physical Property			11/19/90	10/30/91	
Truckee River above Squaw Creek near Squaw Valley	USGS	Physical Property			11/19/90	10/30/91	
Truckee River below Squaw Creek near Squaw Valley	USGS	Physical Property			11/19/90	10/30/91	
Truckee R Tr .4 mi above Pole Creek, near Squaw Valley	USGS	Physical Property			11/19/90	10/30/91	
Truckee River above Rocky wash, near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Rocky wash at mouth, near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Truckee R. near Truckee	USGS	Physical Property			10/5/60	5/9/66	
Truckee R. above Donner Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	monthly	monthly	10/4/89	present	grab
Truckee R. above Donner Creek near Truckee	USGS	Physical Property			11/18/90	11/18/90	
Truckee R. below Donner Creek near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Truckee R at HWY 267 near Truckee	USGS	Physical Property			6/2/80	10/30/91	
Truckee R above Trout Creek	USGS	Physical Property			11/19/90	10/30/91	
Truckee R. above Martis Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	monthly	monthly	9/1/99	present	grab
Truckee R. near Polaris	TTSA	alk, Cl-, DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly			grab
Truckee R. at Polaris	USGS	Physical Property			11/19/90	10/30/91	
TruckeeR. below Martis Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	monthly	monthly	10/2/91	present	grab
TruckeeR. below Martis Creek	TTSA	alk, Cl-, DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly	1978	present	grab
Truckee R at old US 40 Bridge below Truckee	USGS	Physical Property			6/2/80	10/30/91	
Truckee R at Boca Bridge near Truckee	USGS	Physical Property			6/2/80	8/8/80	
Truckee R below Prosser Creek, near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Truckee R below little Truckee R near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Truckee R. Above Juniper Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	monthly	monthly	9/1/99	present	grab
Truckee R below Juniper Creek near Hirschdale	USGS	Physical Property			11/19/90	10/30/91	
Truckee R above Bronco Creek, near Floriston	USGS	Physical Property			11/19/90	10/30/91	
Truckee R. @ Farad, CA	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	monthly	monthly	8/11/66	present	grab
Near Stateline	TTSA	alk, Cl-, DO, T & F coli, MBNAS, soluble TOC, TKN, turbidity, Fe, pH, OP, TP, TDS, temp	monthly	monthly	1978	present	grab
Truckee R. @ Farad, CA	USGS	Physical Property					
Truckee R. below Farad Powerhouse @ Farad, CA	USGS	Physical Property			4/1/92	9/2/92	
Truckee R. above Fleish power diversion near Verdi	USGS	Physical Property			11/20/90	11/20/90	
Dewme TSS Cave near Tahoe City	USGS	Physical Property			5/13/93	5/13/93	
Bear Creek at mouth, near Alpine Meadows	USGS	Physical Property			11/19/90	10/30/91	
Squaw Creek at Squaw Valley Road at Squaw Valley, CA	USGS	Physical Property			8/8/80	8/8/80	
Squaw Creek at HWY 89 near Squaw Valley	USGS	Physical Property			11/19/90	10/30/91	
Deer Creek 200 fett above mouth, near Squaw Valley	USGS	Physical Property			11/19/90	10/30/91	
Silver Creek at HWY 89 near Squaw Valley	USGS	Physical Property			11/19/90	10/30/91	
Pole Creek at mouth near Squaw Valley	USGS	Physical Property			11/19/90	10/30/91	
Unnamed Tributary upstream of Deep Creek, near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Deep Creek above Mouth, near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Cabin Creek at HWY 89, near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Donner Lake at Sample Point 1 near Truckee	USGS	Physical Property			11/28/72	12/6/73	
Donner Lake at Sample Point 2 near Truckee	USGS	Physical Property			5/16/73	12/6/73	
Donner Ck at Donner Lk	USGS	Physical			6/2/80	8/8/80	
Donner Ck at mouth, near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Trout Creek at mouth, near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Martis Creek at HWY 267 near Truckee	USGS	Physical Property			8/14/73	10/16/85	

Table 19. Truckee River basin watershed monitoring sites, physical parameters (continued).

Martis Creek Lake near Truckee	USGS	Physical Property			5/1/74	8/14/95	
Martis Creek near Truckee	USGS	Physical Property			8/14/73	8/14/95	
Martis Creek at Mouth at Truckee R near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Union Valley Creek at mouth near Truckee	USGS	Physical Property			11/19/90	10/30/91	
Sagehen Creek	USGS	Physical Property			5/16/68	8/6/96	
Prosser Creek below Prosser Creek Dam near Truckee	USGS	Physical Property			6/2/80	8/8/80	
Prosser Creek at mouth near Truckee	USGS	Physical Property			11/20/90	11/20/90	
Little Truckee River below Boca Dam	USGS	Physical Property			6/2/80	8/8/80	
Juniper Creek at mouth near Hirschdale	USGS	Physical Property			11/19/90	10/30/91	
Gray Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	approx. annual	approx. annual	05/17/68	24-Jul-75	grab
Bronco Creek	DRI	TPO4, OPO4, NO2, NH4, TDS, TSS, TKN, color, TU, pH, EC, HCO3, CO3, Cl, SO4, Na, K, Ca, Mg, Si, NO3	approx. annual	approx. annual	06/02/67	07/24/75	grab
Bronco Creek at mouth, near Floriston	USGS	Physical Property			11/20/90	10/30/91	
Canyon 24 at mouth near Floriston	USGS	Physical Property			11/20/90	11/20/90	
Mystic Canyon at mouth near Floriston	USGS	Physical Property			11/20/90	11/20/90	
Puny Dip Canyon at mouth near Floriston	USGS	Physical Property			11/20/90	11/20/90	
Deep Canyon at mouth near Verdi	USGS	Physical Property			11/20/90	11/20/90	

4.1.4 Biological measurements

Fecal coliform and streptococci; Total coliform and E. Coli; Periphyton (chlorophyll A and B), periphyton biomass; Phytoplankton (chlorophyll A and B), phytoplankton (total count), identification of predominant forms; and Macroinvertebrate analysis.

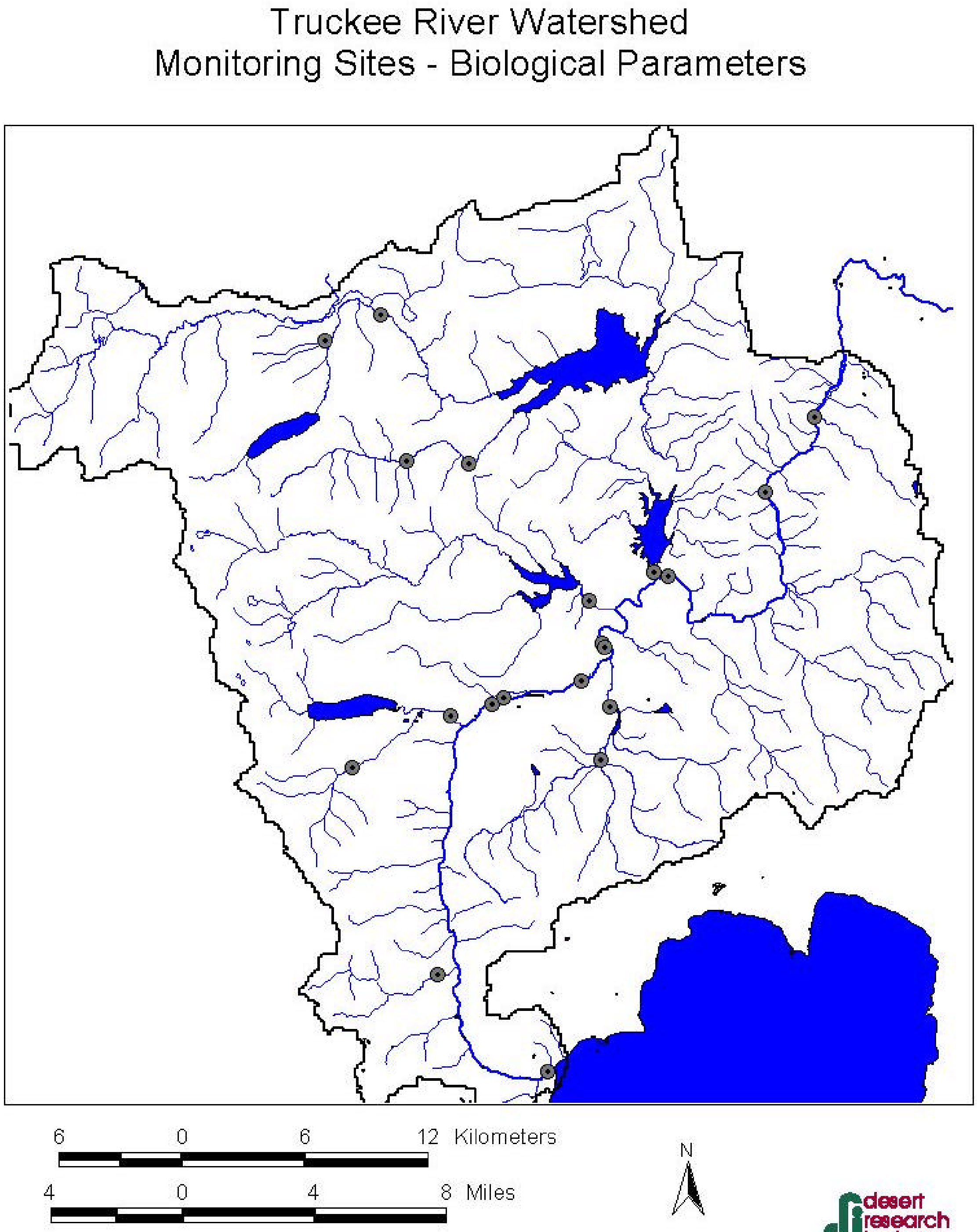
DRI has been conducting monthly monitoring for Fecal and Total coliform and E. coli since the mid 60's *at Farad*, *above Donner Creek* since 1989, and *below Martis Creek* since 1991. Newer locations along the Middle Truckee include *at Tahoe City, above Martis Creek,* and *above Juniper Creek* since September of 1999. The grab samples are analyzed by the Nevada State Health Laboratory at the UNR campus, and results are submitted to NDEP. This represents the longest continuous data set for biological measurements.

TTSA collects monthly grab samples to be analyzed for certain constituents at three locals on the Truckee River above and below their sewage treatment facility. The sites are *near Polaris*, *below Martis Creek* and *near the Stateline*. The record extends back to 1978 for these constituents.

The USGS has also sampled for certain constituents on the Truckee River and in some of the tributaries during 1980. Truckee River sites included*: at Tahoe City, at Highway 267 near Truckee, at the old US 40 Bridge below Truckee, at Boca Bridge near Truckee,* and *at Farad*. Biological information was also collected in Squaw Creek, Donner Creek and Martis Creek at this time. Sampling in Sagehen Creek has occurred from 1969-1996. Samples are collected by the integrated technique.

Two groups have recently collected macroinvertebrate samples in the Middle Truckee watershed. The Sierra Nevada Aquatic Research Lab (SNARL) collected samples in August and September of 2000 from the following sub-basins: Squaw Creek (at 6 different sites including the north and south tributaries of Squaw Creek), Bear Creek, Prosser Creek, Pole Creek, Sagehen Creek, the Little Truckee River and Cold Creek. General Creek, located in the Tahoe basin, was sampled for comparative purposes. Samples are currently being analyzed at the SNARL lab in Mammoth, California.

The Truckee River Aquatic Monitoring (TRAM) citizen's group has sampled six sites: Cold Creek, Trout Creek, Martis Creek, Sagehen Creek, Independence Creek, and the Little Truckee River. Samples were taken in the summers of 1999 and 2000. The 2000 samples are currently being processed. One sample will be analyzed by TRAM, while the others will be sent off for laboratory analysis. Historic data exists for the Prosser Creek and Sagehen Creek watersheds.



Truckee River Watershed
Monitoring Sites - Biological Parameters

Figure 35. Biological properties monitoring sites.

Table 20. Truckee River basin watershed monitoring sites, biological parameters.

Location	Sampled By	Constituent	Sample Freq. Reported	Begin	End	Method
Truckee R. @ Tahoe City	USGS	Biological		6/2/80	8/8/80	
Truckee R at HWY 267 near Truckee	USGS	Biological		6/2/80	8/8/80	
Truckee R at old US 40 Bridge below Truckee	USGS	Biological		8/8/80	8/8/80	
Truckee R at Boca Bridge near Truckee	USGS	Biological		8/8/80	8/8/80	
Truckee R. @ Farad, CA	USGS	Biological				
Squaw Creek at Squaw Valley Road at Squaw Valley, CA	USGS	Biological		8/8/80	8/8/80	
Cold Stream	TRAM	macroinvertebrates		7/31/00	7/31/00	
Donner Ck at Donner Lk	USGS	Biological		6/2/80	8/8/80	
Trout Creek	TRAM	macroinvertebrates		07/08/00	07/08/00	
Martis Creek at HWY 267 near Truckee	TRAM	macroinvertebrates		8/23/00	8/23/00	
Martis Creek near Truckee	USGS	Biological		6/2/80	6/2/80	
Sagehen Creek	USGS	Biological		4/23/69	8/6/96	
Sagehen Creek	TRAM	macroinvertebrates		6/22/00	6/22/00	
Independence Creek	TRAM	macroinvertebrates		10/11/99	10/11/99	
Prosser Creek below Prosser Creek Dam near Truckee	USGS	Biological		6/2/80	8/8/80	
Little Truckee	TRAM	macroinvertebrates		09/18/99	09/18/99	
Little Truckee River below Boca Dam	USGS	Biological		6/2/80	8/8/80	

4.1.5 Streamflow

Streamflow in the basin is continuously monitored by the USGS. Water discharge measurements are available at the following website: http://s601dcascr.wr.usgs.gov/Sites/h1605.html. This web site displays the real time USGS gaging stations locations, and provides links to historical streamflow values.

Surface water monitoring sites presently include (station # in parenthesis): Truckee River at Tahoe City (10337500), Truckee River near Truckee (10338000) Donner Lake near Truckee (10338400), Donner Creek at Donner Lake (10338500), Donner Creek at Hwy 89 near Truckee (10338700), Martis Creek near Truckee (10339400), Prosser Creek Reservoir near Truckee (10340300), Prosser Cr below Prosser Dam (10340500), Independence Lake near Truckee (10342900), Independence Cr nr Truckee (10343000), Stampede Reservoir near Boca (10344300), Little Truckee R above Boca (10344400), Boca Reservoir near Truckee (10344490), Lower Truckee River below Boca Dam (10344500), and Truckee R at Farad (10346000).

The flow conditions at these sites are updated every 15 minutes. All values are considered provisional data and are subject to revision until published in the USGS Annual Water Resources Data Report. In this document, daily average flow values are reported, and statistical summaries, such as monthly and yearly averages, are provided. Flow data is also available for Bronco Creek near Floriston for water years 1993-1997.

Flow is based on stage-discharge relations (Figure 36). The stage is measured by a pressure transducer, which is then converted to a flow value based on the rating curve for the station. The rating curves are adjusted once per month, at which time the stage is recorded and discharge is measured.

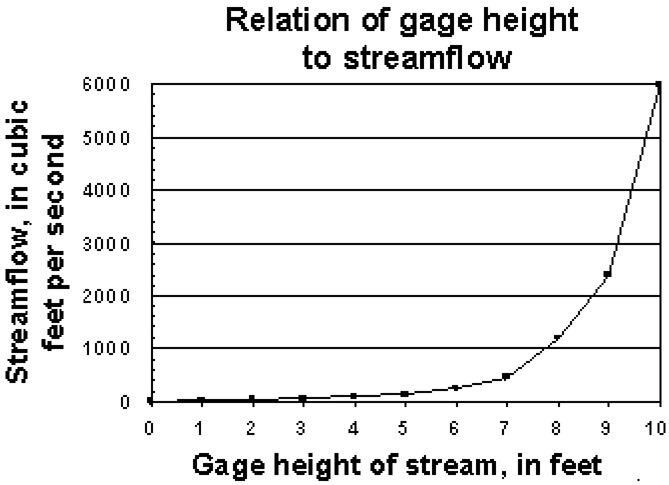


Figure 36. Typical streamflow rating curve.

After determining the stream width, spacing of the verticals is calculated so that between 20-30 verticals would be used to measure velocity at the cross section. (An exception would be the case where streams are less than 5 ft wide, where vertical spacing widths would be 0.5 ft.) At each vertical, velocity, depth, and distance from the initial point is recorded. Velocity measurements are taken at 0.6 of the depth for streams less than 2.5

feet deep, or recorded as the average of the .2 and .8 depth velocities for streams deeper than this. Recorded measurements reflect the velocity averaged over a several minute time interval. Once the velocity, depth, and distance of the cross section were determined, the mid-section method was used to determine the discharge in each increment, according to the equation:

$$Q_n = (w_{i+1} - w_i)\left(\frac{d_{i+1} + d_i}{2}\right)\left(\frac{v_{i+1} + v_i}{2}\right), \qquad (25)$$

where n is the individual increment number, w_i is the horizontal distance from the initial point, d_i is the water depths for each section, and v_i is the measured velocity for each section. The total stream discharge is computed simply as the sum of the increment discharges. If any of the individual segments was originally in excess of ten percent of the total discharge, the segment was broken down into a smaller increment until this criteria was fulfilled.

To compute instantaneous suspended sediment discharge, DRI measured flow at the same time SSC samples were taken in tributaries to the Truckee River. Ten to 23 SSC and flow rate values were recorded for Bear, Squaw, Trout, Martis, Juniper, Gray and Bronco Creeks. Standard USGS protocols (explained above) were followed for the measurement of discharge.

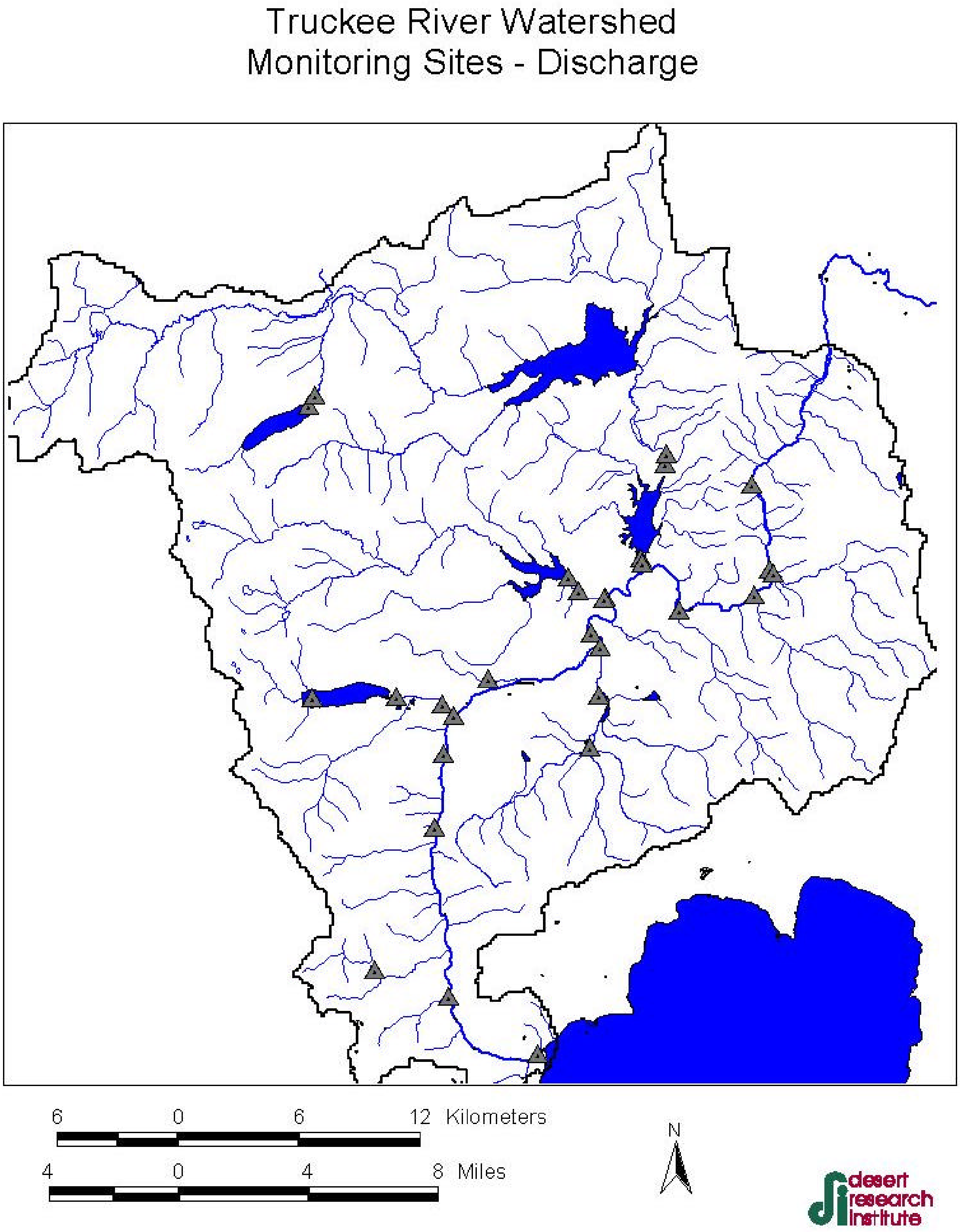


Figure 37. Existing streamflow monitoring sites.

Table 21. Truckee River basin watershed monitoring sites, discharge.

Location	Sampled By	Constituent	Sample Freq.	Reported	Begin	End	Method
Truckee R. @ Tahoe City	USGS	discharge	15 min intervals	daily max/min/mean	1/1/99	present	
Truckee R. near Truckee	USGS	discharge	15 min intervals	daily max/min/mean	12/1/44	9/30/61	
Truckee R. near Truckee	USGS	discharge	15 min intervals	daily max/min/mean	06/28/77	9/30/82	
Truckee R. near Truckee	USGS	discharge	15 min intervals	daily max/min/mean	10/1/92	9/30/95	
Truckee R. near Truckee	USGS	discharge	15 min intervals	daily max/min/mean	10/1/96	9/30/99	
Truckee R. @ Farad, CA	USGS	discharge	15 min intervals	max/min/mean	1/1/09	present	
Bear Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Squaw Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
North Fork Squaw Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Donner Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Donner Lk near Truckee	USGS	discharge			NA	present	
Donner Ck at Donner Lk	USGS	Discharge			1/1/29	present	
Donner Ck @ HWY 89 near Truckee	USGS	Discharge			3/24/93	present	
Trout Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Martis Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Martis Creek near Truckee	USGS	Discharge			10/01/58 - 11/04/90	06/16/93 -pres	
Prosser Creek Res near Truckee	USGS	discharge			NA	present	
Prosser Creek below Prosser Creek Dam near Truckee	USGS	discharge			10/01/1942 - 12/31/1950	07/01/1951 - pres	
Independence Lk near Truckee	USGS	discharge			NA	present	
Independence Creek near Truckee	USGS	discharge			08/01/68	present	
Stampede Res near Boca	USGS	discharge			NA	NA	
Little Truckee River above Boca Dam	USGS	discharge			09/01/39	present	
Boca Res near Truckee	USGS	discharge			NA	NA	
Little Truckee River below Boca Dam	USGS	discharge			01/01/11 - 09/30/15	01/01/39 - pres	
Juniper Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Gray Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Bronco Creek	DRI	SSC, Tu, discharge			04/01/00	10/01/00	integrated
Bronco Creek at mouth, near Floriston	USGS	Discharge			4/23/93	10/08/98	
Truckee R. @ Tahoe City	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Bear Creek	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Squaw Creek	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Truckee R. above Donner Creek	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Donner Creek	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Truckee R. below Donner Creek near Truckee	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Trout Creek	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Truckee R below Prosser Creek, near Truckee	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Prosser Creek at mouth near Truckee	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Little Truckee River below Boca Dam	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Truckee R. @ Farad, CA	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	
Martis Creek at Mouth at Truckee R near Truckee	LRWQCB	discharge, TU, TSS			1/1/96	12/31/96	

4.2 Proposed Monitoring

It is critical that a complete monitoring plan meets the goals of the users of the data. As a result of conducting this study and discussions with the Technical Advisory Committee (TAC) Monitoring Subcommittee, it is clear that more integrated, in-stream suspended sediment data needs to be collected. For example, Table 4 shows the wide range of uncertainty in the predicted sediment load. An increase in number of integrated samples will reduce the uncertainty range and lend more confidence in the prediction. In-stream suspended sediment concentrations (and sediment loads) are directly related to the beneficial uses outlined above. Also, in-stream concentration encompasses all the sediment-producing processes in the basin and is therefore an appropriate evaluation of upland land management processes.

Another issue is the frequency of sampling. Integrated samples are time-consuming and costly. A review of the existing monitoring program reflects the difficulty in collecting integrated samples - especially during snowmelt floods and the short-duration, high-intensity rain events typical of late summer and early fall. A solution to this problem is to remotely collect continuous (or discrete at short time intervals) turbidity. As discussed above, there is a deterministic relationship between turbidity and suspended sediment loads.

The relationship can be determined through development of a SSC-turbidity rating curve. Development of the rating curve requires integrated sampling at the full range of expected flows. Once the rating curve is established, the near-continuous turbidity data can be converted to SSC. The advantages of this method are a long-term cost savings and ability to practically obtain data during short-duration events—data that typically has not been obtained because of logistics.

One disadvantage to this technique is the bias toward fine-grained sediment (discussed above). Also, the correlation between SSC and turbidity will not be perfect and additional error will be introduced to the estimates. The authors feel, however, that these concerns are easily outweighed by the quantity of data able to be collected, the relative ease of data acquisition, and the low total cost. Also, additional analysis should be performed on grain size distribution of samples.

Currently, the CalDWR has set up a network of turbidimeters along the length of the Truckee River. At the time this report was written, data from three sites was available and three additional sites are proposed. The turbidimeters are components of the YSI 6600 Sonde multi-parameter monitoring instruments. Readings are logged every hour, and represent the average of several measurements. The instruments filter out anomalous values before the average is recorded.

DRI will continue its monitoring program but is open to modifying locations or methods to suit the needs of the larger community. Though it is a relatively small program, there exists some flexibility. It is expected that TTSA, SPPCo, and the USGS will continue their programs with little modification. Therefore, all proposed monitoring summarized in this report should be considered additions to the existing monitoring programs.

Consultation with LRWQCB staff and the TAC monitoring subcommittee yielded a list of areas of concern in the basin. Many of these areas are expected to experience, or have experienced, some change in land use; whether it be a disturbance—often in the form of urban development, or a best management practice. In these situations it is important to collect sediment data prior to the land-use change to establish its effect on in-stream conditions. The effect of disturbance, or effectiveness of the BMP, will be evaluated through changes in suspended sediment concentration. As noted above, suspended sediment concentration was chosen for this system as the water column indicator and evaluation of the target. The proposed monitoring of turbidity (as a surrogate for SSC) will therefore be used to evaluate changes in numeric targets and indicators.

The following is a list of proposed monitoring sites and the motivation for including them. For each site, it is proposed that a turbidimeter capable of collecting continuous data be installed and that sediment rating curves (described above) be established.

Truckee River at Tahoe City: The CalDWR has installed a continuous-recording tubidimeter at a temporary location on the Truckee River at Tahoe City. This location represents the upstream boundary of the Truckee River system; it is therefore necessary that high-quality data be gathered there. Because this site is so important, it is recommended that a permanent site be established.

Cold Creek: There is much data already collected at Donner Creek at its confluence with the Truckee. However, the Cold Creek and Donner Creek basins are very different geologically and structurally. The dam at Donner Lake serves to trap much of the sediment; therefore, to isolate land-use effects in the Cold Creek basin from the Donner Creek basin, it is necessary to monitor at Cold Creek.

Martis Creek above East Martis Creek: This basin is slated for development both upstream and downstream of the proposed site. Upstream effects of land use can be isolated with this proposed gage. If necessary, another site could be established at the mouth of Martis Creek.

Additionally, the following four sites have been identified by LRWQCB staff and the monitoring subcommittee as areas of concern:

- Alder Creek above Prosser Reservoir
- Prosser Creek above Prosser Reservoir
- Little Truckee River above Stampede Reservoir
- Davies Creek above Stampede Reservoir

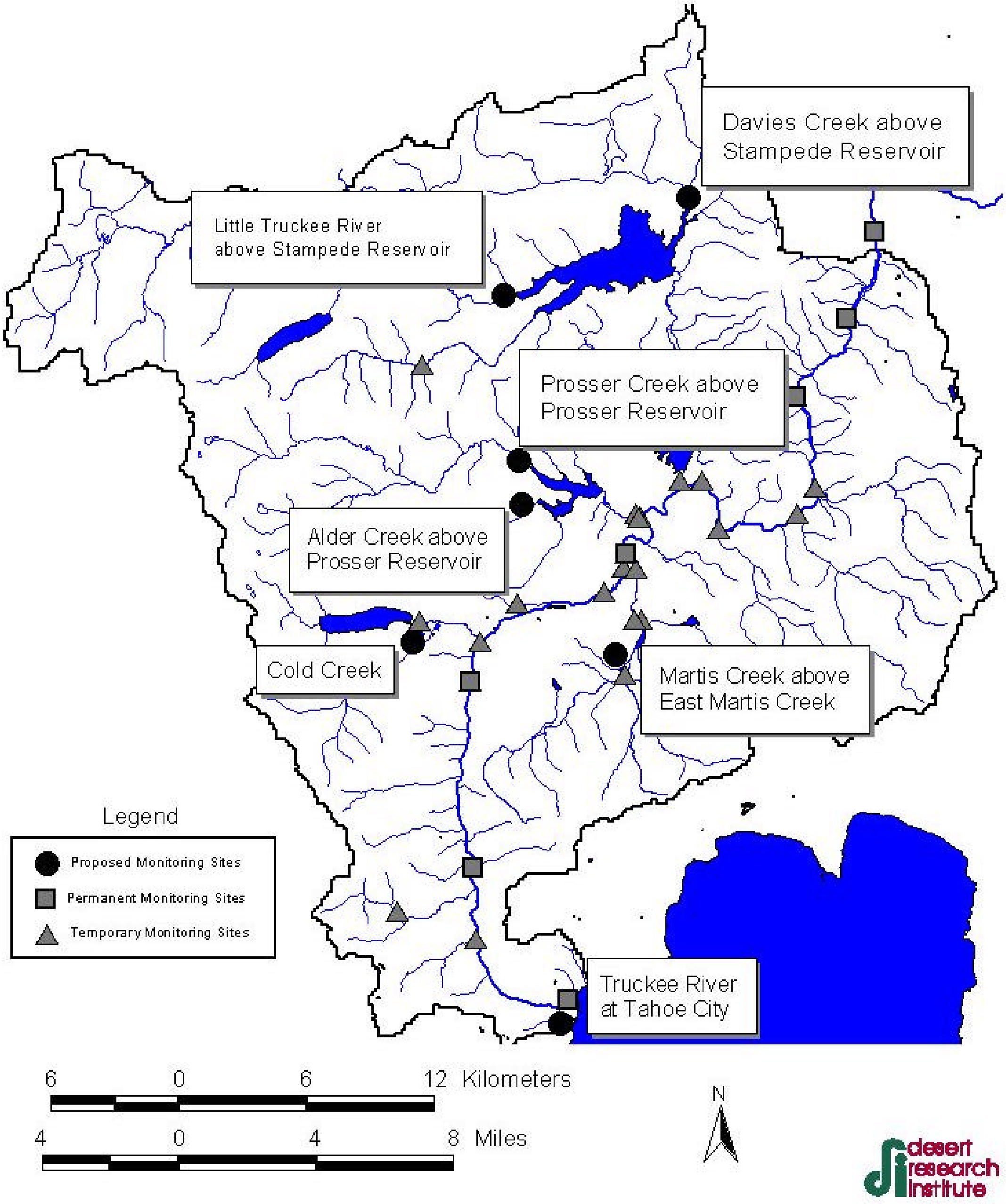


Figure 38. Proposed sediment and turbidity monitoring locations.

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6. APPENDIX A—PUBLIC PARTICIPATION

The purpose of this appendix is to document the public participation portion of this study. Some of the most valuable contributions to the direction of this study came from the Technical Advisory Committee (TAC) The TAC comprises members of the scientific community who agreed to review the work in progress and guide the scientists in their decisions as well as provide information on data availability. The effectiveness of the TAC is its members' willingness to engage in constructive examination of preliminary results.

There were three TAC meetings and one TAC subcommittee meeting over the course of the project. The dates and topics are listed below:

January 11, 2000: The purpose of the Jan. 11 meeting was to give the TAC an introduction to the project, including overview, goals, and deliverables, and to use the TAC's collective knowledge to determine data needs and sources.

November 17, 2000: On Nov. 17, the project team presented intermediate results and a more detailed description of the approach. After direction from the TAC, mid-project corrections concerns were made in approach to specific modeling and data availability.

February 21, 2001: A TAC subcommittee was formed to discuss future monitoring plan for the Truckee River Basin. Topics discussed included data gaps and appropriate methods of data collection.

April 11, 2001: The study team presented the draft report and source analysis results. Comments and suggestions for improving the report were solicited.

In addition to participation with the TAC, DRI personnel attended meetings of the Truckee River Watershed Council (TRWC, formerly called the Coordinated Resource Management Planning Group or CRMP). TRWC meetings occur monthly and include discussion from interested stakeholders of the Truckee River Basin. DRI personnel frequently provided informal updates on the study. Also, the Watershed Subcommittee of the TRWC met monthly. DRI attended nearly all meetings over the course of the project and is considered a valuable member of the subcommittee.

7. APPENDIX B—AVAILABLE AERIAL PHOTOGRAPHS FROM THE TAHOE NATIONAL FOREST

Bear Creek/Squaw Creek

Date	Photo Number
6/27/39	12-6, 12-7, 12-8, 12-9, 12-10, 12-11 (6)
6/27/39	12-36, 12-37, 12-38, 12-39, 12-40, 12-41 (6)
6/28/39	13-16, 13-17, 13-18, 13-19, 13-20 (5)
6/28/39	13-51, 13-52, 13-53, 13-55, 13-56, 13-57 (6)
8/22/55	2-5, 2-6, 2-7, 2-8, 2-9, 2-10, 2-11, 2-12, 2-13 (9)
7/15/66	9-266, 9-267, 9-268, 9-269, 9-270, 9-271, 9-272 (7)
7/16/66	11-74, 11-75, 11-76, 11-77, 11-78 (5)
7/16/66	11-8, 11-15, 11-16, 11-17 (4)
7/17/66	10-113, 10-114, 10-115, 10-116 (4)
7/21/66	14-111, 14-112, 14-113, 14-114, 14-115 (5)
7/12/72	1472-197, 1472-199, 1472-200 (3)
8/04/72	1972-170 (1)
9/12/72	0872-153, 0872-154, 0872-155, 0872-212, 0872-214 (5)
8/31/77	377-10, 377-11, 377-12, 377-13, 377-14, 377-15 (6)
8/31/77	377-66, 377-67, 377-68, 377-69, 377-70, 377-71 (6)
8/31/77	377-94, 377-95, 377-96, 377-97, 377-98 (5)
8/31/77	377-155, 377-158, 377-159 (3)
9/06/83	1582-39, 1582-40, 1582-42, 1582-43, 1582-71, 1582-74, 1782-125, 1782-127, 1782-169, 1782-171 (10)
7/16/87	487-127, 487-128, 487-129, 487-130, 487-131 (5)
7/16/87	487-147, 487-148, 487-204 (3)
7/16/87	487-201 (1)
7/31/92	692-83, 692-85, 692-115, 692-116, 692-122, 692-123, 692-124, 692-155, 692-163 (9)
7/12/97	1-1, 1-2, 1-3, 1-4, 1-5, 1-6, 1-7, 1-8, 1-9, 2-1, 2-2, 2-3, 2-4, 2-5, 2-6, 2-7, 2-8, 3-1, 3-2, 3-3 (20)
8/15/97	1097-12, 1097-13, 1097-14, 1097-15, 1097-16, 1097-17 (6)
8/15/97	1097-54, 1097-55, 1097-56, 1097-57, 1097-58, 1097-59, 1097-60, 1097-61, 1097-62 (9)
8/15/97	997-35, 997-36, 997-37, 997-38 (4)
8/15/97	997-66, 997-66, 997-68, 997-69, 997-70 (5)

Gray Creek/Juniper Creek

Date	Photo Number
6/29/39	15-59, 15-60, 15-61, 15-62, 15-63, 15-64, 15-65, 15-66 (8)
6/29/39	16-33, 16-34, 16-35, 16-36, 16-37, 16-38, 16-39 (7)
6/29/39	16-52, 16-53, 16-54, 16-55, 16-56 (5)
7/16/66	12-273, 12-274, 12-275, 12-276, 12-277, 12-278, 12-279 (7)
7/21/66	14-128, 14-129, 14-130, 14-131, 14-132, 14-133, 14-134, 14-135 (8)
9/21/66	15-81, 15-82, 15-83, 15-84, 15-85, 15-86, 15-87, 15-88, 15-89, 15-90 (10)
6/21/72	1072-55, 1072-56, 1072-57, 1072-58, 1072-59, 1072-60, 1072-61, 1072-62, 1072-63 (9)
6/21/72	1072-75, 1072-76, 1072-77, 1072-78, 1072-79, 1072-80, 1072-81, 1072-82 (8)
6/21/72	1072-96, 1072-97, 1072-98 (3)
7/30/92	192-95, 192-96, 192-97, 192-98 (4)
7/30/92	192-121, 192-122 (2)
8/10/97	797-135, 797-136, 797-137, 797-138, 797-139, 797-140, 797-141, 797-142 (8)
8/14/97	897-43, 897-44, 897-45, 897-46, 897-47, 897-48 (6)

East Fork - Martis Creek

Date	Photo Number
6/28/39	15-41, 15-42, 15-43, 15-44, 15-45, 15-46, 15-47, 15-48 (8)
6/28/39	15-60, 15-61, 15-62 (3)
6/21/72	972-150, 972-151, 972-152, 972-153, 972-154, 972-155, 972-156, 972-157, 972-158 (9)
6/21/72	972-234, 972-235, 972-236, 972-237, 972-238, 972-239, 972-240, 972-241 (8)
6/21/72	1072-8, 1072-9, 1072-10, 1072-11, 1072-12, 1072-13, 1072-14, 1072-15 (8)
6/21/72	1072-60, 1072-61, 1072-62, 1072-63 (4)
6/21/72	1072-75, 1072-76 (2)
6/21/72	1072-120, 1072-121, 1072-122, 1072-123, 1072-124, 1072-125 (6)
7/27/87	587-122, 587-123, 587-124, 587-125 (4)

8/10/97	797-134, 797-135, 797-136, 797-137 (4)
8/14/97	897-78, 897-79, 897-80, 897-81, 897-82, 897-83, 897-84, 897-85 (8)
8/14/97	897-25, 897-26, 897-27, 897-28, 897-29, 897-30, 897-31 (7)

East Fork - Martis Creek

Date	Photo Number
6/28/39	14-37, 14-38, 14-39, 14-40, 14-41, 14-42, 14-43, 14-44 (8)
6/28/39	14-86, 14-87, 14-88, 14-89, 14-90, 14-91 (6)
7/27/87	587-31, 587-32, 587-33, 587-34, 587-35, 587-36 (6)
7/27/87	587-75, 587-76, 587-77, 587-78, 587-79, 587-80 (6)
8/14/97	897-223, 897-224, 897-225, 897-226, 897-227, 897-228, 897-229, 897-230 (8)
8/14/97	897-145, 897-146, 897-147, 897-148, 897-149, 897-150, 897-151 (7)

8. APPENDIX C—DATABASE DICTIONARY DESCRIBING THE METADATA FOR THE TRUCKEE RIVER WATERSHED GIS DATABASE

A. Core Project Data Sets

ArcView Grid: truckdemf

Coverage description: The truckdemf grid is a continuous raster grid of elevation values for the entire Truckee River watershed.

Coverage type: Arc/Spatial Analyst grid

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 8/3/00

Feature type: cell

Data source: U.S. Geological Survey 7.5 minute 30 meter Digital Elevation Models

Source map units: meters

Source map scale: 1:24,000

Source map projection: UTM zone 11

Source map datum: NAD 27

Input/Transfer method and History: mosaicked original 7.5 minute quadangles into single grid representing entire watershed; ran averaging filter over quadrangle edges to smooth tile intersections; reprojected from UTM zone 11 to zone 10.

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

File: truckdemf.vat (Grid value attribute table)

VALUE	elevation in meters
COUNT	number of cells in database with same elevation value

ArcView Shapefile names: I80f.shp, I80f.dbf, I80f.shx, I80f.prj

Coverage description: The I80f shapefile is a line feature shapefile of Interstate 80 as it runs through the Truckee River watershed.

Coverage type: Arcview shapefile

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 3/09/01

Feature type: line

Data source: U.S. Geological Survey 1:100,000 Digital Line Graph data

Source map units: meters

Source map scale: 1:100,000

Source map projection: UTM zone 11

Source map datum: NAD 83

Input/Transfer method and History: Selected the I80 road line feature from the USGS DLG transportation data layer.

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

File: I80f.dbf (ArcView Feature Attribute Table)

SHAPE	Polyline
LENGTH	Line segment length

ArcView Shapefile names: streamsf.shp, streamsf.dbf, streamsf.shx, streamsf.prj

Coverage description: The streamsf shapefile is a line feature shapefile of all the streams, creeks and rivers found in the Truckee River watershed.

Coverage type: Arcview shapefile

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 3/09/01

Feature type: line

Data source: U.S. Geological Survey 1:100,000 Digital Line Graph data and USGS 1:24,000 Digital Line Graph data.

Source map units: meters

Source map scale: 1:24,000 and 1:100,000

Source map projection: UTM zone 11

Source map datum: NAD 83

Input/Transfer method and History: Clipped the 1:100k DLG for the area to fit the Truckee River watershed

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

File: streamsf.dbf (ArcView Feature Attribute Table)

SHAPE	Polyline
LENGTH	Line segment length
ID_NUM	USGS Identification number
BASIN	Basin the stream is found in
NAME	Feature name
SCALE	Scale of original base data
COMMENT	Details of USGS data input procedure

ArcView Shapefile names: lakesf.shp, lakesf.dbf, lakesf.shx, lakes.prj

Coverage description: The lakesf shapefile is a polygon feature shapefile of all the lakes found in the Truckee River watershed.Coverage type: Arcview shapefile

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 3/09/01

Feature type: line

Data source: U.S. Geological Survey 1:100,000 Digital Line Graph data and USGS 1:24,000 Digital Line Graph data.

Source map units: meters

Source map scale: 1:24,000 and 1:100,000

Source map projection: UTM zone 11

Source map datum: NAD 83

Input/Transfer method and History: Clipped the 1:100k DLG for the area to fit the Truckee River watershed

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

File: lakesf.dbf (ArcView Feature Attribute Table)

SHAPE	Polygon
AREA	Area of lake polygons
PERIMETER	Perimeter of lake polygons
ID_NUM	USGS Identification number
NAME	Feature name
SCALE	Scale of original base data
COMMENT	Details of USGS data input procedure

ArcView Shapefile names: Boundaryf.shp, Boundaryf.dbf, Boundaryf.shx, Boundaryf.prj

Coverage description: The Boundaryf shapefile is a polygon feature shapefile of the Truckee River watershed hydrographic basin.

Coverage type: Arcview shapefile

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 1/24/01

Feature type: polygon

Data source: AnnAGNPS model output

Source map units: meters

Source map scale: 150 meter Minimum Mapping Unit

Source map projection: UTM zone 11

Source map datum: NAD 83

Input/Transfer method and History: AnnAGNPS output an ascii raster image file of the hydrographic basin based on the USGS DEM. The ascii raster file was converted to an Arc grid, then converted to an Arcview shapefile.

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

File: Boundaryf.dbf (ArcView Feature Attribute Table)

SHAPE	Polygon
AREA	Area of polygon
PERIMETER	Perimeter of polygon
GRID-CODE	Original grid code of input Arc Grid

ArcView Shapefile names: Dirtroadsf.shp, Dirtroadsf.dbf, Dirtroadsf.shx, Dirtroadsf.prj

Coverage description: An Arcview line feature shapefile of the dirt roads in the Truckee River watershed.

Coverage type: Arcview shapefile

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 2/23/01

Feature type: line

Data source: Tahoe National Forest (TNF) roads database from 1986 USGS quads, Updated 1998; USGS DLGs at 1:100,000; Landsat Enhanced Thematic Mapper (ETM) scene from August 17, 1999; various historical aerial photographs

Source map units: meters

Source map scale: 1:24,000, 1:100,000, 15 meter Landsat ETM satellite imagery, 1:15,000 to 1:24,000 aerial photography.

Source map projection: UTM zone 10

Source map datum: NAD 27

Input/Transfer method and History: The dirt roads database was created in several steps; first the TNF data set for the California side of the basin and the USGS DLG data set for the Nevada side were merged and then clipped using the hydrographic basin for the Truckee. The resultant data layer was then edited to update dirt roads that have since been paved in several geographic regions, including Tahoe-Donner, Donner Lake, and the Glenshire area, using the August, 1999 Landsat ETM satellite image and aerial photographs from the TNF.

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

File: Dirtroadsf.dbf (ArcView Feature Attribute Table)

SHAPE	Polyline
LENGTH	Length of road segments
REVISION-D	Revision date for updating road condition
RTE_NO	TNF Route Number
DESCRIPTION	Road type: DIRT, IMPROVED, SECONDARY, HIGHWAY

ArcView Shapefile names: Landcoverf.shp, Landcoverf.dbf, Landcoverf.shx, Landcoverf.prj

Coverage description: An Arcview polygon feature shapefile of the land cover of the Truckee River watershed.

Coverage type: Arcview shapefile

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 1/31/01

Feature type: polygon

Data source: The land cover database was derived from a combination of a TNF timber type data set, a UNR-Biological Resource Research Center (BRRC) vegetation database, the USFWS Gap vegetation data set, and image interpretation of a Landsat Enhanced Thematic Mapper (ETM) scene of the study area acquired in August of 1999

Source map scale: TNF Timber type - 1:24,000, BRRC vegetation map - 1:24,000, USFWS Gap data - 1 km minimum mapping unit, 15 meter Landsat ETM satellite imagery.

Source map projection: UTM zone 10

Source map datum: NAD 27

Input/Transfer method and History: The development of the land cover database involved the integration and merging of the TNF, BRRC, and USFWS vegetation data sets, as no one vegetation data set covered the entire study area. The Landsat satellite data were used to update burn and regrowth areas and determine accurate land cover at the intersection of the input data sets. Some of the data sets, in particular the TNF timber data, were rather old (the TNF timber type data were originally created in 1979-1980 by the Forest Service). The resultant, integrated attribute tables of land cover had to then be edited and checked for completeness and consistency with respect to land cover categories and canopy cover percentage classes. The completed shapefile was converted to a grid format for export to the AnnAGNPS model.

The metadata descriptions for the TNF timber type database can be found in the veg80.rtf document on the Data Product CD. The BRRC (NPR) vegetation map metadata can be found in the nprveg and nprveg.apx files (rich text format) on the CD. Please note that the BRRC document and appendices are drafts and should be cited accordingly. The data dictionary for the California Gap data can be found at the following web site:

http://www.biogeog.ucsb.edu/projects/gap/data/meta/landcovdd.html.

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

File: Landcoverf.dbf (ArcView Feature Attribute Table)

SHAPE	Polygon
ID	Arcview grid identification number
GRIDCODE	Original gridcode id for land cover type

1 - Lodgepole; Forest
2 - White Fir, Ponderosa Pine, Mixed Forest, Forest Clearcuts (partial regrowth); Forest
3 - Red Fir, White Pine; Forest
4 - Nonwoody vegetation (meadows)
5 - Woody shrubs (sagebrush)
6 - Barren and Rocks
7 - Water bodies
8 - Plantations
9 - Bare ground and clearcut areas
10 - Urban Developed
11 - Miscellaneous hardwoods

LANDCOVER	Land cover descriptions

ArcView Shapefile names: Canopycoverf.shp, Canopycoverf.dbf, Canopycoverf.shx, Canopycoverf.prj

Coverage description: An Arcview polygon feature shapefile of the canopy cover, by percentage, of the Truckee River watershed.

Coverage type: Arcview shapefile

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 1/31/01

Feature type: polygon

Data source: The canopy cover database was derived from a combination of a TNF timber type data set, a UNR-Biological Resource Research Center (BRRC) vegetation database, the USFWS Gap vegetation data set, and image interpretation of a Landsat Enhanced Thematic Mapper (ETM) scene of the study area acquired in August of 1999

Source map scale: TNF Timber type - 1:24,000, BRRC vegetation map - 1:24,000, USFWS Gap data - 1 km minimum mapping unit, 15 meter Landsat ETM satellite imagery.

Source map projection: UTM zone 10

Source map datum: NAD 27

Input/Transfer method and History: The development of the canopy cover database involved the integration and merging of the TNF, BRRC, and USFWS vegetation data sets, as no one vegetation data set covered the entire study area. The Landsat satellite data were used to update burn and regrowth areas and determine accurate land cover at the intersection of the input data sets. Some of the data sets, in particular the TNF timber data, were rather old (the TNF timber type data were originally created in 1979-1980 by the Forest Service). The resultant, integrated attribute tables of canopy cover percentage had to then be edited and checked for completeness and consistency with respect to land cover categories and canopy cover percentage classes. The completed shapefile was converted to a grid format for export to the AnnAGNPS model.

The metadata descriptions for the TNF timber type database can be found in the veg80.rtf document on the Data Product CD. The BRRC (NPR) vegetation map metadata can be found in the nprveg and nprveg.apx files (rich text format) on the CD. Please note that the BRRC document and appendices are drafts and should be cited accordingly. The data dictionary for the California Gap data can be found at the following web site:

http://www.biogeog.ucsb.edu/projects/gap/data/meta/landcovdd.html.

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866

Datum	NAD 27

Description of Database Attributes:

File: Canopycoverf.dbf (ArcView Feature Attribute Table)

SHAPE	Polygon
ID	Arcview grid identification number
GRIDCODE	Original gridcode Id for canopy cover percentage

1 - 0%
2 - less than 20%
3 - 20 to 39%
4 - 40 to 69%
5 - 70% and above
6 - variable canopy cover (mixed percent cover within the same polygon)

CANOPYCOV	Canopy cover percentage classes

ArcView Shapefile names: statsgosoilsf.shp, statsgosoilsf.dbf, statsgosoilsf.shx, statsgosoilsf.prj

Coverage description: An Arcview polygon feature shapefile of the NRCS STATSGO level soils for the entire Truckee River watershed

Coverage type: Arcview shapefile

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 2/12/01

Feature type: polygon

Data source: USDA Natural Resource Conservation Service (NRCS) State Soil Geographic (STATSGO) Data Base for California and Nevada

Source map projection: Albers Equal Area

Source map datum: NAD 27

Input/Transfer method and History: Original plans to use the high resolution (1:24,000 scale) NRCS SSURGO soils data for the study area had to be modified when it was discovered that the only SSURGO-level or SSURGO equivalent soils data set available for the California side of the study area was the TNF Level 3 soils resource inventory. Although the spatial scale of the data set was more than adequate for sediment modeling purposes (1:24,000 scale), the critical soil parameters necessary for AnnAGNPS were not available in the limited attribute table associated with the Level 3 data. The only attribute parameters available from the TNF data set were map unit name, slope class, and a soil phase related to erodibility. Other parameters were available from a soil survey document file (Adobe Acrobat PDF format, 1994) obtained from the TNF, but were limited to soil profile descriptions, some soil properties (effective root depth, water capacity class, available water capacity, permeability, erosion hazard) and some soil management interpretations, all of which would have had to been entered into the attribute table for the approximately 3000 Level 3 soil unit polygons found in the study area, then cross-correlated with the SSURGO map units in an attempt to add the missing parameters to the TNF Level 3 soil units.

Therefore, DRI used the STATSGO level soils databases for California and Nevada. The two data sets were joined together, then reprojected. A soilcode unique to each soil unit was assigned to the resultant feature attribute table. Separate map unit, layer, and composition tables were extracted from the STATSGO database and linked to the feature attribute table to derive the parameters required for AnnAGNPS.

The data dictionary for the STATSGO soils database can be found on the Data Product CD. It is a Adobe Acrobat PDF file called statsgo_db.pdf. The data dictionary descriptions for the TNF level 3 soils database and the TNF 1994 soils survey document (Adobe Acrobat PDF format) can be found in the following documents on the Data Product CD; tnfsoils.doc and tnfsoils.pdf.

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

File: statsgosoilsf.dbf (ArcView Feature Attribute Table)

SHAPE	Polygon
AREA	Area of each soil unit polygon
PERIMETER	Perimeter of each soil unit polygon
MUID	A symbol that consists of the state alpha Symbol FIPS code and a three digit Arabic number. It uniquely identifies a mapunit within a state. It is the common field used to link to other STATSGO parameter tables.
IDS	The three digit Arabic number representation of the mapunit
MUNAME	Correlated name of the mapunit (recommended name or field name for surveys in progress).
SOILCODE	Internal soil code attached to each mapunit

File: castat_comp.dbf (California STATSGO soil composition data)

See STATSGO data dictionary PDF file - statsgo_db.pdf, Appendix A.

File: castat_layer.dbf (California STATSGO soil layer data)

See STATSGO data dictionary PDF file - statsgo_db.pdf, Appendix A.

File: castat_mapunits.dbf (California STATSGO soil mapunit data)

See STATSGO data dictionary PDF file - statsgo_db.pdf, Appendix A.

File: nvstat_comp.dbf (Nevada STATSGO soil composition data)

See STATSGO data dictionary PDF file - statsgo_db.pdf, Appendix A.

File: nvstat_layer.dbf (Nevada STATSGO soil layer data)

See STATSGO data dictionary PDF file - statsgo_db.pdf, Appendix A.

File: nvstat_mapunit.dbf (Nevada STATSGO mapunit data)

See STATSGO data dictionary PDF file - statsgo_db.pdf, Appendix A.

ArcView Shapefile names: modelbasinsf.shp, modelbasinsf.dbf, modelbasinsf.shx, modelbasinsf.prj

Coverage description: An Arcview polygon feature shapefile of the subwatershed basins calculated by the AnnAGNPS model.

Coverage type: Arcview shapefile

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 3/08/01

Feature type: polygon

Data source: The AnnAGNPS sediment model.

Source map scale: 150 meter minimum mapping unit

Source map projection: UTM zone 11

Source map datum: NAD 83

Input/Transfer method and History: The AnnAGNPS sediment model exports an ascii raster file which must first be imported into ArcView, converted to a Grid, then converted to a ArcView shapefile. There are a total of 869 subwatershed basins calculated for the entire Truckee River watershed. Using the gridcode field of the feature attribute table, and the cell id of the AnnAGNPS data tables as the common fields, the feature attribute table for this shapefile can be linked to the sediment loading results calculated by AnnAGNPS.

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

File: modelbasinsf.dbf (Arcview Feature Attribute Table)

SHAPE	Polygon
GRIDCODE	The cell identification number for each subwatershed basin
COUNT	The number of 150 meter cells found for each subwatershed basin

File: truck96_mass.dbf (AnnAGNPS 1996 total mass results data table)

CELLID	The cell identification number for each subwatershed basin
CLAY	Mass of clay for each sub-basin (tons)
SILT	Mass of silt for each sub-basin (tons)
SAND	Mass of sand for each sub-basin (tons)

SMALLAG	Mass of small aggregate for each sub-basin (tons)
LARGEAG	Mass of large aggregate for each sub-basin (tons)
TOTAL_TONS	Total mass of all components for each sub-basin (tons)

File: truck96_massarea.dbf (AnnAGNPS 1996 total mass/unit area results data table)

CELLID	The cell identification number for each subwatershed basin
CLAY	Mass/unit area of clay for each sub-basin (tons/acre)
SILT	Mass/unit area of silt for each sub-basin (tons/acre)
SAND	Mass/unit area of sand for each sub-basin (tons/acre)
SMALLAG	Mass/unit area of small aggregate for each sub-basin (tons/acre)
LARGEAG	Mass/unit area of large aggregate for each sub-basin (tons/acre)
TTONS/ACRE	Total Mass/unit area of all components for each sub-basin (tons/acre)

File: truck97_mass.dbf (AnnAGNPS 1997 total mass results data table)

CELLID	The cell identification number for each subwatershed basin
CLAY	Mass of clay for each sub-basin (tons)
SILT	Mass of silt for each sub-basin (tons)
SAND	Mass of sand for each sub-basin (tons)
SMALLAG	Mass of small aggregate for each sub-basin (tons)
LARGEAG	Mass of large aggregate for each sub-basin (tons)
TOTALMASS_	Total mass of all components for each sub-basin (tons)

ArcView Shapefile names: landscape_sensf.shp, landscape_sensf.dbf, landscape_sensf.shx, landscape_sensf.prj

Coverage description: The landscape_sensf shapefile is a polygon feature shapefile of landscape units sensitive to erosion and sediment transport.

Coverage type: Arcview shapefile

Coverage extent: Truckee River watershed

Coverage creator: DRI

Creation date: 3/16/01

Feature type: polygon

Data source: image interpretation of high resolution aerial photographs from different acquisition dates as well as Landsat Enhanced Thematic Mapper (ETM) imagery of the study area acquired in August of 1999.

Source map units: meters

Source map scale: 1:15,000 to 1:24,000 scale aerial photographs. Landsat imagery at 15 meter spatial resolution.

Source map projection: aerial photography not projected; Landsat image projected to UTM zone 11

Source map datum: NAD 83

Input/Transfer method and History: Manual interpretation of susceptible landscape units performed on aerial photography, then transposed to the digital Landsat imagery for validation and conversion to electronic format.

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

File: landscape_sensf.dbf (ArcView Feature Attribute Table)

SHAPE	Polygon
ID	Internal ArcView number

The 869 subwatershed basins in the modelbasinsf shapefile were aggregated into 17 major basins by selecting the appropriate sub-basins in ArcView and converting the aggregated basins to individual shapefiles. The following shapefiles were created:

Graybasin.shp - Gray Creek basin

Broncobasin.shp - Bronco Creek basin

Squawbasin.shp - Squaw Creek basin

Bearbasin.shp - Bear Creek basin

Juniperbasin.shp - Juniper Creek basin

Uppermartisbasin.shp - Upper Martis Creek basin (above the reservoir)

Lowermartisbasin.shp - Lower Martis Creek basin (below the reservoir)

Donner-coldbasin.shp - Donner Creek/Cold Creek basin

Littletruckeebasin.shp - Little Truckee River basin

Prosserbasin.shp - Prosser Creek basin

Daviesbasin.shp - Davies Creek basin

Upperlittletruckbasin.shp - Upper Little Truckee River basin

Sagehenbasin.shp - Sage Hen Creek basin

Upperprosserbasin.shp - Upper Prosser Creek basin

Alderbasin.shp - Alder Creek basin

Troutbasin.shp - Trout Creek basin

I-80corridorbasin.shp - I-80 corridor basin below Prosser Creek

Each of the above named shapefiles has the following file names: *.shp, *.shx, *.dbf, *.prj. The fields for each feature attribute table are:

SHAPE	Polygon
GRIDCODE	The cell identification number for each subwatershed basin
COUNT	The number of 150 meter cells found for each subwatershed basin
DISSFACTOR	A constant value that can be used to remove all the subwatershed basin boundaries within the major basins

ArcView Image File Names: TruckLand7.bil, TruckLand7.hdr

Coverage description: An Arcview image file of a Landsat 7 Enhanced Thematic Mapper Scene acquired in August, 1999.

Coverage type: Arcview image file

Coverage extent: Truckee River watershed area (far western edge cut off by scene boundary)

Coverage creator: DRI

Creation date: 10/31/00

Feature type: cell

Data source: USGS EROS Data Center

Source map scale: 15 meter Landsat ETM satellite imagery

Source map projection: UTM zone 11

Source map datum: WGS84

Input/Transfer method and History: Landsat ETM scene Path/Row 43/33 was clipped to the study area, and multispectral bands 5,4, and 1 (30m resolution) were fused with 15m panchromatic data to create a false color composite of the study area. The image data were reprojected to zone 10, nad 27.

Coordinate System Description:

Projection	UTM
Zone	10
Units	meters
Spheroid	Clarke 1866
Datum	NAD 27

Description of Database Attributes:

None

B. Additional Spatial Data Sets acquired from Public Domain sources but not directly used for the project:

A number of additional data sets were acquired from a variety of public domain data sources, but were not used for the project. These data sets have been included on the Data Product CD. These data, their original sources, and the shapefile names are listed below:

Arcview shapefiles

Tahoe National Forest (TNF) administration boundaries - TNF: **tnfadmin.shp**

fire history - TNF: **tnffires.shp**

fire history - Toiyabe National Forest: **toyfire.shp**

Public Land Survey System - TNF: **tnfplss.shp**

USGS quadrangle sheet boundaries - USGS: **usgsquads.shp**

9. APPENDIX D – HISTORIC DATA USED FOR SOURCE ASSESSMENT