Lake Tahoe Basin Framework Implementation Study: Sediment Loadings and Channel Erosion

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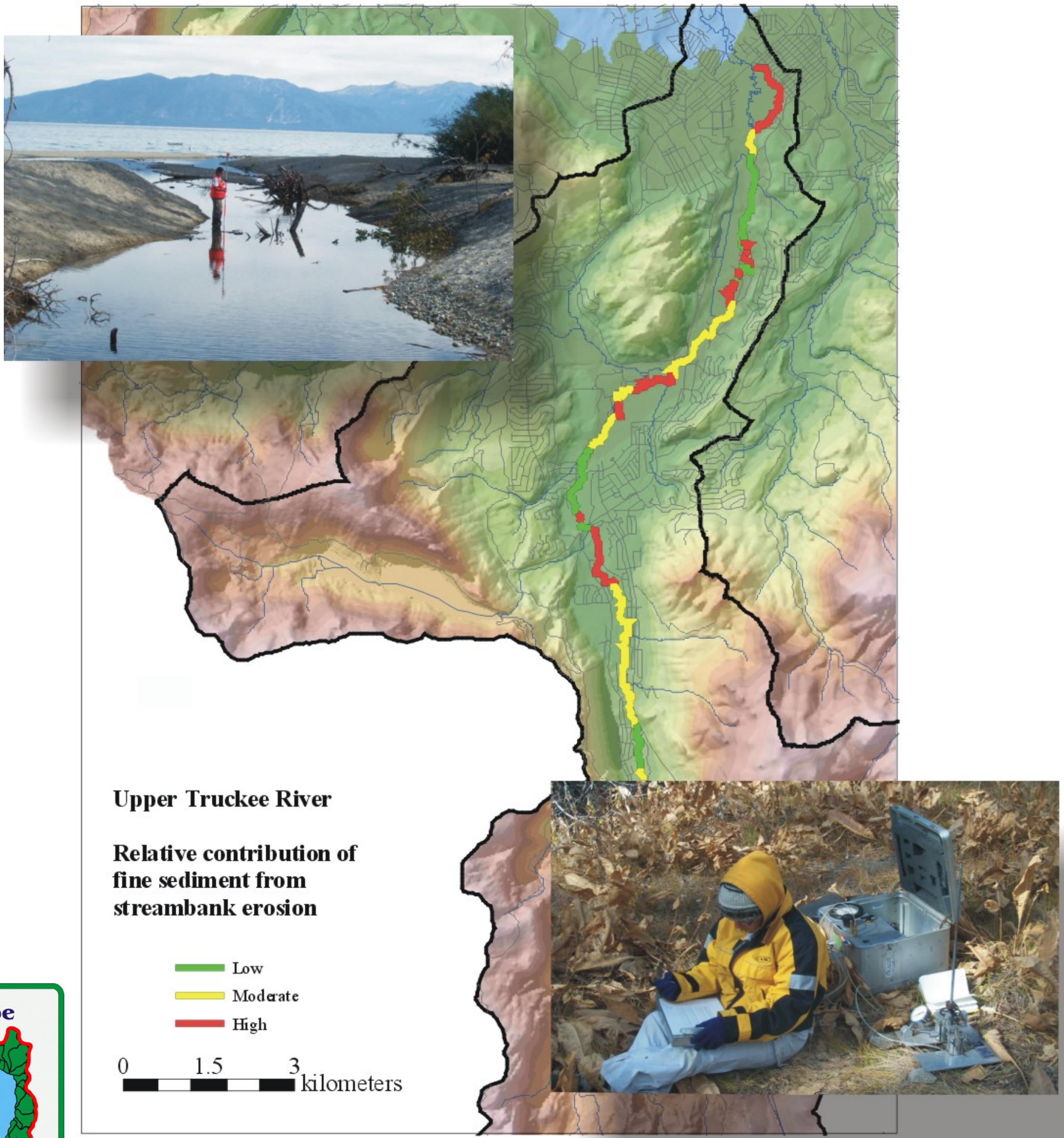

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EXECUTIVE SUMMARY

The study was designed to combine detailed geomorphic and numerical modeling investigations of several representative watersheds with reconnaissance level evaluation of approximately 300 sites to determine which basins and areas were contributing sediment to Lake Tahoe. Numerical modeling of upland- and channel-erosion processes over then next 50 years was conducted using AnnAGNPS and CONCEPTS on three representative watersheds, General and Ward Creeks, and the Upper Truckee River. GIS-based analysis of land use, land cover, soil erodibility, steepness, and geology was used to evaluate upland-erosion across the basin. Channel contributions were determined by comparing cross-sectional geometries of channels originally surveyed in either 1983 or 1992. Sites along General, Logan House, Blackwood, and Edgewood Creeks, and the Upper Truckee River were re-occupied and re-surveyed in 2002. Historical flow and sediment-transport data from more than 30 sites were used to determine bulk suspended-sediment loads (in tonnes) and yields (in tonnes/km^2) for sites all around the lake. Eighteen index stations, defined as those with long periods of flow and sediment-transport data and, located in a downstream position were selected. These stations were used to make comparisons between sediment production and delivery from individual watersheds and between different sides (directional quadrants) of the lake. Fine-grained sediment transport was determined from historical data for 20 sites based on relations derived from particle-size distributions across the range of measured flows.

Suspended-sediment loads and yields vary over orders of magnitude from year to year, from west to east and north to south across the basin. Median annual suspended-sediment loads for index stations range from about 2200 tonnes/yr (T/y) from the Upper Truckee River to 3 T/y from Logan House Creek. Based on the historical data, the largest annual contributors of sediment are in decreasing order, Upper Truckee River (2200 T/y), Blackwood Creek (1930 T/y), Second Creek (1410 T/y), Trout Creek (1190 T/y), Third Creek (880 T/y) and Ward Creek (855 T/y). Data from Second and Third Creeks may be somewhat misleading though because of a short period of data collection in the case of the former, and the fact that data collection occurred during major construction activities in these basins. In fact, analysis of suspended-sediment transport ratings with longer periods of record (17 to 20 years) show that sediment loads from the northeast streams have significantly decreased across the entire range of flows. Based on the historical data, the lowest contributors of suspended sediment from index stations, in increasing order are Logan House (3.0 T/y), Dollar (4.6 T/y), Quail Lake (6.4 T/y), Glenbrook (8.9 T/y), and Edgewood Creeks (21.3 T/y).

That the Upper Truckee River and Trout Creek are major sediment contributors is not surprising given their large drainage areas in relation to the other streams in the Lake Tahoe Basin. Per unit area, the western and northern streams produce the most sediment although for different reasons, and sediment yields from the northern streams have been decreasing since the early 1970's. Suspended-sediment yields from the Upper Truckee River are also decreasing with time but at a slower rate than in Third and Incline Creeks for example. In other parts of the watershed, temporal trends of decreasing loads per unit area and unit water were subtler. No statistically significant trend of increasing suspended-sediment loads or yields was identified as reported recently by other workers.

Fine-grained loads show a similar pattern as total loads with the greatest contributors being the Upper Truckee River (1010 T/y), Blackwood Creek (844 T/y), Trout Creek (462 T/y) and Ward Creek (412 T/y). The lowest contributors are Logan House Creek (2.3 T/y), Dollar Creek (2.6 T/y), Quail Lake Creek (3.2T/y) and Glenbrook Creek (7.0 T/y). In terms of fine-grained loadings per unit area, a slightly different picture emerges. Blackwood, Third, and Ward Creeks, all disturbed streams have the greatest fine-grained suspended-sediment yields at 21.5, 20.2, and 16.4 T/y/km^2. In comparison, the Upper Truckee River produces 7.1 T/y/km^2; General Creek, 2.8 T/y/km^2; and Logan House Creek, 0.4 T/y/km^2.

A first approximation of total, annual suspended-sediment loadings to Lake Tahoe is made by extrapolating average-annual and median-annual data from the index stations. Using this technique average-annual and median-annual loadings are 28,600 T/y and 18,300 T/y, respectively. About 6,300 T/y of fine-grained materials are delivered to the lake, based on median-annual data. A somewhat more refined estimate of total, annual suspended-sediment loads is made by extrapolating the sum of the average, median-annual values within each quadrant. In this case the annual loadings value to Lake Tahoe is about 25,500 T/y.

Sediment yields were also used to discriminate between loadings from disturbed and undisturbed watersheds. For example, although the western streams produce more sediment per unit area than eastern streams General Creek can be considered as a “reference” stream because of a lack of significant human intervention. Sediment yield from General Creek is about 9 T/y/km^2. In contrast, yields from Blackwood and Ward Creeks, streams disturbed to different degrees by human activities are about 66 and 34 t/y/km^2, respectively. On the eastern side of the lake, relatively undisturbed Logan House Creek produces 0.6 t/y/km^2 compared to the developed Edgewood Creek watershed that produces about 3 T/y/km^2. The effects of human disturbance on streams draining the northeast part of the Lake Tahoe watershed (Third, Second and Incline) are shown to have produced orders of magnitude more sediment in the 1970’s (during construction and development) than at present.

The contribution of channel materials to sediment loads also varies widely. Undisturbed channels tend to have greater amounts of their sediment load emanating from upland areas. In the General Creek watershed, numerical modeling shows that about 78% of the fine materials passing the downstream-most gauge, originate from upland sources, with only 22% coming from channel sources. Simulations of the percentage of upland sediment contributions may be overestimated because of overestimates of runoff during the low-flow winter months. This results in simulations of erosion preferentially in upland areas rather than in channels because precipitation was simulated as rain instead of snow. Still, similar proportions of upland and channel materials were simulated on Ward Creek, suggesting that this may be typical of the wetter, western watersheds. This is not to say that General and Wards Creeks supply similar amounts of streambank materials. Per unit of channel length, Ward Creek supplies almost 5 times the amount of sediment and fine-grained material from streambanks than General Creek (Table 7-1). Analysis of monumented cross sections shows that on average, 14.6 m^3/y/km of streambank materials (or 1.5 m^3/y/km of fine-grained materials) are eroded from the lower 8.5 km of General Creek. These values are within 27% of those simulated by CONCEPTS. The disturbed channels of Blackwood Creek provide about 217 m^3/y/km of sediment; 12.2 m^3/y/km of fines. This represents about 14 times the amount of streambank-derived sediment per km of channel than from General Creek, almost 4 times more than Ward Creek, but 66% less than from the Upper Truckee River (Table 7-1). On the Upper Truckee River, channel contributions increase significantly with distance downstream from the most upstream stream gauge. These changes reflect the increasing disturbance to the Upper Truckee River in the vicinity of Washoe Meadows and downstream of the South Lake Tahoe airport as well as the decreasing influence of upland slopes. Edgewood and Logan House Creeks have been net sinks for sediment over the past 20 years. Of the streams where numerous bank-material samples were collected, relative proportions of fine-grained materials comprising the channel banks are greatest along Ward Creek and the Upper Truckee River (17% and 14%, respectively) and lowest along Edgewood and Incline Creeks.

Table 7-1. Average annual contributions of streambank materials expressed in m^3/y/km.

Stream	Total simulated	Total measured	Fines simulated	Fines measured
Blackwood	-	217	-	12.2
General	10.6	14.6	0.90	1.5
Upper Truckee[1]	54.5	645	9.5	90.3
Ward	45.6	-	4.4	-

[1] Rate reflects surveys over a short (2.9 km), unstable reach and, therefore are not indicative of the entire length of river.

The effect of the 1997 rain on snow event varied widely across the basin, from being a 60-year sediment event on Blackwood Creek to a 1.4-year sediment event along Third Creek. Based on magnitude-frequency analysis, western streams such as Ward, Blackwood, and General Creeks were impacted the greatest while the northeast streams were impacted the least. The January 1997 event represented only an 8-year sediment event on the Upper Truckee River near its mouth and served to flush sediment from this and other drainages. Post-1997 suspended-sediment loads are generally lower than previous because the flushing of stored sediment has made less sediment available for transport. However, in channels such as the Upper Truckee River and perhaps Trout Creek with broad, relatively flat, sinuous alluvial reaches, sediment contributions from streambank erosion have increased. This is due to extension and elongation of meanders with the ultimate development of cut-offs. Documented rates of meander migration of a reach of the Upper Truckee River have been quantified herein for the past 60 years and also show a decreasing rate of activity. It does not seem, therefore, that the runoff event rejuvenated stream channels throughout the basin. In fact, 1997 was not the peak sediment year in a number of watersheds.

Numerical simulations of suspended-sediment loadings from disturbed and undisturbed western streams, and the Upper Truckee River for the next 50 years shows a trend of decreasing sediment delivery to Lake Tahoe. This is particularly significant for the western streams because they currently produce some of the highest loadings to the lake and, over the past 20 years these high loads (per unit runoff) have remained relatively constant. That future loadings from the Upper Truckee River are simulated to decrease is significant because: (1) it is the largest contributor of suspended- and fine-grained sediment to the lake, (2) streambank erosion has increased recently, in part due to the effects of the January 1997 storm, and (3) notwithstanding the recent increase in bank erosion, loads (per unit runoff) over the longer term (past 24 years) have been shown to be decreasing. Results of simulations on the Upper Truckee River indicate that this longer-termed trend will continue and that the effects of 1997 event will be short-lived in the modeled watersheds. The accuracy and reliability of the numerical simulations is somewhat less than expected, however, because of a lack of detailed, high-quality climate data that could account for broad variations in precipitation and temperature between watersheds, and within a single watershed with elevation.

Rapid geomorphic assessments (RGAs) at 300 stream sites and stream walks were used to calculate a semi-quantitative stability index based on diagnostic characteristics of the channel and adjacent side slopes. Basinwide maps of the occurrence of bank erosion and the silt/clay content of those banks can be used to evaluate potentially critical stream reaches or specific locations. Streambank-erosion classes, taking into account the proportion of fine-grained sediment in the banks were assigned to almost 50 km of channels including Blackwood, Edgewood, General, Incline, Logan House and Ward Creeks, and the Upper Truckee River.

A similar analysis of the potential for upland contributions is based on GIS analysis of five parameters including slope steepness, surficial geology, precipitation, land use/landcover, and soil erodibility. The relative percentage of high upland-erosion potential within a drainage basin was positively correlated with median, annual suspended-sediment yields and can also be used to evaluate potentially critical areas.

The most significant findings of this research are that:

- Streambank erosion is an important contributor of suspended-sediment from disturbed streams,
- The Upper Truckee River is the greatest contributor of suspended-sediment and fine-grained sediment in the Lake Tahoe Basin,
- Sediment delivery from the Upper Truckee River could be significantly reduced by controlling streambank erosion in the reaches adjacent to the golf course and downstream from the airport,
- Blackwood Creek is a major contributor of both total and fine-grained sediment, particularly for the size of its drainage area and loads from disturbed western streams remain high.
- Loads from western streams are not increasing with time as reported by others,
- Median, long term suspended-sediment yields (per unit runoff) from northern streams are high, about the same as the wetter western streams but yields have shown significant decreases from the major development period in the 1960s and 1970s.
- Third Creek still produces a great deal of sediment for its size as a result of both upland and channel contributions.
- Disturbed watersheds contribute considerably more suspended sediment than their stable counterparts in each basin quadrant.
- Eastern streams produce the lowest sediment loads and those studied are net sinks for sediment.
- The major runoff event of January 1997 impacted western streams and the Upper Truckee River most severely, but did not seem to rejuvenate these fluvial systems. Effects were minor in the northern streams,

- The most significant effect of the January 1997 was to flush stored sediment from alluvial valleys resulting in generally lower transport rates in the years following the event,
- Numerical simulations of General and Ward Creeks and the Upper Truckee River show that suspended-sediment loads will continue to decrease from these streams over the next 50 years.

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1 BACKGROUND

1.1 Introduction

The Lake Tahoe Basin has a long history of human interaction and exploitation dating back to the 1850s. Activities such as logging, road construction, mining, overgrazing and urbanization have led to degradation of land and water resources and threaten to do irreparable damage to the lake. In particular are concerns over lake clarity, which have been partly attributed to the delivery of fine-grained sediment emanating from upland and channel erosion. Over the past 35 years, a trend of decreasing water clarity, as measured by secchi depth has been documented (Figure 1-1). There are 63 watersheds that drain directly into Lake Tahoe and all are within the Sierra Nevada, Level III ecoregion (Figure 1-2).

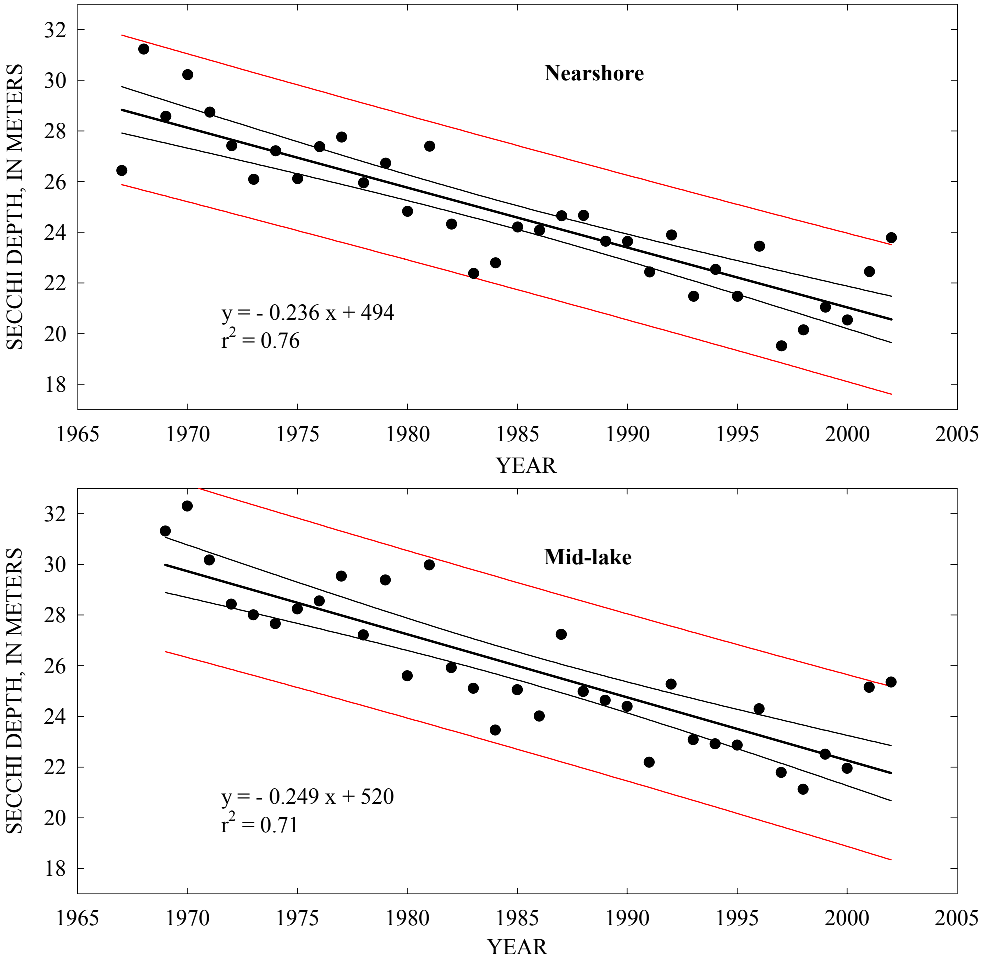

Figure 1-1. Trend of decreasing water clarity in Lake Tahoe as measured by secchi-depth for nearshore (top) and mid-lake stations (bottom). Raw data from Tahoe Research Group (TRG); Red lines denote 95% prediction limits.

A number of studies have been completed in the past 25 years to address sediment delivery issues from various watersheds in the Lake Tahoe Basin. Most of these studies have each focused on only a few streams within the watershed (Kroll, 1976; Glancy, 1988; Hill and

Nolan, 1991; Stubblefield, 2002). Recent work by Reuter and Miller (2000) and Rowe *et al.* (2002) used suspended-sediment transport data from the Lake Tahoe Interagency Monitoring Program (LTIMP), which brought together data from streams all around the watershed. These works have indicated that the following streams are among the largest contributors of suspended sediment to Lake Tahoe: Incline, Third, Blackwood, and Ward Creeks, and the Upper Truckee River. Most of the sediment is delivered during the spring snowmelt period (predominantly May and June), which correlates well with the spring reduction in secchi depth. Because lake clarity is related to the very fine particles that remain in suspension and that transport adsorbed constituents, it is essential to identify the load of fine-grained materials. For the purposes of this report, fine-grained sediment refers to particles 0.062mm or finer.

Selection of appropriate management strategies must be founded on the identification of the controlling processes and associated source areas of fine sediment. These source areas can be broadly separated into uplands and channels. More specifically, upland sources may include slopes, fields, roads, construction-site gullies etc., while channel sources may include channel beds, bars and streambanks. Moreover, the magnitude of sediment production, transport and delivery to the lake varies widely across the basin as a function of differences in precipitation, surficial geology, land use/land cover, and channel instabilities. Restoration and management strategies that may be based on targets of sediment loadings will need to consider different "reference" conditions from one side of the basin to another based on "background" rates of sediment transport for that part of the basin. For example, although General Creek is generally accepted to represent a stable sediment-transport regime, because it is located on the wetter, western side of the basin, it will not be an appropriate "reference" for the drier, eastern side of the basin. Conversely, it would be unreasonable to expect suspended- sediment loads or yields (loads per unit area) from even the most stable western streams to approach the extremely low values reported for Logan House Creek which drains the eastern slopes of the basin.

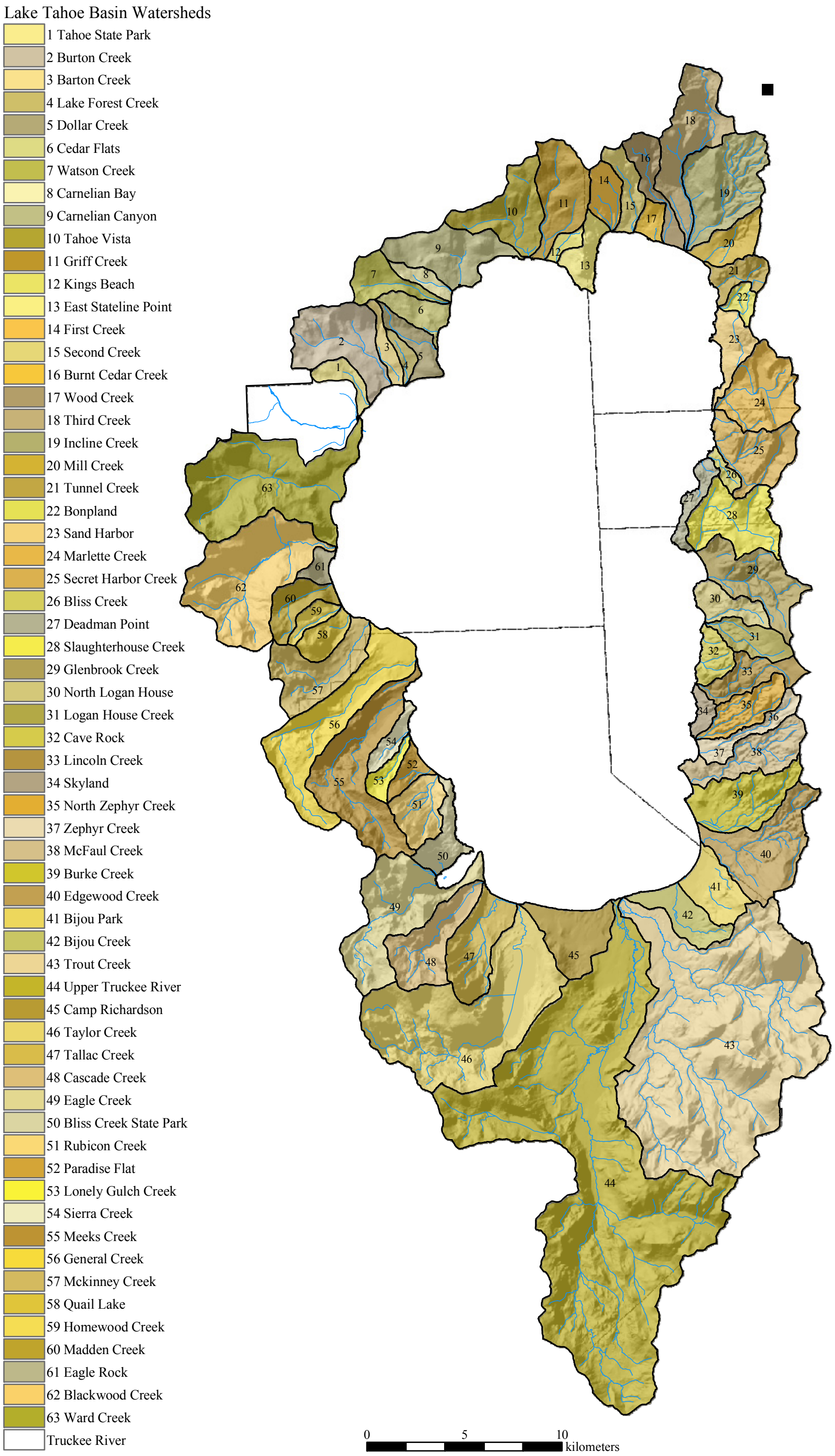

Figure 1-2. Map of Lake Tahoe Basin showing the 63 watersheds draining to the lake. Map obtained from the Tahoe Regional Planning Agency (TRPA).

1.2 Purpose and Scope of Investigation

The broad purpose of the research was to quantify sediment loads to Lake Tahoe from stream channel erosion. The project was of relatively short duration (10 months), and because the geographic scope of the project covered the entire Lake Tahoe Basin, work had to be scaled accordingly. The research was initiated in late August 2002, necessitating field work completion before snow blanketed the basin. Specific objectives of the work included:

1. Determine historical suspended-sediment transport rates and temporal trends to Lake Tahoe;
2. Evaluate contributions of suspended-sediment from stream channels across the watershed;
3. Determine a bulk loading number for sediment from individual streams, and the relative contributions of fine- and coarse-grained materials for use in subsequent TMDL analysis;
4. Evaluate the effect of the large runoff event of January 1997 on future suspended-sediment loadings;
5. Simulate suspended-sediment loadings for the next 50 years for a minimum of three representative watersheds using the upland model AnnAGNPS and the channel evolution model CONCEPTS;
6. Determine differences in loadings rates from disturbed and undisturbed streams in the basin;
7. Specify in detail the methodology used to determine estimates of loadings and reference conditions;
8. Evaluate what combinations of watershed and stream condition, soil type, rainfall characteristics, etc. pose the greatest hazard in terms of sediment erosion and delivery for the purpose of prioritizing areas requiring restoration; and
9. Provide suggestions as to future data needs and research projects.

1.3 Acknowledgments

This project, more than almost any other one we had ever been involved with previously could not have been successfully completed without the combined, dedicated efforts of the staff of the Channel and Watershed Processes Research Unit at the National Sedimentation Laboratory (NSL). These are the people that don’t get their names on the covers of reports but work tirelessly both in the field and at their computers to help produce an excellent research product. We thank Lauren Farrugia for conducting and supervising the geotechnical and sampling aspects of the field work and for keeping it all organized when we got back; Charlie Dawson and Mark Griffith, for leading survey crews throughout the basin; Brian Bell for field work assistance and anlaysis of temporal trends; Micah Findeisen for production of scores of GIS-based maps and analysis of GIS data; and Danny Klimetz for production of GIS-based maps and statistical analyses. This project could not have been completed without their help.

The great majority of the funding for this research was provided by the U.S. Army Corps of Engineers (CoE), Sacramento District, where Phillip Brozek and his assistant Mellissa Kiefer provided straightforward management and oversight of the work. David Biedenharn, CoE, Coastal and Hydraulics Laboratory, Engineer Research and Development Center (ERDC) also

provided funding out of the Regional Sediment Management Project. Agricultural Research Service discretionary research funds were also provided by NSL to support this effort. We owe a great debt to Ronnie Heath, ERDC, for recommending our research group to the Sacramento District to undertake this project.

Many people from other interested agencies and universities played vital roles in the successful completion of this project. To David Howard Roberts, Lahontan Regional Water Quality Control Board who went out of his way to provide avenues to people, resources, information and data that were essential for this research. To John Reuter, Tahoe Research Group (TRG), University of California at Davis, for asking tough questions, providing tough answers and making secchi-depth data available to our staff. To K. Mike Nolan, USGS, Menlo Park, for providing copies of raw field and survey notes taken almost 20 years during his study in the basin and for having the foresight in the early 1980s to "really" monument channel cross sections. To Cynthia Walck, California State Parks, Tahoe City, for providing 10 years worth of time-series cross sections of the Upper Truckee River when we thought we couldn't search any further. To Andrew Stubblefield, TRG, for providing data and for leading us to historical cross-section locations in the western side of the basin. To Rita Whitney, Tahoe Regional Planning Agency, (TRPA) for reams of information on previous studies in the basin. To the U.S. Forest Service for providing two field vehicles and field support during our three-month stay in the Lake Tahoe area. To Dave Kearney and Scott Valentine, U.S. Forest Service for weeks of field assistance.

Given the amount of work that had to be completed over the 10-month duration of this project, the assistance provided by the people and agencies listed above were absolutely crucial. It is encouraging to see in this day and age, the kind of inter-agency cooperation that occurred during the course of this research. We thank you.

1.4 Overview of Research Approach

At the outset of the project, hard copy and/or digital maps and air photos were obtained for the entire watershed and registered in a GIS framework. A review of previous studies and availability of data and previously published results were conducted. All historical flow, suspended-sediment transport, and particle-size data from U.S. Geological Survey gauging stations were downloaded for use in determining magnitudes and trends in sediment-transport rating curves.

Rowe *et al*., (2002) has analyzed flow and suspended-sediment transport data for the 1990s. There are 38 stream sites in the Lake Tahoe Watershed where the USGS had at least 30 matching samples of instantaneous flow and suspended-sediment concentration data. Precipitation and snowfall data to be used for numerical modeling was acquired from available sources because the 50-year climate simulation to be supplied by a concurrent research effort was not available at the time the modeling was conducted.

The research approach to address the nine sub-objectives combines empirical analysis of field assessments and site-specific data with historical data on flow, sediment transport, land use and stream morphology, with deterministic numerical simulations of uplands and channel erosion. In general terms we aim to utilize broad reconnaissance techniques (by ground and data analysis) to initially characterize streams and watersheds into groups (perhaps stable/unstable, western, eastern, northern and southern) then select a representative stream(s) from each group that has an extensive historical data base of flow, sediment transport, bed-material characteristics and morphology to perform detailed field work and numerical simulations.

Ground reconnaissance involved rapid geomorphic assessments (RGAs) of stream-channel conditions and identification of the dominant geomorphic processes, extent of channel instabilities, and stage of channel evolution (Simon and Hupp, 1986; Simon, 1989). As part of the RGA procedure, a semi-quantitative channel-stability index was modified to include potential side-slope erosion (combined-stability index) and calculated for hundreds of sites along the studied streams based on diagnostic criteria obtained during each RGA. Results provide insights into dominant channel-processes around the basin and can be used to identify critical channel areas. In addition, samples of bed and bank material were obtained at all ground reconnaissance sites for use in determining potential sources of fine-grained sediment. The RGAs were supplemented by more detailed geomorphic evaluation conducted by walking and sampling representative, sediment-producing streams to delineate specific sources of fine-grained streambank materials.

Sediment-transport rates for all streams with available data were analyzed to determine annual loadings and yields. Because of the great variability in precipitation-runoff characteristics around the Lake Tahoe Basin, watersheds were segregated by geographical quadrant (north, south, east, and west) to delineate differences in suspended-sediment transport loadings between quadrants. Disturbed and undisturbed streams in each of the quadrants were compared to determine background sediment-transport rates and to evaluate the effect of upland and channel disturbances on suspended-sediment transport rates from the four quadrants. For example, data from Logan House Creek in the east, and General Creek in the west, considered “reference” streams, and along with median annual values from a given quadrant, were used to contrast loading rates from other unstable streams. Intra-basin variations were evaluated for those watersheds with more than one station with historical data.

Loads and yields of fine-grained suspended-sediment were calculated from mean-daily loads (calculated from measured flow and instantaneous concentration data) and relations developed between the percentage of silt and clay, and discharge. Any temporal trends in both total- and fine-grained suspended –sediment loadings were established through rigid statistical tests of annual and mean-daily data.

Rates of sediment transport at gauging stations provided information on bulk loadings past the respective gage over various periods of time (storm event, day, season year). Re-surveying of historical, monumented cross sections were used to determine directly, channel contributions over specified lengths of five main stem streams: Blackwood, General, Edgewood and Logan House Creeks, and the Upper Truckee River (Figure 1-3). Data supplied by the U.S. Geological Survey and California State Parks were essential to this effort. To differentiate the relative magnitudes of upland and channel sediment sources, numerical simulations were performed on three representative watersheds within the Lake Tahoe Basin: General and Ward Creeks, and the Upper Truckee River (Figure 1-3). In combination with the streams specified above, these tributaries to the lake represent the seven intensely studied streams in this project. These streams were selected for more detailed investigation based on several factors: availability of historical flow and suspended-sediment concentration data, availability of historical cross sections, and a documented large sediment contributor or reference stream.

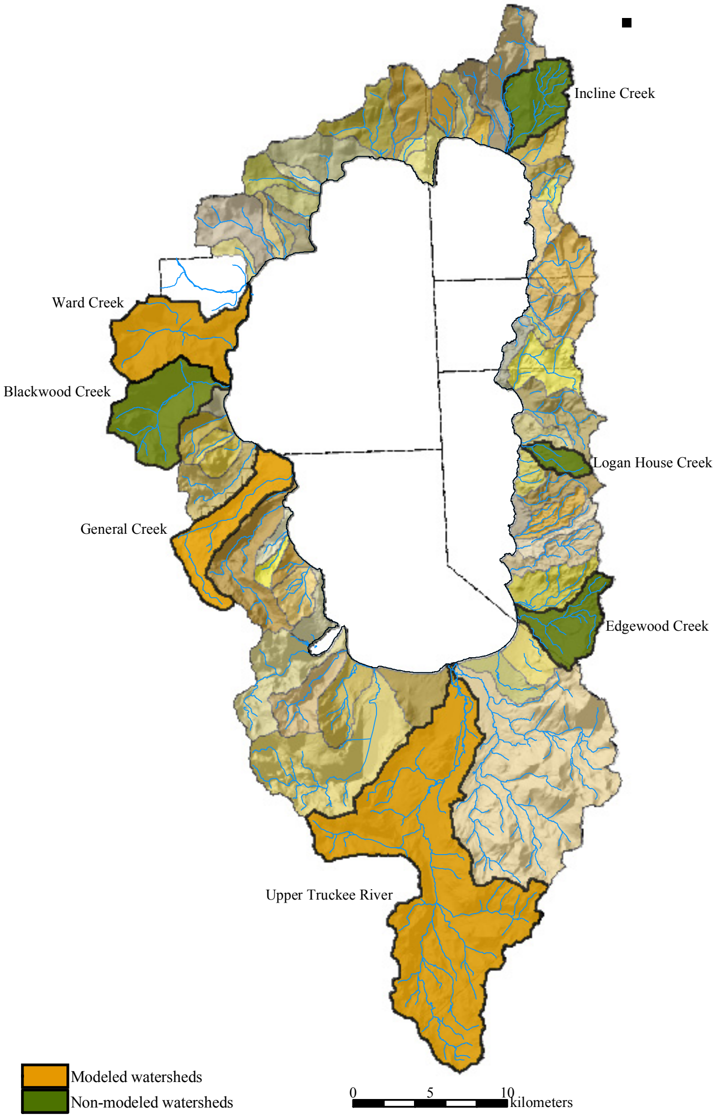

Figure 1-3. Map of the Lake Tahoe Basin showing the seven intensely studied watersheds. Numerical simulations were conducted on General and Ward Creeks, and the Upper Truckee River.

To support the modeling effort, intensive field-data collection of channel cross sections, bed- and bank-material particle size, bank-toe erodibility (erodibility coefficient 'k' and critical shear stress 'τ_o') and bank-material shear strength (cohesion 'c_a', friction angle 'ϕ', and unit weight 'γ') were carried out *in situ* along each of the modeled streams. The AnnAGNPS model was used to generate upland flow and sediment contributions to the main channels. Output from AnnAGNPS output was validated using historical flow and sediment-transport loadings calculated in this study to generate additional model inputs for the CONCEPTS channel-evolution model. This deterministic numerical-simulation model was used to determine channel changes over time during the validation periods and to simulate channel changes and sediment loads for 50 years into the future. Estimates of sediment loads from AnnAGNPS and CONCEPTS were used to evaluate the relative contributions of sediment from upland and channel sources.

The effects of the large January 1997 runoff event was evaluated empirically, by investigating shifts in sediment-transport rating relations for all stations with sufficient data, and by numerical simulation in the three modeled watersheds.

Analysis of an upland-erosion potential index was carried out using five GIS-based layers of upland variables and mean-annual precipitation. The resulting map can be used to identify potential areas of high upland-sediment contributions. This differs from the evaluation of side-slope erosion that represented direct contributions from slopes adjacent to channels.

1.5 General Description of Basin Characteristics

There exist numerous, thorough descriptions of the pertinent aspects of the Lake Tahoe Basin, its physiography, climate, land use, and history. For the basin as a whole, we provide only an abridged version of this description and direct the reader to the various sources referenced in this section. More attention is given to the seven streams that were studied more intensely than the others (Figure 1-3): Blackwood, Edgewood, General, Incline, Logan House, and Ward Creeks, and the Upper Truckee River.

The Lake Tahoe Basin covers approximately 800 km^2 along the crest of the Sierra Nevada Mountains of California and Nevada. Lake Tahoe itself encompasses approximately 500 km^2 in the center of the basin. Elevations within the basin range from 1898 m above sea level at the lake level to 3000 m at the peaks (Goldman et al. 1974). Graben faulting and volcanism influenced the primary geologic environment found in the Lake Tahoe Basin. It is these processes that formed Lake Tahoe. Geologic units present in the basin are: Early Mesozoic metamorphic rocks of sedimentary and volcanic origin, Granitic rocks of the Sierra Nevada Batholith, Late Mesozoic Tertiary and Quaternary volcanics, and Quaternary glacial, fluvial, and lacustrine deposits. The Basin was extensively glaciated during the Pleistocene epoch affecting the west side of the Basin more than the eastern. Glaciations eroded the surrounding mountain valleys forming moraine and depositing outwash in the basin as far as the current shores of Lake Tahoe (Stubblefield 2002). Rivers reworked the glacial material between and during glacial advances forming alluvial deposits.

The Lake Tahoe Basin is divided into 63 watersheds feeding into Lake Tahoe (Figure 1-2). The Truckee River drains Lake Tahoe to the northwest into Pyramid Lake located in northwestern Nevada. The climate of Lake Tahoe's drainage basin is characterized by four sharply defined seasons. Summers are dry with maximum average daily temps around 24^{o} C, and winters are cold with daily average temperatures around –1.1^{o} C. The current climate is wetter than the climate that existed at the turn of the 20th century (Murphy 2000). Significant precipitation occurs between November and March as snow or mixed rain and snow. The eastern shore receives half the yearly precipitation of the west shore. The annual average on the west shore for the period 1989-1996 was 86 cm (Mussetter Engineering, 2001). As of 1991, approximately 68 % of the land area in the basin was forested.

A period of rapid population growth occurred from the 1950s through the 1970s. Since 1990 the total population in the basin has remained around 55,000. It was during this rapid growth that human activity such as livestock grazing, logging, and mining began to influence the basin. While the basin contributes eight percent of the regions population, it supplies 24% of the jobs. Beginning in the 1860s to the 1890s logging in response to the Comstock Mining boom was a primary activity around most parts of the Lake Tahoe basin. Post 1960s the majority of logging occurred on private lands along the north shore in the form of second-growth pine at a much smaller scale. In the 1990s, 31,600 acres supported either cow or horse grazing. Currently, approximately 15% of the basin's land area is developed with residential or commercial buildings, and 70 % of this developed land is located in forested areas (Murphy 2000).

1.6 <u>Characteristics of the Intensely Studied Streams</u>

1.6.1 Blackwood Creek

Blackwood Creek was selected for intensive study for several compelling reasons. As one of the highest sediment producers in the Lake Tahoe watershed, it offered an excellent opportunity for study because of the extensive cross-section surveying undertaken in 1983, 1984 and 1987 by the USGS (Hill *et al*., 1990; Nolan and Hill, 1991) and the long period (40 years) of flow and suspended-sediment sampling at a station close to the mouth.

The Blackwood Creek Basin covers 29 km^2 on the west-central side of the Lake Tahoe Basin (Tetra Tech, 2001) (Figure a). The valley has an eastern aspect near the mouth and a northern aspect near the headwaters. The total relief of the stream, per topographic map (Homewood 1:24000 quadrangle), is 500 m over 9 km of valley length. Geologically, the basin is underlain by extrusive volcanics (Tetra Tech, 2001) with large areas classified as rockland and rubble (Stubblefield, 2002). Pleistocene glaciation of the watershed has created a broad lower valley overlain with soils generated from glacial moraines and outwash from the volcanic uplands (Stubblefield, 2002). Four similarly sized streams, about 4 km long each--North Fork, Middle Fork, a major tributary of the Middle Fork, and the main stem of Blackwood Creek--join together in the upper third of the basin.

Precipitation averages 1500 mm per year over the entire watershed. Precipitation is greatest at the higher elevations, which receive an annual average of 2000 mm where the average near the lake is about 1000 millimeters per year (Tetra Tech, 2001). About 90% of the precipitation falls as snow (Tetra Tech, 2001) with the remainder occurring during rare summer thunderstorms (Stubblefield, 2002). Upland vegetation occurring throughout the watershed includes white fir, red fir, and lodgepole pine. Riparian vegetation includes dogwood, alder, willow, aspen, cottonwood and sedges (Tetra Tech, 2001).

Human influences historically included livestock grazing, logging, and mining. Livestock grazing occurred from 1864 until 1962 after the overstocked range had degraded to poor condition. Logging was initiated in 1890 to supply lumber for the Comstock mines and ended by 1898 when all marketable timber had been harvested (Murphy, 2000). Second growth forests were harvested near the north fork from 1956 until 1970 (Stubblefield, 2002). From 1960 to 1968 a gravel mining operation took place in the basin. At that time the stream channel was diverted to allow mining in the floodplain; it was later returned to the gravel pit area in 1978 (Stubblefield, 2002). Presently the area is used for recreation including hunting, fishing, camping, and off-road vehicle riding. One paved road follows the length of the watershed from highway 89 to Barker Pass. Additionally several unpaved roads exist in the watershed. The recent and extensive use of off-road vehicles has led to rechannelization of hillslope drainages (Stubblefield, 2002) and has slowed the recovery of vegetation on many logging roads (Tetra Tech, 2001). A more detailed description of the watershed history can be found in the Blackwood Creek TMDL Feasibility Project report by Tetra Tech, 2001.

1.6.2 Edgewood Creek

Edgewood Creek was also one of the streams investigated in the 1980's by the USGS, providing a baseline by which to compare channel contributions over the past 20 years. In addition, it represents a developed watershed on the drier, eastern side of the basin with a fairly extensive gage record at various locations throughout the watershed.

The Edgewood creek watershed covers 17.3 km^2 on the southeast side of the Lake Tahoe Basin (Figure-1.3). Over 90% of the watershed is underlain by granitic bedrock. The remainder consists of glacial outwash and lacustrine deposits near the mouth (Hill, 1987). The average annual precipitation is about 584 mm (Hill, 1987). Above Highway 50, the watershed is well forested with second growth conifers. Below Highway 50, the stream flows through the Edgewood Golf course, where grass and sparse forest are the primary cover.

During the Comstock era, the watershed was logged. Since the 1960s, urbanization has taken place along the major roads. Highway 50 near the lake has undergone commercial development. Highway 207, which provides an eastern route from the Tahoe Basin through the northern half of the watershed, has been developed residentially within several hundred meters of the watershed divide near Daggett Pass. Ski lifts, roads, buildings, and other ski resort infrastructure have been constructed for the Heavenly Ski Resort. This ski area is located at higher elevations along the central and southern parts of the watershed.

1.6.3 General Creek

General Creek is representative of relatively stable, undisturbed conditions on the wetter, western side of the basin and an extensive sediment record near its mouth was used to compare sediment loads and yields from disturbed watersheds such as Ward and Blackwood Creeks. Historical cross-section surveys were also conducted by the USGS at numerous locations along the main stem in the 1980s.

The General Creek watershed covers 19.3 km^2 (Hill, 1987) on the west central side of the Lake Tahoe basin (Figure-1.3). The total relief of the stream, per topographic map, (Homewood 7.5 minute quadrangle) is 500 m over 13.6 km of valley length. The main channel flows in two distinct valleys. The upper valley, with a northwestern aspect and low gradient, was glacially scoured leaving many rounded and plucked granitic bedrock exposures in the valley. The lower valley contains depositional glacial features such as moraines and tills.

Precipitation in the watershed averages 1270 mm per year (Hill, 1987) with snowfall being the dominant form. Upland vegetation consists of pine forests throughout the watershed. The upper valley floor, however, has manzanita covering large areas, especially near the channel. The lower valley floor varies in width from a talus lined sharp V-shape near its head to an outwash plain near the lake. Alders and dogwoods dominate the riparian zone along the entire lower valley.

Human influences include the road and building infrastructure associated with Sugar Pine State Park near the mouth and a U.S. Forest Service road providing vehicular access to both sides of the stream over the lower 3.5 km. A hiking/mountain biking trail provides visitor access to the upper parts of the watershed. While specific historical logging information on the watershed was not found, it is assumed that like neighboring watersheds, the lower valley was logged during the late 19th century.

1.6.4 Incline Creek

Incline Creek has been the subject of several studies on the effects of development on sediment transport, most notably, Glancy (1988). Its selection as a watershed to study in detail was based on a relatively long flow and sediment-concentration record at several gaging stations as well as one that could be used as a measure of the effects of development.

The Incline Creek watershed drains 19 km^2 on the northeast side of the Lake Tahoe Basin (Figure-1.3). The valley has a southwestern aspect. The total relief of the stream is 750 m over 7.9 km of valley length (Entrex, 2001). Geologically, the upper watershed is composed of Cretaceous granodiorites and Tertiary andesites. The surficial geology of the lower watershed consists of Quaternary glacial outwash, alluvium, and lakeshore sediments (Entrix, 2001).

Precipitation in the watershed is estimated to average 630 mm annually with 70% occurring as snowfall (Glancy, 1988). Second growth pine forests covering the upper two thirds of the watershed dominate upland vegetation. Urbanization activities starting in the 1950s have thinned upland vegetation considerably from the lower third of the watershed. Riparian vegetation includes willow, alder, and grasses throughout both the urban and non-urban reaches.

Historically, human influences have included logging, livestock grazing, and urbanization. From 1875 until 1897 the Crystal Bay area was clearcut. Since that time, secondary forests have re-grown throughout the watershed (Glancy, 1988). The upper, non-forested slopes were grazed by sheep following the logging era. Rapid urbanization began in the 1960's when development in the watershed was expanded from a few roads and summer homes to include a ski and golf resort as well as a proper town area, covering approximately 30% of the watershed (Entrex, 2001).

1.6.5 Logan House Creek

Originally selected because it was another of the USGS study streams in the 1980's, Logan House Creek has the lowest suspended-sediment yields of any stream with historical data. Therefore, it serves as a reference stream for the eastern side of the basin.

The Logan House Creek watershed covers 5.4 km^2 located on the east central side of Lake Tahoe (Hill, 1987) (Figure-1.3). The valley has a western aspect and the total relief of the stream channel, per topographic map, (Glenbrook 7.5 minute quadrangle) is 750 m over 5 km of valley length. A major tributary joins the main channel approximately 700 m above the mouth. Geologically, the watershed is underlain with decomposing granodiorite over the lower 70%, while the upper 30% is underlain with undifferentiated metamorphics (Hill, 1987). Precipitation averages 635 mm per year over the entire watershed (Hill, 1987) with the majority being snowfall. Upland vegetation consists of firs, while riparian vegetation consists of aspen, alder, willow, dogwood, and grasses.

Loggers clearcut the watershed during the Comstock era (Murphy, 2000). Presently, the watershed is forested in secondary growth. A residential development, covering approximately 0.2 km^2, is located over the lowest 700 m above the mouth. The remainder of the watershed is undeveloped with the exception of one U.S. Forest Service road crossing through the upper end.

1.6.6 Upper Truckee River

As the largest watershed in the Lake Tahoe Basin, the Upper Truckee River delivers more sediment to the lake than any other stream. Several gaging stations having relatively long periods of record and are conveniently located such that interpretations can be advanced regarding which reaches produce fine-grained sediment. Additionally, historical cross-section surveys covering a 10-year span were made available by California State Parks allowing direct comparison of changes in channel morphology over a 2.9 km reach.

The Upper Truckee River drains 142 km^2 on the south side of the Lake Tahoe Basin. The watershed has a northern aspect. The geology of the upper third of the watershed is primarily granitic bedrock. The middle third is overlain by glacial till and moraine. The lower third is primarily underlain by glacial outwash and Quaternary lake sediments (Mussetter, 2001).

Average annual precipitation ranges from 500 mm at low elevations to over 1500 mm at the highest elevations in the watershed. Most of the precipitation falls from late fall to early spring, primarily in the form of snow. There are, however, occasional thunderstorms in the summer (Resources Agency, 1969). Dominant vegetation types include meadow grasses and sedges, willows, alders, aspen, and lodgepole pine (USDA Forest Service, 1990).

Human influence has played an important role in stream conditions. From 1873 until 1890 heavy fir and pine logging associated with the Comstock mining operation left the area mostly deforested. After 1890, the basin was left to revegetate, and mining traffic decreased. Urbanization has now become a major influence on stream conditions as well. From 1960 to 1965, the population of the basin doubled and has continued to increase dramatically since then

(Musseter Engineering, 2001). The area between Stateline and Meyers, CA has seen considerable road construction and watershed urbanization especially in the upland areas. Along with these indirect channel alterations, direct planform changes were made on the Upper Truckee River, such as the realignment of a stream reach along the airport in 1968 (Resources Agency, 1969).

1.6.7 Ward Creek

Ward Creek was selected for detailed study as another of the large sediment contributors and because of a series of gauging stations having flow and sediment-concentration data. Additionally, it serves as a reasonable comparison to the adjacent Blackwood Creek watershed that is notable for its level of disturbance and high suspended-sediment loads.

The Ward Creek watershed drains 25.1 km^2 and is located on the west central side of the Lake Tahoe Basin immediately north of the Blackwood Creek watershed. The total relief of the stream channel, per topographic map, (Tahoe City 1:24000 quadrangle) is 490 m over 9.5 km of valley length. The watershed has an eastern aspect. Geologically, the steep valley slopes of the watershed are underlain by andesitic breccias. Glacial moraine deposits cover the valley floor. Basalt outcrops occur about 2 km above the mouth. A grade control is created where basalt outcrops into the channel.

The climate is presumed to be similar to that of Blackwood Creek with an average annual precipitation of 1500 mm per year over the entire watershed. High elevations receive an annual average of 2000 mm, whereas the average near the lake is about 1000 mm per year (Tetra Tech, 2001). About 90% of the precipitation falls as snow (Tetra Tech, 2001), with the remainder occurring during rare summer thunderstorms (Stubblefield, 2002). Upland vegetation occurring throughout the watershed includes white fir, red fir, and lodgepole pine. Riparian vegetation includes dogwood, alder, willow, aspen, cottonwood and sedges (Tetra Tech, 2001). Beaver dams frequent the watershed. Floodplains built up behind the dams create sedge meadows and provide are dominated by young willows.

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Human intervention in the watershed includes logging throughout the Comstock era (Murphy, 2000) and sheep grazing managed by Basque herders (Stubblefield, 2002). Present influences include residential developments near the mouth as well as 6 km up the valley on the northern valley wall. A U.S. Forest Service road runs along the valley floor to a washed out bridge at about the 6 km point. Beyond the bridge, the road has become a trail for hikers and mountain bikers. Stream restoration efforts have taken place along the central portion of the watershed. The channel has been modified to create a trout habitat. Erosion control netting has been installed on several of the steep, poorly vegetated banks of fine, unconsolidated materials.

2 FIELD-DATA COLLECTION AND ANALYSIS OF SEDIMENT-TRANSPORT DATA

2.1 Introduction

Collection of field data was required to support several aspects of the research. Given that the research scope covered the entire basin, it was essential that as much information was collected first hand as possible to evaluate channel, upland, and sediment-transport conditions. Some of the data-collection activities such as ground reconnaissance and rapid geomorphic assessments (RGAs), as well as the GIS-based upland-erosion potential index will be described in later sections as appropriate. This section concentrates on field work that was used to support numerical modeling, re-surveying of monumented historical, channel cross sections and computational techniques used in the analysis of suspended-sediment transport loadings.

2.2 Cross-Section Surveys

Ground surveys of channels were required for two main purposes:

(1) To provide input geometries of stream channels for the CONCEPTS channel-evolution model; and
(2) To compare previously surveyed locations with current (2002) conditions.

A total of 245 cross sections were surveyed in the Lake Tahoe Basin during a three-month data-collection campaign in the fall of 2002. Vertical-control surveys were conducted on General Creek (37 cross sections), Incline Creek (48 cross sections), Logan House Creek (21 cross sections), the Upper Truckee River (38 cross sections), and Ward Creek (44 cross sections). A vertical-control survey is a survey in which elevations are carried through a series of benchmarks (the majority of the benchmarks were not established, documented benchmarks). Detailed channel- geometry surveys were conducted at regularly spaced intervals along the channel, from a predetermined upper boundary (usually a major confluence) to the outlet at the lake, to provide input information for CONCEPTS or comparison with historic cross sections.

Historic cross-section information was available for Blackwood Creek (31 cross sections), Edgewood Creek (26 cross sections), General Creek (12 cross sections), Logan House Creek (11 cross sections), Ward Creek (8 cross sections), and the Upper Truckee River (33 cross sections). Because many of these cross sections had been last surveyed in 1987 it was not possible to re-locate all of the historical section monuments. Cross-section data for Blackwood Creek, Edgewood Creek, General Creek, and Logan House Creek were provided by K. Nolan (USGS, written communication, 2003). A. Stubblefield (U. California at Davis, written commun., 2002) provided location information and newly monumented cross-section information for Blackwood Creek and Ward Creek, and the Upper Truckee River cross-section information was provided by C. Walck (California State Parks, written commun., 2003).

2.3 Geotechnical Data for Analysis of Streambank Stability

The adjustment of channel width by mass-wasting and related processes represents an important mechanism of channel response and a potential major contributor to sediment loads in the Lake Tahoe Basin. In the loess area of the Midwest United States, for example, bank material contributes as much as 80% of the total sediment eroded from incised channels (Simon and Rinaldi, 2000). In the Lake Tahoe watershed, sediment entrained from bank failures are blamed as a major contributor to the sediment and lake-clarity problems affecting the lake.

Conceptual models of bank retreat and the delivery of bank sediments to the flow emphasize the importance of interactions between hydraulic forces acting at the bed and bank toe, and gravitational forces acting on *in situ* bank materials (Carson and Kirkby, 1972; Thorne, 1982; Simon *et al*., 1991). Failure occurs when erosion of the bank toe and the channel bed adjacent to the bank have increased the height and angle of the bank to the point that gravitational forces exceed the shear strength of the bank material. After failure, failed bank materials may be delivered directly to the flow and deposited as bed material, or dispersed as wash load, or deposited along the toe of the bank as intact blocks, or as smaller, dispersed aggregates (Simon *et al*., 1991). Analysis of streambank stability within CONCEPTS is based on measured field data using *in situ* devices such as the borehole shear test (Figure 2.1) and the submerged jet-test device (Figure 2.2).

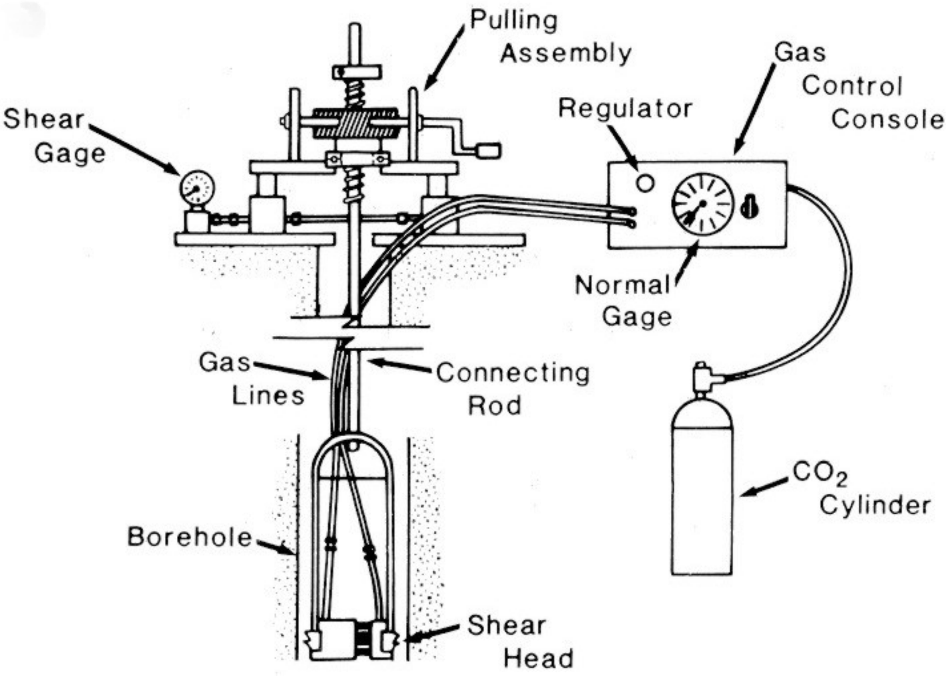


Figure 2-1. Schematic representation of borehole shear tester (BST) used to determine cohesive and frictional strengths of *in situ* streambank materials. Modified from Thorne *et al*., 1981.

2.3.1 Borehole Shear Testing and Bulk Unit Weights

To properly determine the resistance of cohesive materials to erosion by mass movement, data must be acquired on those characteristics that control shear strength; that is cohesion, angle of internal friction, pore-water pressure, and bulk unit weight. Cohesion and friction angle data can be obtained from standard laboratory testing (triaxial shear or unconfined compression tests), or by *in-situ* testing with a borehole shear-test (BST) device (Lohnes and Handy 1968; Thorne *et al.* 1981; Little *et al.* 1982; Lutenegger and Hallberg 1981). The BST provides, direct, drained shear-strength tests on the walls of a borehole (Figure 2.1). BST results for the General, Incline, Ward and Upper Truckee watersheds are shown in Tables 2-1 to 2-3. Advantages of the instrument include:

1. The test is performed *in situ* and testing is, therefore, performed on undisturbed material;
2. Cohesion and friction angle are evaluated separately with the cohesion value representing apparent cohesion (c_a). Effective cohesion (c') is then obtained by adjusting c_a according to measured pore-water pressure and ϕ^b (ϕ^b = rate of increase in strength with matric suction).
3. A number of separate trials are run at the same sample depth to produce single values of cohesion and friction angle based on a standard Mohr-Coulomb failure envelope.
4. Data and results obtained from the instrument are plotted and calculated on site, allowing for repetition if results are unreasonable; and
5. Tests can be carried out at various depths in the bank to locate weak strata (Thorne *et al.* 1981).

Table 2-1. BST values obtained for General Creek.

Site name	River kilometer	Bank	Depth (m)	Material	c_a (kPa)	c' (kPa)	ϕ' (degrees)	Pore-water pressure (kPa)
56-36	0.30	Right	0.45	Sand/Silt	1.80	1.10	33.1	3.75
56-30	0.89	Right	0.45	Sand/Silt	6.50	2.90	21.9	20.7
56-23	2.20	Right	0.40	Sand/Silt	0.920	0.00	22.3	70.1
56-19	3.25	Right	0.45	Sand/Silt	2.40	0.00	14.8	68.1
56-17	3.60	Right	0.50	Sand/Silt	0.00	0.00	15.0	66.4
56-12	4.73	Right	0.45	Sand/Silt	6.28	1.30	21.7	57.2
56-06	5.90	Right	0.43	Sand/Silt	1.04	0.00	35.1	51.5
56-05	6.06	Right	0.32	Sand	8.09	1.00	33.0	50.5
56-03	6.50	Right	0.44	Sand/Silt	1.50	0.00	32.5	71.5

Table 2-2. BST values obtained for Incline Creek.

Site name	River kilometer	Bank	Depth (m)	Material	c_a (kPa)	c' (kPa)	ϕ' (degrees)	Pore-water pressure (kPa)
18-33	0.72	Left	0.45	Silt	0.00	0.00	35.8	54.0
18-32	0.85	Left	0.38	Silt	5.79	0.100	34.9	65.1
18-31	1.08	Right	0.45	Silt/Sand	14.5	6.00	26.6	48.3
18-10	4.53	Left	0.30	Silt/Sand	6.11	0.700	12.5	61.5
18-5	5.22	Left	0.40	Silt/Sand	0.00	0.00	21.1	2.30
18-2	5.61	Left	0.40	Silt/Sand	3.51	1.60	34.3	10.9

Table 2-3. BST values obtained for Ward Creek.

Site name	River kilometer	Bank	Depth (m)	Material	c_a (kPa)	c' (kPa)	ϕ' (degrees)	Pore-water pressure (kPa)
63-43	0.25	Right	0.70	Sand/Silt	0.00	0.00	32.2	68.6
63-39	0.78	Right	0.70	Sand/Silt	2.27	0.00	18.4	-
63-37	1.11	Left	0.35	Sand/Silt	0.00	0.00	31.5	50.7
63-33	1.42	Left	0.35	Sand/Silt	1.99	0.00	35.8	55.2
63-29	2.08	Left	0.40	Sand/Silt	0.00	0.00	33.1	68.6
63-21	3.64	Left	0.70	Sand/Silt	0.00	0.00	33.3	46.0
63-19	4.06	Left	0.40	Sand/Silt	0.65	0.00	35.0	65.8
63-14	5.12	Right	1.50	Silt	1.04	0.00	33.4	55.6
63-12	5.53	Right	0.80	Sand/Silt	3.09	0.500	33.6	59.1

2.4 Submerged Hydraulic Jet Testing: Erodibility of Fine-Grained Materials

The submerged jet-test device is used to estimate erosion rates due to hydraulic forces in fine-grained *in situ* materials (Hanson 1990; 1991; Hanson and Simon, 2001) (Figure 2.2). The device shoots a jet of water at a known head (stress) onto the streambed causing it to erode at a given rate. As the bed erodes, the distance between the jet and the bed increases, resulting in a decrease in the applied shear stress. Theoretically, the rate of erosion beneath the jet decreases asymptotically with time to zero. A critical shear stress for the material can then be calculated from the field data as that shear stress where there is no erosion.

The rate of erosion ε (m/s) is assumed to be proportional to the shear stress in excess of a critical shear stress and is expressed as:

$$\varepsilon = k\,(\tau_o - \tau_c)^{a} = k\,(\tau_e)^{a} \qquad (1)$$

where *k* = erodibility coefficient (m^3/N-s); τ_o = average boundary shear stress (Pa); τ_c = critical shear stress; a = exponent assumed to equal 1.0l and τ_e = excess shear stress (Pa). An inverse relation between τ_c and *k* occurs when soils exhibiting a low τ_c have a high *k* or when soils having a high τ_c have a low *k*. The measure of material resistance to hydraulic stresses is a function of both τ_c and *k*. Based on observations from across the United States, *k* can be estimated as a function of τ_c (Figure 2.3). This is generalized to:

$$k = 0.1\,\tau_c^{-0.5} \qquad (2)$$

Two jet tests were conducted at each site where cohesive bed or bank-toe material was present. In general, the average value of the two tests were used to represent the cross section and for input into CONCEPTS. Values for the Upper Truckee watershed are shown in Table 2-4.

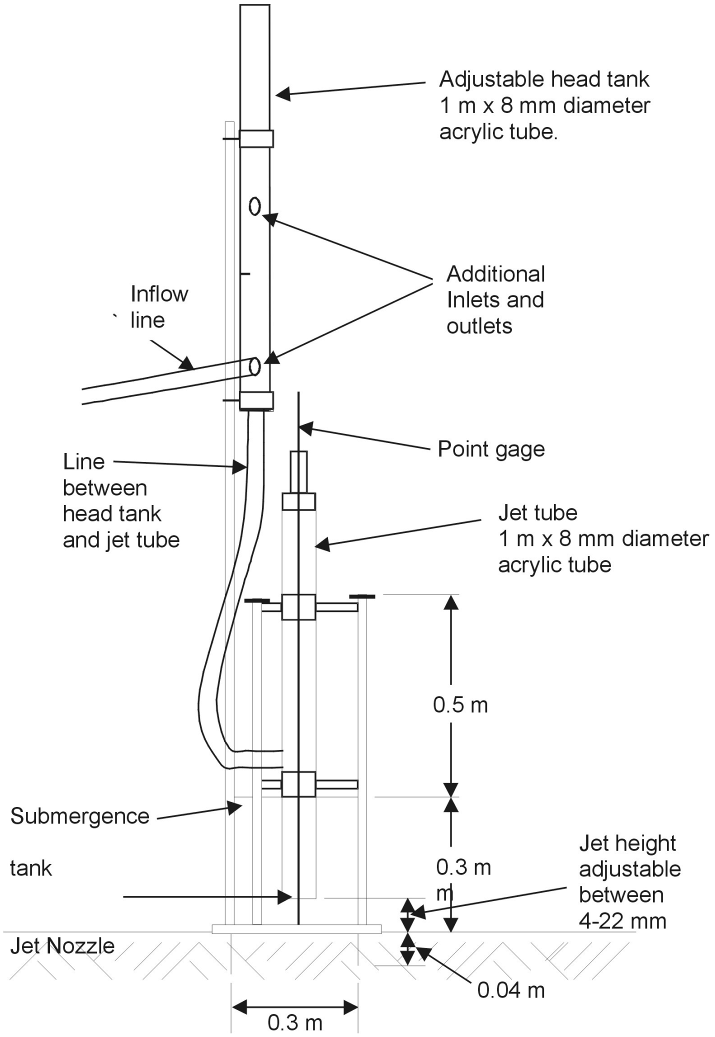


Figure 2-2. Schematic of submerged jet-test device used to measure the erodibility coefficient *k*, and the critical shear stress of fine-grained materials.

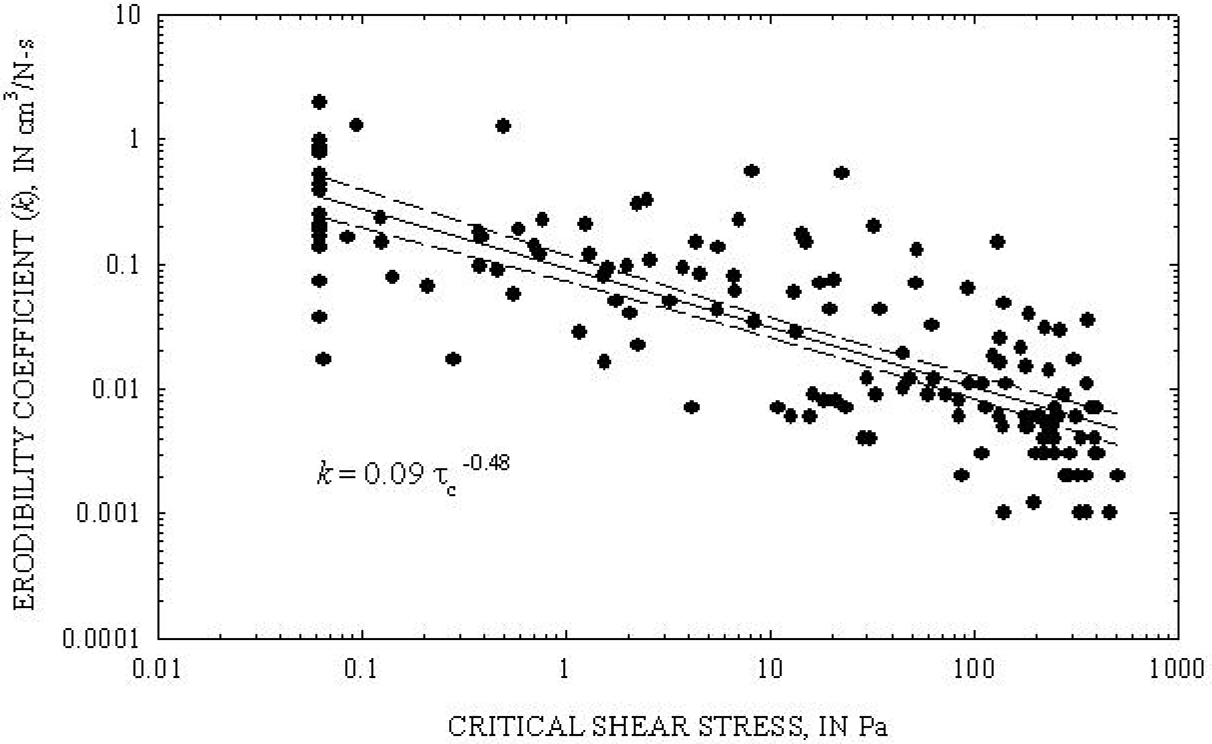


Figure 2-3. General relation between the erodibility coefficient *k*, and critical shear stress τ_c for fine-grained materials based on hundreds of jet tests from across the United States (Hanson and Simon, 2001).

Table 2-4. BST and submerged jet-test values obtained for the Upper Truckee River.

Site name	River kilometer	Bank	Depth (m)	Material	c_a (kPa)	c' (kPa)	ϕ' (degrees)	Pore-water pressure (kPa)	Jet location	τ_c (Pa)	k (cm^3/N-s)
44-110	1.56	Left	0.60	Silt Clay	7.95	2.20	37.6	65.5	-	-	-
44-92	2.94	Left	1.00	Sandy Silt	0.772	0.00	36.8	25.2	LBface	5.24	2.76
44-92	2.94	-	-	-	-	-	-	-	LBtoe	1.92	4.24
44-87	4.51	Right	0.30	Sand	0.160	0.00	31.0	4.30	-	-	-
44-85	5.06	Right	0.90	Silt	1.21	0.00	31.1	72.1	LBtoe	0.390	5.65
44-85	5.06	-	-	-	-	-	-	-	LBface	0.500	13.5
44-78	7.14	Left	0.35	Silt	4.20	0.90	32.5	75.7	-	-	-
44-75	8.46	Right	1.00	Silty Sand	3.30	2.60	27.4	4.20	RBtoe	0.280	29.6
44-75	8.46	-	-	-	-	-	-	-	RBface	0.360	4.87
44-68	10.8	Right	0.20	Silt	5.67	0.70	6.58	57.1	RBtoe	0.611	11.7
44-43	13.1	Right	1.15	Silty Sand	4.20	1.20	21.8	69.0	RBtoe	1.65	7.98

44-43	13.1	-	-	-	-	-	-	-	RBface	0.991	11.7
44-39	13.5	Right	0.30	Sandy Silt	0.230	0.00	30.5	70.4	RBtoe	1.15	12.5
44-39	13.5	-	-	-	-	-	-	-	RBface	1.29	16.8
44-26	14.8	Right	0.40	Sandy Silt	3.84	0.600	31.0	73.5	RBface	0.104	14.9
44-20	17.8	Left	0.40	Sandy Silt	1.77	0.00	18.8	39.5	LBface	1.49	4.28
44-20	17.8	-	-	-	-	-	-	-	LBtoe	0.0160	28.3
44-15	19.9	Left	0.89	Silty Sand	3.17	1.00	31.0	25.2	LBtoe	0.400	27.9
44-12	20.7	Right	1.10	Silty	2.38	0.00	28.7	73.4	LBface	0.78	29.0
44-04	23.0	Right	0.40	Silt	2.84	0.60	31.0	51.1	RBtoe	1.65	4.71

2.4.1 Bank-Toe Erodibility

In watersheds including Ward, General, Logan House, Edgewood, Blackwood, Incline and Upper Truckee, *in situ* bank-toe materials are composed predominantly of sands inter-mixed with cohesive material, gravel and cobbles. As with determining the erodibility of cohesive streambed materials, a submerged jet-test device (modified to operate on inclined surfaces) was used to determine values of τ_c and *k*. Values for sites in the Upper Truckee are shown in Table 2-4. Erosion of bank-toe materials is then calculated using an excess shear stress approach. For coarse-grained materials, bulk samples were obtained for particle-size analysis. Critical shear stress of these types of materials can then be calculated using conventional techniques as a function of particle size and weight.

2.5 Texture of Bank and Bed Materials

Fine-grained sediment is one of the main concerns in the Lake Tahoe area because of the nature of fine sediment to remain in suspension for longer periods of time and degrade lake clarity. Although alluvial materials are dominated by materials of sand size and coarser, fine-grained sediments can be found in varying quantities in streambanks. This sediment is released from the banks when the banks fail. To determine where bank failures were occurring, rapid geomorphic assessments were conducted across the watershed and bulk samples of bank material were collected at each of these sites. The purpose of this was for users of this report to be able to correlate the occurrence of bank failures with the relative proportion of fine sediments delivered by those bank failures not only for the seven intensely studied streams, but in the remainder of the watersheds as well.

The spatial distribution of fine-grained streambank materials, expressed as percent finer than 0.062 mm is illustrated in Figure 2.4. Values ranged from 0 to about 27 %, with the lower reaches of the Upper Truckee River having the greatest volume of fine-grained materials in its banks and an average fine-grained content of 14%. Ward Creek had the highest average concentration of fines, 17%. The average composition of fine-grained bank material for each of the intensely studied watersheds is shown in Table 2-5. Fine-grained materials were not found in measurable quantities on channel beds.

Table 2-5. Average percentage of fine-grained material contained in the banks of each modeled watershed.

Stream	Number of samples	Silt plus clay (%)
Upper Truckee	62	14
Ward	44	17
General	46	10
Edgewood	4	2
Blackwood	13	6
Incline	63	5

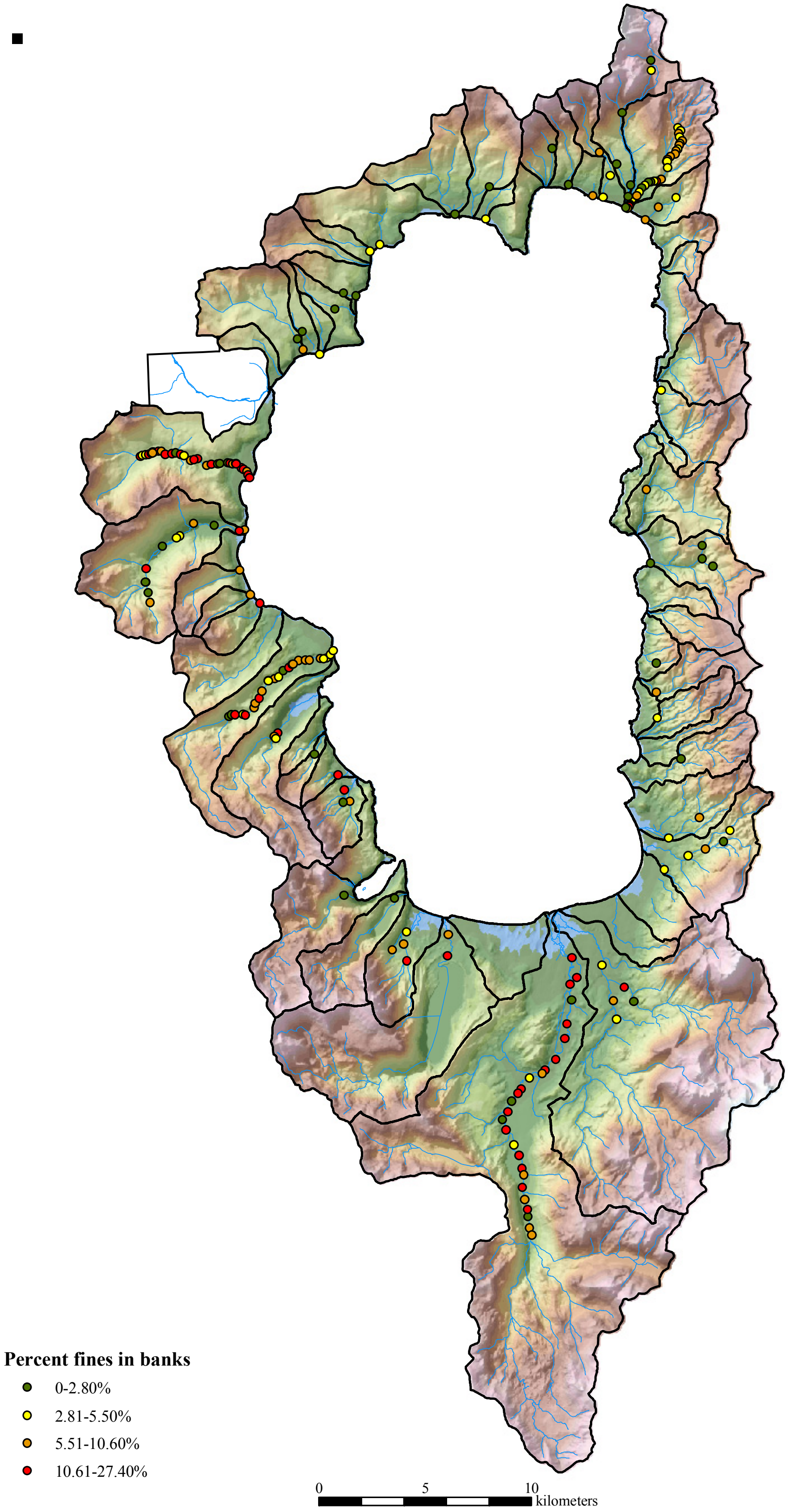


Figure 2-4. Spatial distribution of fine-grained bank materials.

CONCEPTS requires information on sediment texture to determine sediment routing and sorting processes. Bulk samples of bed materials were collected at the survey and RGA sites to be analyzed in the laboratory for particle-size distributions. If the bed was dominated by gravel-sized and boulder-sized material a count of a minimum of 100 particles was made to determine the distribution of particle sizes. In cases where streambeds were composed of a bi-modal mixture of sediment sizes with coarser-grained gravels, cobbles and boulders, particle-size distributions were weighted by the percentage of the bed covered by each type of sample (ie. bulk and particle count). Bed-material particle-size distributions for each cross section in each of the modeled watersheds are shown in Appendix B. The total number of particle-size samples for each stream is shown in Table 2-6.

Table 2-6. Total number of particle-size samples taken for each stream.

Stream	Total number of samples taken		
	Bed	Bank toe	Bank (internal and bank face)
Upper Truckee	31	28	62
Ward	32	17	44
General	27	7	46
Edgewood	14	0	5
Blackwood	10	0	13
Incline	35	0	63
Logan House Creek	3	0	0

Most study sites in the Lake Tahoe Basin area are characterized by streambeds composed of sand, gravel and cobbles (Appendix B). Resistance of these non-cohesive materials is a function of bed roughness and particle size (weight), and is expressed in terms of a dimensionless critical shear stress (Shields 1936):

$$\tau^* = \tau_o / (\rho_s - \rho_w)\, g\, D \qquad (3)$$

where τ^* = critical dimensionless shear stress; ρ_s = sediment density (kg/m^3); ρ_w = water density (kg/m^3); g = gravitational acceleration (m/s^2); and D = characteristic particle diameter (m). Average boundary shear stress (τ_o) is the drag exerted by the flow on the bed and is defined as:

$$\tau_o = \gamma_w R S_b \qquad (4)$$

where γ_w = unit weight of water (N/m^3); and R = hydraulic radius (area/wetted perimeter)(m). Critical shear stress (τ_c) in dimensional form can be obtained by invoking the Shields criterion and, for hydrodynamically rough beds, utilizing a value of 0.06 for τ^*.

$$\tau_c = 0.06\, (\rho_s - \rho_w)\, g\, D \qquad (5)$$

Thus, the shear stress required to entrain a grain of diameter *D* can be estimated. Other commonly used values of τ^* are 0.03 and 0.047 (Vanoni 1957). CONCEPTS uses 13 particle-size classes to analyze entrainment and sorting of non-cohesive sediment by invoking the Shields' criteria (Equations 3 and 5).

2.6 Generation of Suspended-Sediment Rating Relations

2.6.1 Introduction

Suspended sediment loads originating from watersheds draining to Lake Tahoe have been shown to be a principal cause of increased turbidity. Therefore, calculation of river suspended loads for different Lake Tahoe watersheds will provide a clear indication of problematic watersheds contributing to the reduced clarity in the lake observed over previous decades (Figure 1-1).

A function of the USGS, Water Resources Division is to collect continuous flow data supplemented by water-quality sample data at thousands of river gauging stations nationwide. The watersheds that drain to Lake Tahoe contain numerous gauging stations, albeit with differing periods of record and availability of water-quality data. One of the water quality parameters sampled on a regular basis is concentration of suspended sediment. When used in conjunction with the instantaneous discharge at sample collection, this sample data can be utilized to compute suspended-sediment transport rates. Integration with continuous flow records allows suspended-sediment loads contributed into the Lake Tahoe basin to be estimated.

2.6.2 Data Sources

Gauged suspended sediment and flow data were acquired from several sources. Instantaneous suspended-sediment concentration with associated instantaneous flow data for 38 (USGS) gauging stations within the Lake Tahoe Basin were downloaded from the USGS web site. Additional gauging-station data for Edgewood, Glenbrook, Dollar, Quail Lake, Eagle, Meeks, Burke and Wood Creeks, and various road gutters (within Grass Lake Creek, Eagle Creek, Meeks Creek and Quail Lake Creek watersheds) were obtained from tables in several reports, outlined in Table 2-7.

Table 2-7. Sources other than USGS Web sites with suspended-sediment data.

Watershed name	Data source
Edgewood Creek (including some additional data USGS 10336756)	Garcia (1988)
Glenbrook Creek (including some additional data for USGS 10336730)	Glancy (1977)
Dollar Creek	Kroll (1976)
Quail Lake Creek	Kroll (1976)
Eagle Creek	Kroll (1976)
Meeks Creek	Kroll (1976)
Burke Creek	LTBMU (2003)
Wood Creek	Glancy (1988)
Road Gutters (within Grass Lake Creek, Eagle Creek, Meeks Creek and Quail Creek watersheds)	Kroll (1974)

Data availability ranged considerably between gages. Of the twenty six gages with mean- daily flow data, the duration varied from 2.6 years (10336756, Edgewood Creek Tributary) to 41.0 years (10336660: Blackwood Creek and 10336780: Trout Creek). The number of instantaneous suspended-sediment concentration measurements with associated discharges also varied from single figures for several gages (Highway Gutter gages and temporary gages on Glenbrook Creek), to 824 records (10336698: Third Creek). Again, the relation between discharge and sediment can be assessed more accurately for gages with larger datasets, covering a greater duration and containing a more varied range of discharges.

2.6.3 Methods

From the available data, suspended-sediment rating relations were generated for the 68 gaging stations listed in Table 2-8. Scattergraphs in log-log space were generated to examine the correlation firstly between:

(1) suspended-sediment concentration (in mg/l) and discharge (in meters cubed per second; m^3/s), and

(2) load (in tonnes per day ;T/d) and discharge.

The latter was used for subsequent total load and yield calculations. A daily load was calculated for each sample using the following formula:

$$L = 0.0864\ C\ Q \tag{6}$$

where: L = load in T/d;
C = instantaneous concentration, in mg/l; and
Q = instantaneous discharge, in m^3/s.

The value 0.0864 is to convert from seconds to days and from milligrams to tonnes.

Linear regression in log-log space results in power function describing the relation between instantaneous discharge and load as:

$$L = a\ Q^{\,b} \tag{7}$$

where a and b are regression coefficients. Regressions equations of load (L) versus discharge (Q) (like eq. 7) have spuriously high coefficients of determination (r^2) because Q is included on both sides of the equation. This, however, does not effect calculations of load if the alternative (discharge versus concentration) is used.

In cases where there was substantial departure of data from the regression line in a consistent direction, a single power equation was not sufficient to adequately represent the relation. In these cases, either two- or three-linear segments (separate rating equations) were developed for designated flow ranges. The division point between these data ranges was identified by eye, and a manual iterative procedure was carried out to ensure the division point was optimal. Figures 2-5 and 2-6 contain examples of a two- and three-section rating curve, respectively.

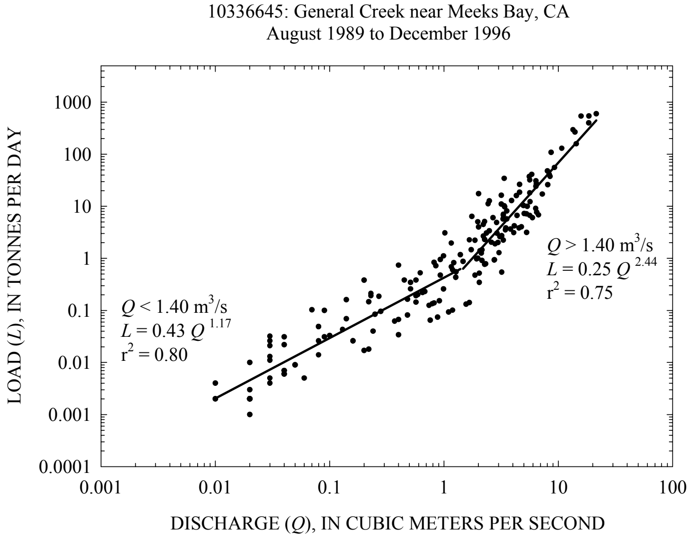


Figure 2-5. Example of two-section suspended-sediment rating relation.

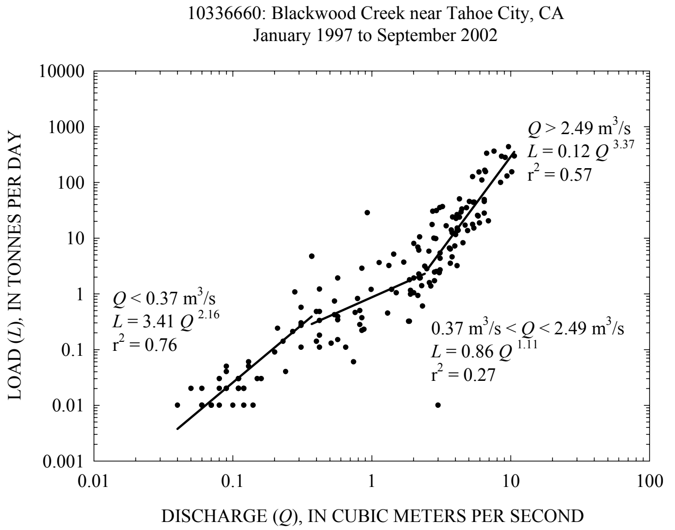


Figure 2-6. Example of three-section suspended-sediment rating relation.

2.6.4 Effect of the January 1997 Rain on Snow Event

Over the 1st and 2nd January 1997, a major rain on snow event occurred in the Lake Tahoe basin, generating the highest peak flows observed in the record period for some gauging stations. To test the effects of this large runoff event on suspended-sediment transport characteristics prior to and following January 1, 1997 sample data were separated throughout the basin into pre-event and post-event datasets and the regression process was repeated. The same methodology described above was adopted to produce the most accurate set of regression equations for each dataset. Plots of the pre- and post-event transport ratings were superimposed enabling comparison of the slopes and intercepts of the regression lines. Examination of these graphs indicated that suspended-sediment transport rates were consistently lower across the range of discharges for many stations following the January 1997 storm event. An example is shown in Figure 2-7.

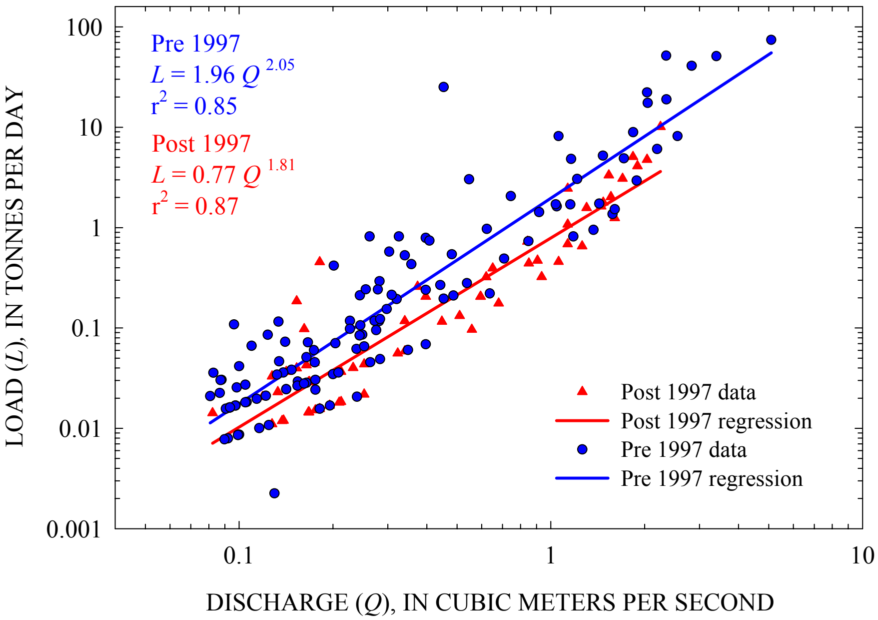


Figure 2-7. Pre and post January 1997 suspended-sediment rating curve: 10336770.

Statistical analyses were used to determine whether the observed lower slope and/or intercept of the post-1997 suspended-sediment ratings were significantly different. Firstly, a Type I sum of squares test was carried out to determine if the slopes of the pre- and post- suspended sediment rating equation were equal to zero. Secondly, a type III test was run to ascertain whether the slopes of the two relations were equal to each other. Finally, an additional type III test was conducted to determine if the intercepts of the two regression lines were equal. Appendix C contains pre-Jan 1997 and post-Jan 1997 suspended-sediment rating curves for all Lake Tahoe gauging stations, and other sites.

2.6.5 Analysis of Shifts in Transport Ratings

For stations with greater than ten years of sample data and a sufficient number of samples, separate rating relations were generated for three to five approximately equal time periods to ascertain whether the relation between discharge and transport rate showed any temporal variation. Rating relations for each station and for each period were plotted on the same axes for each station for ease of comparison. Shifts to a higher load at a given discharge over the range of discharges indicate that suspended-sediment loads are increasing. The reverse is true for identifying decreasing loads.

2.7 Suspended-Sediment Loads

2.7.1 Total Suspended-Sediment Load Calculations

Mean-daily flow data were available for 26 of the USGS gaging stations where sufficient data were available to construct sediment-transport ratings. Data were downloaded from a USGS web site and discharge units were converted to m^3/s. Daily loads were calculated for each gage by applying the appropriate rating equation (ie. pre or post 1997 event) to the mean discharge for each day, giving a total suspended load in T/d. These values were summed by month and by calendar year for validation of the AnnAGNPs and CONCEPTS models and to test for spatial and temporal variations in suspended-sediment transport throughout the Lake Tahoe Basin.

Because of the potential error in extrapolating log-log transport curves beyond their measured bounds, the maximum mean-daily flow was compared with the maximum sampled discharge used to generate the regression equation (Table 2-9). The ratio of maximum daily flow to maximum sampled flow was calculated for each rating of a given gage, and in most cases it was below one. This procedure reduced the risk of introducing error due to the suspended-sediment rating being extrapolated beyond the data used to generate it. On occasions where the maximum mean-daily flow was greater than the maximum sampled flow (post 1997 event data, where only a few years of samples were available), the pre-event rating for that gage was utilized, as this extended to discharges of sufficient magnitude. Table 2-10 summarizes this data.

When using a regression equation generated in log-space to estimate daily loads in arithmetic space it has been proposed that results may be underestimated and a transformation should be applied (Ferguson, 1986; AGU, 1995). In this study, a decision was made not to apply a correction factor, following some preliminary trials using Lake Tahoe gaging-station data which showed inconsistent results. A standard approach to transform this type of data does not exist. Loads were first estimated using the regression equation directly, and second with application of several different correction factors: Quasi Maximum Likelihood Estimator, Smearing Estimator, and Minimum Variance Unbiased Estimator (Ferguson, 1986, USGS, 2003). The various correction factors generated differing results. In an example published by the USGS (2003), the three transformation techniques listed above provided results different in both magnitude and direction. The USGS (2003) also emphasize other factors may be more important than correcting any bias: *"the misspecification of the appropriate regression model in a particular situation can yield sizable errors and render any care taken in correcting for bias as a useless exercise".* Because of the care taken in this study to assure that the regression models used were appropriate, and the uncertainty and lack of consistency in transformation results, no correction factor was applied to the sediment load data reported here.

2.7.2 Fine-Load Calculations

Percentages of fine (<0.062mm) and coarse suspended sediment (>0.062mm) were available for sixteen of the USGS gaging stations with mean-daily flow. Data represent instantaneous values associated with a corresponding instantaneous water discharge. The number of samples at each station is quite variable and can be viewed for each of the 16 stations in Appendix D. Seventeen additional gaging stations possessed percent fine and coarse suspended-sediment data, but had no continuous flow record (Table 2-11).

Using the total load and percent finer for each sample, the fine load and coarse load for each sample was calculated. Separate fine and coarse load scattergraphs and regression curves were generated using this information. Due to substantial data scatter, the total load estimated by the regression equation in comparison to the sum of the fine and coarse loads predicted by the new regression equations often deviated. Therefore, an alternative approach was adopted. The percent fine sediment was plotted against discharge and best-fit lines was added through a trial-and-error approach. Appendix D contains these plots. Using the mean-daily flow record, total load regression equations, and the percent fine suspended-sediment graphs, daily loads in tonnes finer than 0.062mm were calculated. These were summed to provide monthly and annual values.

2.7.3 Suspended-Sediment Yield Calculations

Previous analysis provided absolute magnitudes of suspended-sediment loads discharged from various Lake Tahoe watersheds. However, with watersheds areas varying between 1.61 km^2 (Bliss Creek) and 147 km^2 (Upper Truckee River), it is almost inevitable that the larger drainage basins will contribute higher loads. Therefore, loads were divided by the watershed area to ascertain suspended-sediment yields (T/d/km^2) in order to make a fair comparison of the relative suspended-sediment contributions from different parts of the basin. The area of land upstream from each station was obtained from USGS metadata files. Annual and monthly suspended-sediment yields were subsequently calculated for each station by dividing the load for a given period by the watershed area.

2.7.4 Recurrence Interval of the January 1997 Event

For each of the stations with calculated load data, the day with the highest sediment load was identified for each calendar year having a complete record of mean-daily flows. For most stations, the maximum-daily load occurred during the peak snowmelt period between April and June. The loads on these dates were used to create an annual maximum series and generate a magnitude-frequency curve using the log-Pearson III distribution (Riggs, 1968).

Table 2-8. Summary of suspended-sediment transport data used to generate rating relations. Note: n = number of samples.

Station	Years of flow record	Period of flow record	n	Period of sampling record	Years of record	Rating ?	Pre/Post 1997 Ratings?	Coarse/ Fine Ratings ?
10336760	8.0	10/1/92-9/30/00	251	8/20/92-9/13/02	10.1	Y	Y	-
10336756	2.8	1/1/81-9/30/83	67	4/12/91-4/27/01	10.0	Y	Y	-
103367592	10.9	11/18/89-9/30/00	516	11/2/89-9/13/02	12.8	Y	Y	-
10336696	-	-	34	10/16/69-7/6/70	0.7	Y	-	-
10336690	-	-	51	10/15/69-9/22/70	0.9	Y	-	-
10336670	4.0	10/1/72-9/30/76	37	4/23/73-8/14/76	3.3	Y	-	Y
10336660	41.0	10/1/60-9/30/01	483	5/16/74-8/19/02	28.3	Y	Y	Y
10336698	31.0	10/1/69-9/30/00	824	10/15/69-9/16/02	32.9	Y	Y	Y
10336676	29.0	10/1/72-9/30/01	495	12/20/72-9/19/02	30.0	Y	Y	Y
10336694	-	-	155	10/15/69-8/5/02	32.8	Y	Y	-
10336645	21.3	7/7/80-9/30/01	189	4/30/81-9/19/02	21.4	Y	Y	Y
10336593	3.0	10/1/71-9/30/74	70	5/8/72-6/28/74	2.1	Y	-	Y
10336692	-	-	81	4/11/91-9/5/01	9.4	Y	Y	-
103366092	10.3	6/1/90-9/30/00	287	8/29/89-9/12/02	13.1	Y	Y	-
10336700	31.0	10/1/69-9/30/00	662	10/15/69-9/16/02	32.9	Y	Y	Y

10336674	10.0	10/1/91-9/30/01	256	3/5/91-9/19/02	11.5	Y	Y	-
10336750	17.0	10/1/83-9/30/00	106	8/23/89-8/2/02	13.0	Y	Y	-
10336610	30.0	10/1/71-9/30/01	451	11/4/72-9/12/02	29.8	Y	Y	Y
10336580	10.4	5/12/90-9/30/00	290	8/30/89-9/12/02	13.1	Y	Y	-
10336790	21.0	10/1/71-9/30/92	296	3/4/72-9/11/02	30.5	Y	Y	Y
10336688	-	-	156	10/15/69-8/5/02	32.8	Y	Y	-
10336675	10.0	10/1/91-9/30/01	214	9/1/89-9/20/01	12.0	Y	Y	-
103366965	-	-	83	8/17/89-9/5/00	11.1	Y	Y	-
10336770	10.4	5/22/90-9/30/00	210	11/2/89-9/11/02	12.8	Y	Y	-
103366958	-	-	84	8/17/89-9/6/01	12.1	Y	Y	-
10336780	41.0	10/1/60-9/30/01	110	11/9/73-6/28/02	28.6	Y	-	Y
103366995	10.8	12/28/89-9/30/00	307	8/15/89-9/16/02	13.1	Y	Y	Y
103366993	10.4	5/1/90-9/30/00	314	11/1/89-9/16/02	12.8	Y	Y	Y
103366997	-	-	111	8/17/89-8/6/02	13.0	Y	Y	-
10336673	-	-	155	4/30/73-5/18/70	3.1	Y	-	-
103367585	11.0	10/1/89-9/30/00	280	8/22/89-7/18/02	12.9	Y	Y	Y
10336691	-	-	84	4/11/91-12/8/00	9.6	Y	Y	-
10336765	3.5	4/12/89-9/30/92	83	8/17/89-9/5/00	11.1	Y	Y	Y
10336735	-	-	100	4/12/91-8/1/02	11.3	Y	Y	-
10336775	10.3	6/1/90-9/30/00	289	4/24/89-9/11/02	13.4	Y	Y	-
10336730	29.0	10/1/71-9/30/00	562	10/18/71-9/13/02	30.2	Y	Y	Y
10336725	-	-	88	8/18/89-9/700	11.1	Y	Y	-
10336740	17.0	10/1/83-9/30/00	339	5/10/84-9/13/02	18.3	Y	Y	Y
39-2	-	-	63	3/13/1990-8/17/92	2.5	Y	-	-
39-3	-	-	79	3/17/93-7/2/98	5.5	Y	Y	-
39-4	-	-	14	3/13/90-9/6/90	0.5	Y	-	-
39-7	-	-	117	3/28/91-7/2/98	7.5	Y	Y	-
39-8	-	-	30	3/17/93-5/11/98	5.3	Y	Y	-
28 PL 3.38	-	-	36	10/12/72-4/26/73	0.5	Y	-	Y
28 PL 3.50	-	-	44	11/4/72-4/14/73	0.4	Y	-	Y
89 ED 1.70	-	-	57	4/4/73-5/10/73	0.1	Y	-	Y
89 ED 1.94	-	-	158	10/20/72-8/4/73	0.8	Y	-	Y
89 ED 2.11	-	-	48	10/20/72-6/6/73	0.6	Y	-	Y
89 ED 2.21	-	-	68	10/18/72-6/6/73	0.6	Y	-	Y
89 ED 2.44	-	-	161	10/18/72-9/27/73	0.9	Y	-	Y
89 ED 2.99	-	-	62	12/19/72-5/31/73	0.4	Y	-	Y
89 ED 4.37	-	-	126	10/1/72-6/11/73	0.7	Y	-	Y
89 ED 4.45	-	-	49	11/4/72-5/31/73	0.6	Y	-	Y
89 ED 16.61	-	-	78	10/18/72-5/31/73	0.6	Y	-	Y
89 ED 16.87	-	-	89	11/4/72-8/17/73	0.8	Y	-	Y
89 ED 24.49	-	-	11	1/16/73-4/13/73	0.2	Y	-	Y
89 ED 24.65	-	-	4	1/16/73-4/11/73	0.2	Y	-	Y

89 ED 25.44	-	-	2	1/15/73-1/16/73	0.0	Y	-	Y
89 PL 1.27	-	-	25	11/4/72-5/30/73	0.6	Y	-	Y
89 PL 1.42	-	-	36	12/21/72-5/18/73	0.4	Y	-	Y
10336757	-	-	57	11/13/81-5/24/83	2.3	Y	-	-
10336758	-	-	83	2/12/1981-5/24/83	2.3	Y	-	-
Site A	-	-	9	11/11/71-7/9/74	2.7	Y	-	-
Site D	-	-	41	11/11/71-7/9/74	2.7	Y	-	-
Site E	-	-	4	11/11/71-5/6/74	2.5	Y	-	-
Site G	-	-	7	11/11/71-7/9/74	2.7	Y	-	-
Site H	-	-	6	3/7/72-5/6/74	2.2	Y	-	-
Site I	-	-	2	11/11/71-3/7/72	0.2	Y	-	-

Table 2-9. List of number of rating relations and sections used to calculate daily, monthly, and annual suspended-sediment transport rates.

Stream	Station	Data Period		Pre / Post 1997 data available ?	Number of Rating Sections: Pre 1997	Number of Rating Sections: Post 1997
		Flow	Suspended Sediment			
Blackwood	10336660	10/1/60-9/30/01	5/16/74-8/19/02	Y	3	3
Eagle Rock	103367592	11/18/89-9/30/00	11/2/89-9/13/02	Y	1	1
Edgewood	103367585	10/1/89-9/30/00	8/22/89-7/18/02	Y	1	2
Edgewood	10336765	4/12/89-9/30/92	8/17/89-9/5/00	Y	2	0
Edgewood	10336760	10/1/92-9/30/00	8/20/92-9/13/02	Y	1	1
Edgewood Trib.	10336756	1/1/81-9/30/83	4/12/91-4/27/01	Y	1	1
General	10336645	7/7/80-9/30/01	4/30/81-9/19/02	Y	2	2
Glenbrook	10336730	10/1/71-9/30/00	10/18/71-9/13/02	Y	1	2
Grass Lake	10336593	10/1/71-9/30/74	5/8/72-6/28/74	N	1	0
Incline	103366995	12/28/89-9/30/00	8/15/89-9/16/02	Y	1	1
Incline	103366993	5/1/90-9/30/00	11/1/89-9/16/02	Y	1	2
Incline	10336700	10/1/69-9/30/00	10/15/69-9/16/02	Y	1	1
Logan House	10336740	10/1/83-9/30/00	5/10/84-9/13/02	Y	2	2
Third	10336698	10/1/69-9/30/00	10/15/69-9/16/02	Y	1	1
Trout	10336790	10/1/71-9/30/92	3/4/72-9/11/02	Y	1	0
Trout	10336780	10/1/60-9/30/01	11/9/73-6/28/02	N	1	1
Trout	10336775	6/1/90-9/30/00	4/24/89-9/11/02	Y	1	1
Trout	10336770	5/22/90-9/30/00	11/2/89-9/11/02	Y	1	1
UTR	103366092	6/1/90-9/30/00	8/29/89-9/12/02	Y	2	2
UTR	10336610	10/1/71-9/30/01	11/4/72-9/12/02	Y	1	1
UTR	10336580	5/12/90-9/30/00	8/30/89-9/12/02	Y	2	2
Ward	10336676	10/1/72-9/30/01	12/20/72-9/19/02	Y	2	2
Ward	10336675	10/1/91-9/30/01	9/1/89-9/20/01	Y	2	1
Ward	10336674	10/1/91-9/30/01	3/5/91-9/19/02	Y	2	2
Ward	10336670	10/1/72-9/30/76	4/23/73-8/14/76	N	1	0

Table 2-10. Pre-1997 suspended-sediment rating relations calculated from measured instantaneous flow and concentration data (r^2 values are shown in Appendix C).

Stream	Station	Rating Relations					
		Eq. 1 (T)	Eq. 1 limit (m^3/s)	Eq. 2 (T)	Eq. 2 limit (m^3/s)	Eq. 3 (T)	Eq. 3 limit (m^3/s)
Blackwood	10336660	$L = .07Q^{1.48}$	$Q < 1.47$	$L=1.15Q^{2.09}$	$1.47 < Q < 10.62$	$L =1.35Q^{2.18}$	$Q > 10.6$
Eagle Rock	103367592	$L = 9.3Q^{1.82}$	All flows				
Edgewood	103367585	$L = 2.8Q^{1.70}$	All flows				
Edgewood	10336765	$L=.900Q^{1.20}$	$Q < .116$	$L = .27Q^{1.90}$	$Q > 0.116$		
Edgewood	10336760	$L=3.29Q^{1.84}$	All flows				
Edgewood Trib.	10336756	$L =1.39Q^{1.31}$	All flows				
General	10336645	$L =.430Q^{1.17}$	$Q < 1.40$	$L =.248Q^{2.44}$	$Q >1.40$		
Glenbrook	10336730	$L =2.23Q^{1.34}$	All flows				
Grass Lake	10336593	$L =1.53Q^{1.80}$	All flows				
Incline	103366995	$L =7.01Q^{1.68}$	All flows				
Incline	103366993	$L =3.37Q^{1.61}$	All flows				
Incline	10336700	$L =26.6Q^{2.19}$	All flows				
Logan House	10336740	$L =1.35Q^{1.32}$	$Q <0.038$	$L= 30.3Q^{2.16}$	$Q > 0.038$cms		
Third	10336698	$L =38.6Q^{2.01}$	All flows				
Trout	10336790	$L =1.23Q^{1.61}$	All flows				
Trout	10336780	$L =2.27Q^{1.87}$	All flows				
Trout	10336775	$L =1.03Q^{1.86}$	All flows				
Trout	10336770	$L =1.96Q^{2.04}$	All flows				
UTR	103366092	$L =.213Q^{1.28}$	$Q < 3.00$	$L =.141Q^{2.05}$	$Q >3.00$		
UTR	10336610	$L =.991Q^{1.55}$	All flows				
UTR	10336580	$L =.253Q^{1.33}$	$Q < 2.00$	$L =.135Q^{2.22}$	$Q >2.00$		
Ward	10336676	$L =1.26Q^{1.43}$	$Q < 2.00$	$L =.404Q^{2.69}$	$Q >2.00$		
Ward	10336675	$L =.642Q^{1.33}$	$Q < 3.71$	$L =.094Q^{3.14}$	$Q >3.71$		
Ward	10336674	$L =.792Q^{1.38}$	$Q < 1.40$	$L =.543Q^{2.54}$	$Q >1.40$		
Ward	10336670	$L =6.92Q^{2.10}$	All flows				

Table 2-11. Post-1997 suspended-sediment rating relations calculated from measured instantaneous flow and concentration data(r^2 values are shown in Appendix C).

Stream	Station	Rating Relations					
		Eq. 1	Eq. 1 limit	Eq. 2	Eq. 2 limit	Eq. 3	Eq. 3 limit
		(T)	(m^3/s)	(T)	(m^3/s)	(T)	(m^3/s)
Blackwood	10336660	$L=3.41Q^{2.16}$	$Q < 0.37$	$L =.865Q^{1.11}$	$0.37 < Q < 2.49$	$L = 0.12Q^{3.37}$	$Q > 2.49$
Eagle Rock	103367592	$L =.701Q^{1.05}$	All flows				
Edgewood	103367585	$L =1.43Q^{1.37}$	$Q < 0.096$	$L =86.6Q^{3.10}$	$0.4 > Q > 0.096$	Pre 1997 eq 3	$Q >0.400$
Edgewood	10336765						
Edgewood	10336760	$L =1.32Q^{1.57}$	All flows				
Edgewood Trib.	10336756	$L =23.2Q^{2.02}$	All flows				
General	10336645	$L =.703Q^{1.48}$	$Q < 2.00$	$L =.232Q^{2.93}$	$Q > 2.00$		
Glenbrook	10336730	$L =0.54Q^{1.08}$	$Q < 0.085$	$L =0.27Q^{1.60}$	$Q > 0.085$		
Incline	103366995	$L =4.24Q^{1.92}$	All flows				
Incline	103366993	$L =.477Q^{1.28}$	$Q < 0.20$	$L =10.8Q^{3.15}$	$Q > 0.2$		
Incline	10336700	$L =3.70Q^{1.86}$	All flows				
Logan House	10336740	$L =1.37Q^{1.39}$	$Q < 0.060$	$L = 118Q^{3.09}$	$Q > 0.060$s		
Third	10336698	$L =4.09Q^{1.94}$	All flows				
Trout	10336780	$L =2.27Q^{1.87}$	All flows				
Trout	10336775	$L =.562Q^{1.81}$	All flows				
Trout	10336770	$L =.774Q^{1.81}$	All flows				
UTR	103366092	$L=.169Q^{1.25}$	$Q < 0.351$	$L =.029Q^{2.64}$	$0.351 < Q < 20.0$	Pre 1997 eq 2	$Q > 20.0$
UTR	10336610	$L=.784Q^{1.33}$	All flows				
UTR	10336580	$L =.170Q^{1.23}$	$Q < 2.40$	$L =.054Q^{2.48}$	$Q > 2.40$		
Ward	10336676	$L =.58Q^{1.41}$	$Q < 2.00$	$L =.158Q^{2.98}$	$2.00 < Q < 16.0$	Pre 1997 eq 2	$Q > 16.0$
Ward	10336675	$L =.691Q^{1.62}$	All flows				
Ward	10336674	$L=.330Q^{1.27}$	$Q < 1.50$	$L =.411Q^{2.38}$	$Q > 1.50$		

2.8 General Description of AGNPS Modeling Technology

The Agricultural Non-Point Source Pollutant (AGNPS) watershed simulation model (Bingner and Theurer, 2001a) has been developed as a tool for use in evaluating the pollutant loadings within a watershed and the impact farming and mixed-use activities have on pollution control. Various modeling components have been integrated within AGNPS to form a suite of modules. Each module provides information needed by other modules to enhance the predictive capabilities of each. The modules in AGNPS critical to the Lake Tahoe watershed simulation study include: (1) AnnAGNPS Version 3.30 (Cronshey and Theurer, 1998), a watershed-scale, continuous-simulation, pollutant loading computer model designed to quantify & identify the source of pollutant loadings anywhere in the watershed for optimization & risk analysis; and, (2) Conservational Channel Evolution and Pollutant Transport System (CONCEPTS) (Langendoen, 2000), a set of stream network, corridor, & water quality computer models designed to predict & quantify the effects of bank erosion & failures, bank mass wasting, bed aggradation & degradation, burial & re-entrainment of contaminants, and streamside riparian vegetation on channel morphology and pollutant loadings.

The Annualized Agricultural Non-Point Source Pollutant loading model (AnnAGNPS) is an advanced technological watershed evaluation tool, which has been developed through a partnering project with the United States Department of Agriculture – Agriculture Research Service (USDA-ARS) and Natural Resources Conservation Service (NRCS) to aid in the evaluation of watershed response to agricultural management practices. Through continuous simulation of surface runoff, sediment and chemical non-point source pollutant loading from watersheds, the impact of BMPs on TMDLs can be evaluated for risk and cost/benefit analyses.

AnnAGNPS is a continuous simulation, daily time step, pollutant loading model and includes significantly more advanced features than the single-event AGNPS 5.0 (Young et al., 1989). Daily climate information is needed to account for the temporal variation in the weather. The spatial variability of climate can also be included by assigning appropriate climate files to any location in the watershed. The spatial variability within a watershed of soils, landuse, and topography, is accounted for by dividing the watershed into many homogeneous drainage areas. These simulated drainage areas are then integrated together by simulated rivers and streams, which route the runoff and pollutants from each individual homogeneous area to downstream. From individual fields, runoff can be produced from precipitation events that include rainfall, snowmelt and irrigation. A daily soil water balance is maintained, so runoff can be determined when a precipitation event occurs. The erosion within each field is predicted based on the technology incorporated from the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). The model can be used to examine the effects of implementing various conservation alternatives within a watershed such as alternative cropping and tillage systems including the effects of fertilizer, pesticide, irrigation application rate as well as point source yields and feedlot management (Bosch et al., 1998).

2.8.1 Input Data Requirements

As part of the input data preparation process there are a number of component modules that support the user in developing the needed AnnAGNPS databases. These include: (1) the TOpographic PArameteriZation program (TOPAZ) (Garbrecht and Martz, 1995), to generate cell and stream network information from a watershed digital elevation model (DEM) and provide all of the topographic related information for AnnAGNPS. A subset of TOPAZ, TOPAGNPS, is the set of TOPAZ modules used within AGNPS. The use of the TOPAGNPS generated stream network is also incorporated by CONCEPTS to provide the link of where upland sources are entering the channel and then routed downstream; (2) The AGricultural watershed FLOWnet generation program (AGFLOW) (Bingner et al., 1997; Bingner et al., 2001b) is used to determine the topographic-related input parameters for AnnAGNPS and to format the TOPAGNPS output for importation into the form needed by AnnAGNPS; (3) The Generation of weather Elements for Multiple applications (GEM) program (Johnson et al., 2000) is used to generate the climate information for AnnAGNPS if historical climate is not used; (4) The program Complete Climate takes the information from GEM and formats the data for use by AnnAGNPS, along with determining a few additional parameters; (5) A graphical input editor that assists the user in developing the AnnAGNPS database (Bingner et al., 1998); (6) A visual interface program to view the TOPAGNPS related geographical information system (GIS) data (Bingner et al., 1996); (7) A conversion program that transforms a single event AGNPS 5.0 dataset into what is needed to perform a single event simulation with AnnAGNPS and, (8) An

Arcview program to facilitate the use of Items 1-7. There is an output processor that can be used to help analyze the results from AnnAGNPS by generating a summary of the results in tabular or GIS format.

2.8.2 Contributions from Cells Adjacent to the Main Channel

Loading information to the main channel for use with CONCEPTS is obtained by routing the AnnAGNPS water and sediment discharged by each AnnAGNPS cell through the channel system. At the outlet of each tributary that flows into the main channel AnnAGNPS provides: the flow; sediment by particle sizes of clay, silt, and sand; peak discharge; and, the time of concentration as part of an output file that can be used as an input file into CONCEPTS. This information is used in routing water and sediment by CONCEPTS in the main channel. All tributary channels in each of the Lake Tahoe watersheds simulated by AnnAGNPS is assumed to be stable and therefore not eroding. Although, sediment in transport can be deposited within the tributaries before reaching the main channel simulated by CONCEPTS.

2.8.3 Contributions from Tributaries to the Main Channel

The discharges from the tributaries provide the link between AnnAGNPS cells and CONCEPTS for the water and sediment that does not flow directly into the main channel. There are also AnnAGNPS cells that are along the main channel and deposit water and sediment directly into the main channel. These AnnAGNPS cells are also simulated and provide discharge information to CONCEPTS through an AnnAGNPS output file.

2.9 General Description of CONCEPTS Modeling Technology

CONCEPTS simulates unsteady, one-dimensional flow, transport of cohesive and cohesionless sediments in suspension and on the bed selectively by size class, and bank erosion processes in stream corridors (Langendoen 2000). Hence, it can predict the dynamic response of flow, sediment transport and channel form (‘channel evolution’) to disturbances including channelization, altered hydrologic regime (e.g. by dam construction or urbanization), or instream hydraulic structures.

2.9.1 Hydraulics

CONCEPTS assumes stream flow to be one-dimensional along the centerline of the channel. It computes the flow as a function of time simultaneously at a series of cross sections along the stream using the Saint Venant equations. The governing equations are discretized using the generalized Preissmann scheme, and the resulting set of algebraic equations are solved using Gaussian elimination with partial pivoting for banded matrices. Four types of hydraulic structures are included in CONCEPTS: box and pipe culverts, bridge crossings, grade control (drop) structures, and any structure for which a rating curve is available.

2.9.2 Sediment transport and bed adjustment

CONCEPTS calculates total-load sediment transport rates by size fraction from a mass conservation law, and taking into account the differing processes governing entrainment and deposition of cohesive and cohesionless bed material (Langendoen 2000). CONCEPTS handles particle sizes ranging from clay to cobbles. For graded bed material, the sediment transport rates depend on the bed material composition, which itself depends on historical erosion and deposition rates. CONCEPTS divides the bed into a surface or active layer and a subsurface layer. These layers constitute the so-called ‘mixing layer’. Sediment particles are continuously exchanged between the flow and surficial layer, whereas particles are only exchanged between the surface layer and substrate when the bed scours and fills. For cohesive materials, the erosion rate is calculated by an excess shear-stress approach while the deposition rate is based on particle settling velocity.

2.9.3 Streambank Erosion

CONCEPTS simulates channel width adjustment by incorporating the fundamental physical processes responsible for bank retreat: (1) fluvial erosion or entrainment of bank toe material by flow, and (2) bank mass failure due to gravity (Langendoen 2000). Natural streambank material may be cohesive or noncohesive and may comprise numerous soil layers reflecting the depositional history of the bank materials; each layer can have physical properties quite different from those of other layers. CONCEPTS accounts for streambank stratigraphy by allowing variable critical shear-stresses to be assigned to the bank materials. An average shear-stress on each soil layer is computed, which increases with depth. Because of the resulting shear stress distribution, CONCEPTS is able to more realistically simulate streambank erosion caused by undercutting and cantilever failures.

Bank stability is analyzed via the limit equilibrium method, based on static equilibrium of forces and/or moments. Streambank failure occurs when gravitational forces that tend to move soil downslope exceed the forces that resist movement. The risk of failure is usually expressed by a factor of safety, defined as the ratio of resisting to driving forces or moments. CONCEPTS performs stability analyses of planar slip failures and cantilever failures of overhanging banks by dividing the bank into slices, and evaluating the balance of forces on each slice in vertical and horizontal directions. The slope of the failure surface is defined as that slope for which the factor of safety is a minimum. The bank’s geometry, soil shear-strength (effective cohesion, c', and angle of internal friction, ϕ'), pore-water pressure, confining pressure, and riparian vegetation determine the stability of the bank.

2.9.4 Input Data Requirements

Typical CONCEPTS input data are: water and sediment inflow at the upstream boundary of the model channel and any tributaries; the geometry (cross sections) of the channel; Manning’s *n* roughness coefficients; and composition of bed and bank material. In addition, the user needs to supply bank-material properties for the streambank erosion component of CONCEPTS, such as the critical shear stress required to entrain bank-material particles, and the shear-strength parameters effective cohesion, c', and angle of internal friction, ϕ'.

3 ANNUAL SUSPENDED-SEDIMENT LOADS AND YIELDS

3.1 Introduction

Annualized data on suspended-sediment loads and yields (load per unit area) are a convenient means of interpreting sediment production and delivery. With regard to sediment delivery to Lake Tahoe, data expressed as annual loads (in T/y) provide a means of differentiating those watersheds that are particularly critical in terms of gross amounts of sediment delivered on an annual basis. This is of course essential in interpreting issues involving lake clarity. With other things being equal, however, larger watersheds will generally provide greater suspended-sediment loads than smaller watersheds, but this tells us little about differences in sediment production and delivery processes between watersheds. Suspended-sediment yields, expressed in T/y/km^2 do provide a mechanism to interpret differences in sediment production and delivery because they describe loads per unit of drainage area. Because suspended-sediment yields will vary with time as runoff conditions change, temporal trends of annualized data are also expressed as an annual concentration (load per unit of runoff; in g/m^3) to (1) interpret differences in sediment production and sources within watersheds and, (2) determine temporal trends over the past 40 years.

3.2 Availability and Reliability of Data

Annual suspended-sediment loads and yields are calculated for 32 sites using historical mean-daily flow data and sediment-transport rating relations. The length of record, depending on the number of complete calendar years of flow data, ranged from two to 40 years with a mean of 12 years (Table 3-1). Eleven sites had four years or fewer of mean-daily flow data. Most of these stations were sampled in the early 1970's (1970-1974) by the U.S. Geological Survey (Kroll, 1976; Glancy, 1988). Fortunately, the flow recorded over this period is reasonably representative of longer periods of record. Average, mean-daily flows for the period are only 3 – 5% less than those for the full period of record on Incline and Third Creeks. Annual peak flows on Third Creek are just 9% higher during this short period in the 1970s. Similar patterns are seen on the west side of the lake where a number of gages were operated only during the early 1970s.

First approximation rating relations are derived from linear regression of instantaneous flow and suspended-sediment concentration data plotted in log-log space. As is often the case, this single power curve is inadequate to describe the relation between discharge and sediment load over the entire range of flows. In these cases two- or three-linear segments (in log-log space) are used. The break point for each segment is determined by eye. Example were shown in Figure 2-6. Plots of all rating relations are shown in Appendix C. Where applicable and where sufficient data are available, rating relations are also calculated for transport conditions prior to, and after the January 1-2, 1997 rain on snow runoff event. Finally, the resulting power functions are all closely inspected to make sure that the maximum mean-daily flow that is used to calculate daily loads does not exceed the maximum sampled flow rate. This is particularly critical at high flow rates where a small increment in discharge can result in large errors in the calculated sediment load.

Suspended-sediment loads for each complete calendar year of flow data were calculated by applying the appropriate transport rating to the mean-daily flow for that day. Flow rates based on 15-minute gage readings would have been superior, however, most of the 15-minute gage record contains varying periods of missing data, making it impossible to obtain annual values.

It is important to keep in mind that for a given station, discharge and suspended-sediment loads may range over four to six orders of magnitude. Data scatter around a suspended-sediment transport rating with an r^2 value as high as 0.9 still has only order of magnitude accuracy in predicting loads at a given discharge. Thus, suspended-sediment loadings are not actually measured, but calculated from measured flow and concentration data. In general, caution should be exercised in using 95% prediction limits around rating relations and not 95% confidence limits. The difference is that the confidence limits reflect the reliability of the relation to describe the trend in load with discharge whereas prediction limits refer to the reliability of estimating suspended-sediment loads at a given discharge.

3.3 Basin Quadrants and Index Stations

Precipitation and other basin characteristics vary from one side of the lake to the other resulting in a broad range of sediment-transport rates. To partially account for these differences and to make interpretations of differences in suspended-sediment loads and yields to Lake Tahoe, watersheds are separated into the four principle directional quadrants; north, south, east, and west (Figure 3-1). Streams referred to as “northern” include First, Second, Third, and Incline Creeks. The major “southern” streams are the Upper Truckee River and Trout Creek. “Eastern” streams include Edgewood, Glenbrook and Logan House Creeks, while “western” streams include Blackwood, Ward, and General Creeks.

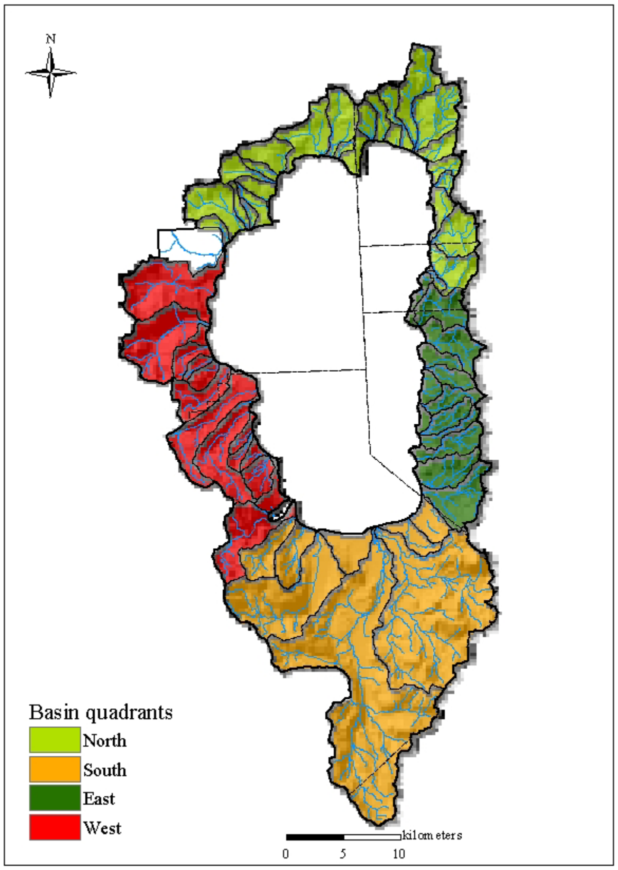


Figure 3-1. Map of Lake Tahoe watershed showing designation of the four basin quadrants.

Index stations were selected from the 32 sampling stations (Table 3-1). The concept of an index station is that sediment loadings and yields from a particular watershed to Lake Tahoe can be represented by sediment-transport data from a specific downstream location in the watershed. Selections of these stations are based on two criteria; (1) the station from a given stream with the longest period of record and, (2) the station had a downstream location. These stations are then used to interpret similarities and differences in sediment delivery to the lake.

Table 3-1. List of index stations used to differentiate suspended-sediment loads and yields to Lake Tahoe from individual watersheds.

Stream	Station number	Basin quadrant	Distance above mouth (km)	Period of record (y)
First	10336688	N	0.13	4
Second	10336691	N	0.52	4
Third	10336698	N	0.19	26
Incline	10336700	N	0.27	17
Wood	10336692	N	0.02	4
Trout	10336780	S	4.52	40
Upper Truckee	10336610	S	2.94	24

Edgewood	103367585	E	3.81	11
Glenbrook	10336730	E	0.04	16
Logan House	10336740	E	0.66	17
Eagle Rock	103367592	E	2.99	10
Blackwood	10336660	W	0.31	40
General	10336645	W	0.65	20
Meeks	10336640	W	0.45	3
Ward	10336676	W	0.44	28
Quail Lake	10336650	W	0.07	3
Eagle	10336630	W	0.57	3

3.4 Total Annual Suspended-Sediment Loads

Annual suspended-sediment loads generally vary over about four orders of magnitude with time at a particular station, and from watershed to watershed. This variability can simply reflect differences in drainage area or, be a function of differences in precipitation, and basin and channel characteristics. Median annual suspended-sediment loads range from about 0.5 T/y on Logan House Creek (10336740) to about 2,200 T/y on the Upper Truckee River (10336610) (Table 3-2). Median values are used for comparison purposes in lieu of means because of the overriding influence of the large runoff events. To compare downstream loadings from individual watersheds, the median-annual loads for the 18 index stations are highlighted in green in Table 3-2. The greatest annual loads, in decreasing order emanate from the Upper Truckee River (2200 T/y), Blackwood (1930 T/y), Second (1410 T/y), Trout (1190 T/y), Third (880 T/y), and Ward Creeks (855 T/y). The lowest annual loads, in increasing order emanate from Logan House (0.5 T/y), Eagle Rock (4.6 T/y), Dollar (4.6 T/y), Quail Lake (6.4 T/y), Glenbrook (8.9 T/y), and Edgewood Creeks (21.3 (T/y). Suspended-sediment yields are discussed in section 3.5.

Table 3-2. Summary of total annual suspended-sediment loads calculated from measured data. Sites shaded in green are index stations (Annual values are provided in Appendix E).

Stream	Station number	Annual load		Quadrant	Complete years of data	Drainage area (km^2)
		Average (tonnes)	Median (tonnes)			
Upper Truckee	10336610	2850	2200	S	24	142
Blackwood	10336660	3060	1930	W	40	29.0
Upper Truckee	103366092	1410	1410	S	10	88.8
Second[2]	10336691	1500	1410	N	4	4.7
Trout	10336780	1790	1190	S	40	95.1
Third	10336698	1680	880	N	26	15.7
Ward	10336676	1730	855	W	28	25.1
Ward	10336670	641	638	W	3	5.2
Wood[2]	10336692	467	490	N	4	5.3
Ward	10336675	551	449	W	9	23.2
First[2]	10336688	402	413	N	4	2.8

Ward	10336674	427	356	W	9	12.9
Trout	10336790	360	355	S	5	105
Upper Truckee	10336580	363	334	S	10	36.5
Trout	10336775	376	331	S	10	61.4
Incline	10336700	612	217	N	17	18.1
Grass[1]	10336593	181	181	S	3	16.6
General	10336645	283	176	W	20	19.3
Incline	103366995	174	163	N	11	11.6
Trout	10336770	158	109	S	10	19.1
Incline	103366993	80.1	90.5	N	10	7.2
Meeks[1]	10336640	79.8	79.8	W	3	22.2
Eagle[1]	10336630	69.9	69.9	W	3	20.4
Edgewood	10336760	34.7	44.8	E	8	14.2
Edgewood	103367585	24.5	21.3	E	11	8.1
Edgewood	10336765	9.5	9.5	E	2	16.2
Glenbrook	10336730	11.3	8.9	E	16	10.5
Quail Lake[1]	10336650	6.4	6.4	W	3	4.2
Dollar[1]	10336684	4.6	4.6	N	3	4.7
Eagle Rock	103367592	5.6	4.6	E	10	1.5
Logan House	10336740	5.6	3.0	E	17	5.4
Edgewood Trib.	10336756	0.5	0.5	E	2	0.6

[1] = Mean values from Kroll (1976)
[2] = Data from Glancy (1988); data from disturbed, high runoff period in 1970s.

The spatial distribution of mean annual suspended-sediment loads (in T/y) are shown broken into five classes and mapped in Figure 3-2 with the darker colors indicating higher suspended-sediment loads. Note that the index stations on Blackwood Creek (10336660) and the Upper Truckee River (10336610) show the greatest values while the eastern streams in general have the lowest. The latter is in part due to the smaller watershed areas on the east side of the lake as well as lower runoff rates. Whereas high loadings rates are expected from large watersheds such as Trout Creek and the Upper Truckee River, the index stations on Blackwood, Ward (10336676) and Third Creeks (10336698) show relatively high loadings for their drainage area, indicating past and or present disturbances and the potential for high rates of channel erosion.

To compare loadings from sampled watersheds, data from Table 3-2 is perhaps better displayed graphically as in Figure 3-3 where median annual suspended-sediment loads are shown in descending order for the 18 index stations (Figure 3-3a) and by basin quadrant (Figure 3-3b). One of the most striking aspects of Figure 3-3b are the exceptionally low loadings rates for the eastern streams including those that have experienced significant urbanization, such as Edgewood Creek, and on Glenbrook Creek where construction of roads and road cuts has been listed as a cause of heightened loads (Kroll, 1976). Median annual water yields for the three main index stations in the east (Glenbrook, Edgewood, and Logan House Creeks) range from 0.09

m^3/m^2 to 0.20 m^3/m^2 for Logan House and Edgewood Creeks, respectively. In contrast, median annual water yields from the three main western index stations range from 0.80 m^3/m^2 to 1.17 m^3/m^2 for General and Ward Creeks, respectively. Still, because of greatly different rates of runoff in comparison with the larger and wetter western streams, suspended-sediment loads from disturbed watersheds in the eastern quadrant do not approach those from the western quadrant.

It is the relatively high water yields of the western streams that make them particularly sensitive to disturbance. Note the vastly greater suspended-sediment loads produced from the Blackwood and Ward Creek watersheds in comparison to the relatively undisturbed General, Meeks, and Eagle Creek watersheds.

Streams draining the northeast, urbanized part of the northern quadrant have relatively high loads of suspended-sediment. This is one of the most intensely developed parts of the basin. Data for streams such as First, Second and Wood Creeks are only from the early 1970’s and although they reflect representative flows, the period comes at the end of a decade of intense development that continued into the sampling period. Glancy (1988) lists 34 development projects in the Incline Village area between 1960 and 1970, and refers to this as a period of “dynamic non-equilibrium” for the streams draining to Crystal Bay. Both Third and Second Creeks also experienced thunderstorm-induced flash floods in 1965 and 1967 respectively that caused large changes in channel characteristics (Glancy, 1988). As such, suspended-sediment loads (per unit amount of water) should be at their highest during this period and attenuate with time (Simon, 1992). Thus, care should be used in interpreting long-term suspended-sediment transport for the northern streams based on data collected only in the early 1970’s. The authors did not include additional data collected since 1993 (6 samples per year) along First, Second and Wood Creeks by the Nevada Department of Environmental Protection. These data were made available only after completion of the draft report.

A first approximation of total, annual suspended-sediment loadings to Lake Tahoe is made by extrapolating average-annual and median-annual data from the index stations. Data from these stations encompass 54% of the total watershed area. Using this technique average-annual and median-annual loadings are 28,600 T/y and 18,300 T/y, respectively. About 6,300 T/y of fine-grained materials are delivered to the lake, based on median-annual data. A somewhat more refined estimate of total, annual suspended-sediment loads is made by extrapolating the sum of the average, median-annual values within each quadrant. In this case the annual loadings value to Lake Tahoe is about 25,500 T/y.

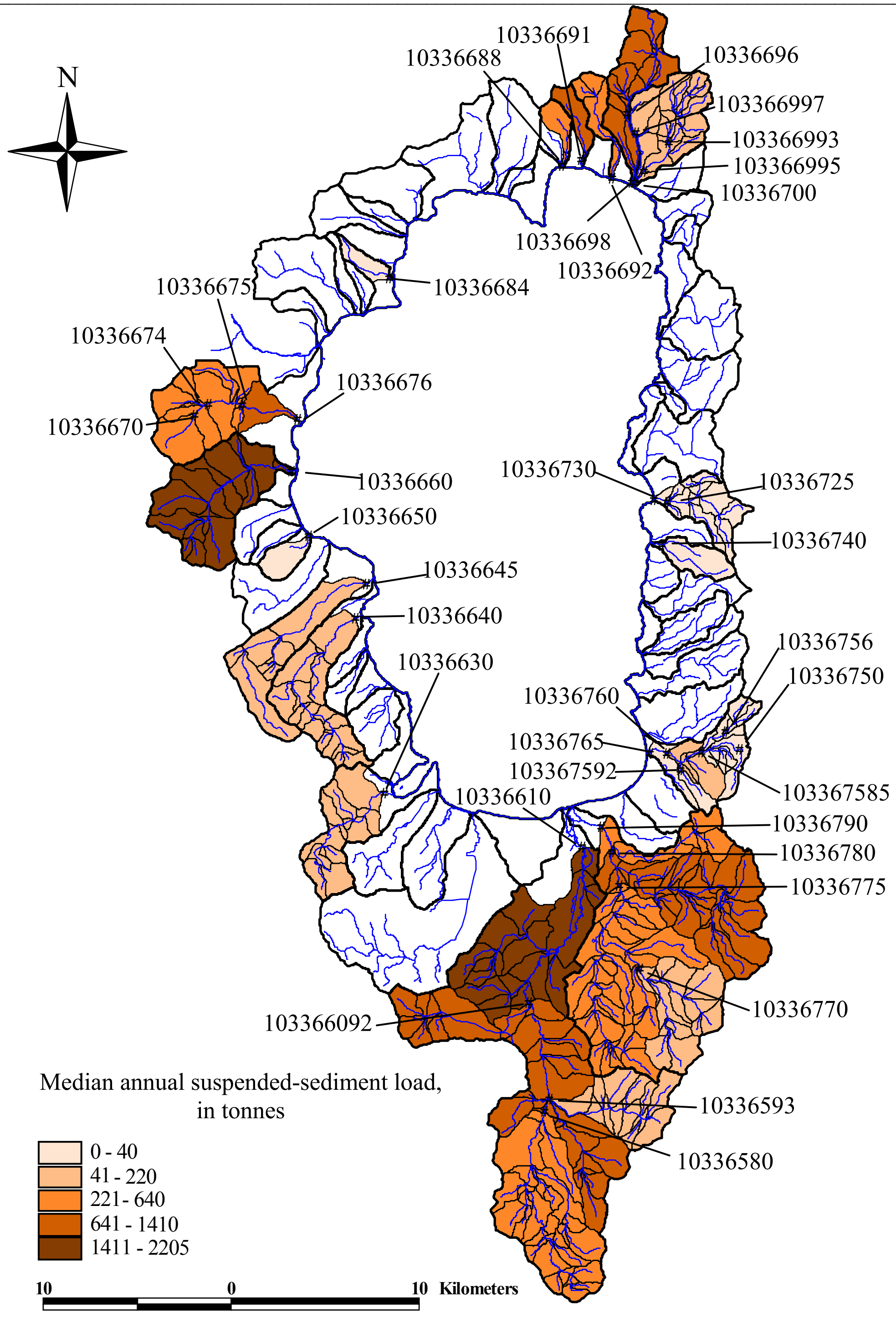
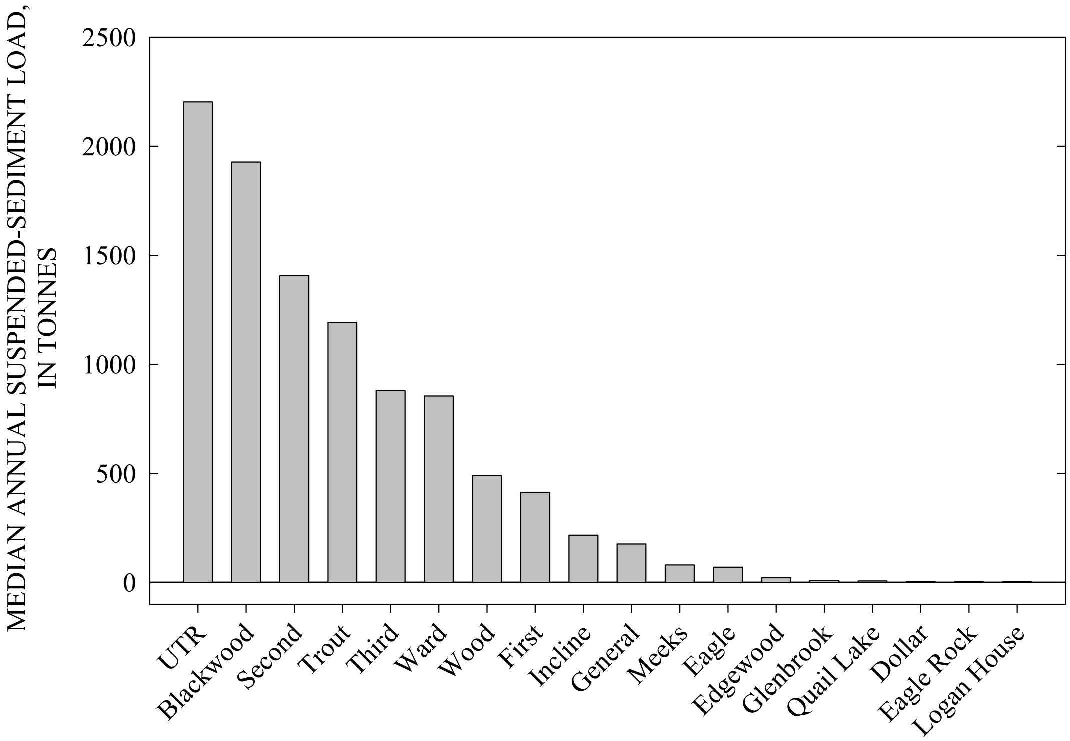


Figure 3-2. Distribution of median annual suspended-sediment loads in tonnes.



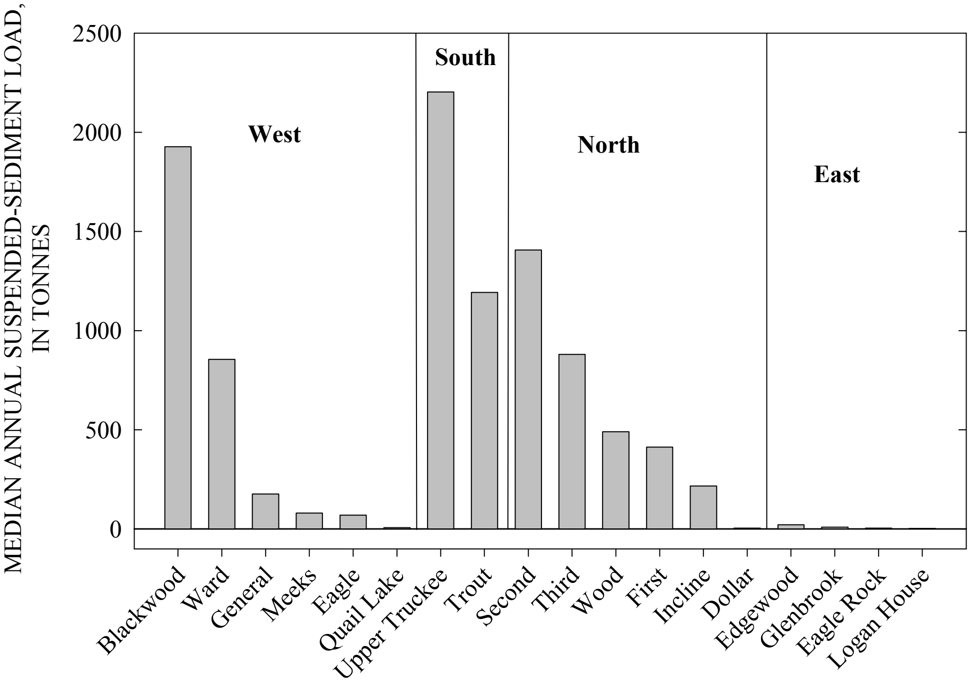


Figure 3-3. Median annual suspended-sediment loads for the 18 index stations sorted in descending order (upper) and, separated by basin quadrant (lower).

Interpretations of the cause of differences in sediment loadings between quadrants, and between watersheds within a given basin quadrant are better expressed in terms of suspended-sediment yields (in T/y/km^2). Still, Figure 3-3 and Table 3-2 provide annual estimates of absolute values and differences in total suspended-sediment loads from most of the largest watersheds draining to Lake Tahoe.

3.4.1 Comparisons with Previously Published Data

Suspended-sediment loads to Lake Tahoe have been the topic of numerous technical publications over the past 30 years (Glancy, 1969; 1988; Kroll, 1976; Leonard, *et al*., 1979; Hill *et al*., 1990; Hill and Nolan, 1990; Nolan and Hill, 1991; Reuter and Miller, 2000; Rowe *et al*., 2002). Results from some of these reports have been used herein (Kroll, 1976 and Glancy, 1988) to enhance geographic coverage of the annual load data. Annual suspended-sediment loads calculated in this study are compared with previously published values in Table 3-3. Data from a recent report by Rowe *et al*., (2002) are not comparable because they are expressed as median monthly values. Simply multiplying by 12 does not produce a reliable annual value because of the uncertainty in the distribution of monthly values.

Given the great temporal and spatial variability in suspended-sediment loads, it is encouraging that data from Kroll (1976), Nolan and Hill (1991), Reuter and Miller (2000) and this study are generally within an order of magnitude. Differences in annual load calculations between the studies does not indicate numerical or methodological errors but are probably related to different periods of record. The current study is at somewhat of an advantage because it has access to longer periods of flow and sediment concentration record. For instance, that Reuter and Miller's (2000) annual load estimates from Incline and Trout Creeks are well below those calculated in this study is probably due to the fact that high sediment-producing years of 1970 and 1971 in the case of the former, and 1967, 1969, 1982, 1983, 1986, and 1997 in the case of the latter, are not included in their data set.

Table 3-3. Comparison of published, average annual suspended-sediment loads unless labeled otherwise. All data expressed in tonnes per year.

Stream	Data from Reuter and Miller, 2000[1]	Data from Nolan and Hill, 1991[2]	Data from Kroll, 1976[3]	This study (averages)	This study (medians)
Blackwood	2090	2030	-	3060	1930
Edgewood	-	40.3	-	24.5	21.3
General	201	201	-	283	176
Glenbrook	31.9	-	-	11.3	8.9
Incline	107[4]	-	-	612	217
Logan House	5.7	3.8	-	5.6	3.0
Trout	798	-	1540	1790	1190
Upper Truckee	3310	-	3900	2850	2200
Ward	899	-		1730	855

[1] Data for water years 1989-1996.

[2] Data for water years 1984-1987.

[3] Data for water years 1972-1974

[4] Revised from J. Reuter (per. commun., 2003).

3.4.2 Timing of Peak Annual Suspended-Sediment Loads

Total annual suspended-sediment loads vary greatly from year to year at a given station across the Lake Tahoe Basin in response to annual variability in rates of runoff and human intervention, making interpretations of temporal trends a complex issue. Years of peak loading rates are not consistent across the basin and again reflect differences in how precipitation-runoff relations vary between basin quadrants. Using the past 40 years as an example, western streams displayed peak loads for their period of record in 1997 in response to the rain on snow event in January of that year (Figure 3-4). In contrast, streams draining the southern part of the Lake Tahoe watershed experienced peak suspended-sediment loads in 1983. Although the northern and eastern streams have shorter periods of record, the dates of peak annual suspended-sediment loads in these quadrants were 1995 and 1996, respectively (Figure 3-4). The scale of temporal variability displayed in Figure 3-4 provides a clear justification for maintaining streamflow and sediment data collection operations for long periods of time. The important question as to whether the delivery of suspended sediment to Lake Tahoe, particularly material finer than .062 mm is changing with time will be treated in a later section of this chapter.

3.4.3 Suspended-Sediment Loads From The January 1-2, 1997 Runoff Event

A New Year's Day rainstorm in 1997 created super-saturated snow packs and resulted in large runoff events throughout the Lake Tahoe Basin. As discussed in the previous section, suspended-sediment loads resulting from this event were very high, representing the peak of record in some watersheds. To address just how large this event was in terms of sediment loads, and how frequently one could expect loads of this magnitude again, peak values were used to determine the recurrence interval of the sediment-transporting event across the basin. The recurrence interval of the instantaneous peak discharge ranged from about 56 years at the index station on the Upper Truckee River (10336610) to about 2.4 years for an upstream station on nearby Trout Creek (10336770) (Table 3-4). Runoff magnitudes for the western index stations ranged from 23 years on General Creek to 35 years on Ward Creek. It is interesting to note that there are considerable differences within basin quadrants. For example, upstream sites on Incline Creek and the index station on Third Creek had relatively low return periods of 6 to 13 years while the index station on Incline Creek (10336700) experienced a calculated 50-year event. In terms of sediment production, however, a different picture emerges.

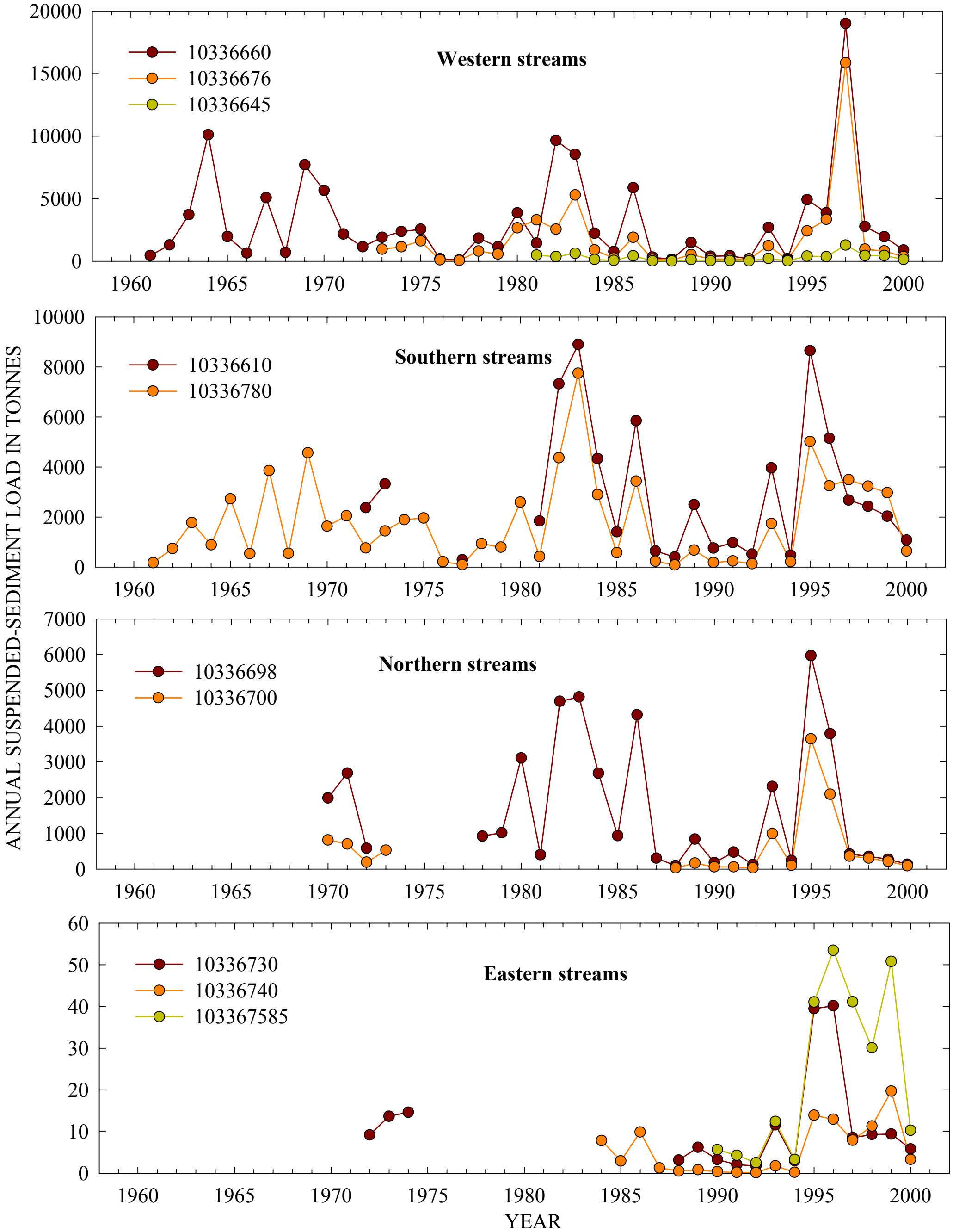


Figure 3-4- Temporal variability in total annual suspended-sediment loads for ten selected index stations in the four basin quadrants.

Table 3-4. Maximum-daily and instantaneous peak discharge for the January 1-2, 1997 runoff event ranked by recurrence interval.

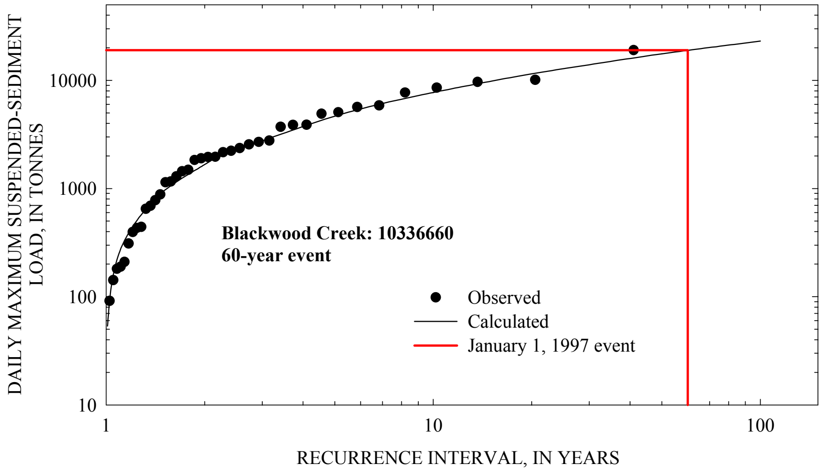
Stream	Station	Quadrant	Max Daily Flow (m^3/s)	Instantaneous Peak (m^3/s)	Recurrence Interval (y)	Flow rank
UTR	10336610	S	89.2	155	55.9	1
Incline	10336700	N	3.17	5.07	49.9	2
Glenbrook	10336730	E	2.41	4.08	37.7	3
Ward	10336676	W	39.4	71.6	35.0	4
Blackwood	10336660	W	56.6	83.2	32.7	5
UTR	10336580	S	32.0	56.9	30.8	6
General	10336645	W	17.0	22.6	23.4	7
Eagle Rock	103367592	E	0.10	0.11	22.9	8
Trout	10336780	S	14.2	15.1	21.2	9
UTR	103366092	S	56.6	145	20.6	10
Ward	10336674	W	20.4	34.5	16.9	11
Ward	10336675	W	36.8	67.1	16.4	12
Edgewood	10336760	E	2.89	3.85	15.0	13
Trout	10336775	S	12.9	14.9	14.9	14
Incline	103366995	N	2.41	4.05	12.9	15
Logan House	10336740	E	0.25	0.34	11.1	16
Edgewood	103367585	E	1.05	1.44	9.7	17
Incline	103366993	N	1.02	1.47	6.5	18
Third	10336698	N	2.27	3.06	5.9	19
Trout	10336770	S	2.27	2.66	2.4	20

Table 3-5. Maximum-daily loads for the January 1-2, 1997 runoff event ranked by recurrence interval.

Stream	Station	Quadrant	Max Daily Load (T/d)	Flow rank	Sediment recurrence interval (y)	Sediment rank
Blackwood	10336660	W	8950	5	60	1
Ward	10336676	W	7840	4	52	2
General	10336645	W	938	7	40	3
Ward	10336674	W	543	11	25	4
Trout	10336780	S	321	9	24	5
UTR	10336580	S	292	6	24	6
Edgewood	103367585	E	13.8	17	21	7
Edgewood	10336760	E	7.0	13	21	8

Glenbrook	10336730	E	1.1	3	17	9
Incline	103366995	N	22.9	15	14	10
UTR	103366092	S	565	10	14	11
Incline	103366993	N	11.5	18	13	12
Logan House	10336740	E	1.6	16	13	13
Trout	10336775	S	58.4	14	12	14
Ward	10336675	W	229	12	8	15
UTR	10336610	S	314	1	8	16
Eagle Rock	103367592	E	0.06	8	7	17
Incline	10336700	N	31.7	2	6	18
Trout	10336770	S	3.4	20	2.4	19
Third	10336698	N	20.0	19	1.4	20

Peak suspended-sediment loads expressed in terms of recurrence interval are dominated by the western streams with index stations registering return periods ranging from 40 to 60 years. In fact, four of the highest return periods were from stations in the western quadrant (Table 3-5). A comparison of how the January 1997 event represented widely varying frequencies of occurrence is shown in Figure 3-5 showing all of the annual, maximum-daily peak suspended-sediment loads for two index stations. For streams draining the eastern quadrant the magnitude of the sediment-transporting event was intermediate with return periods for index stations ranging from 13 to 21 years (Table 3-5).



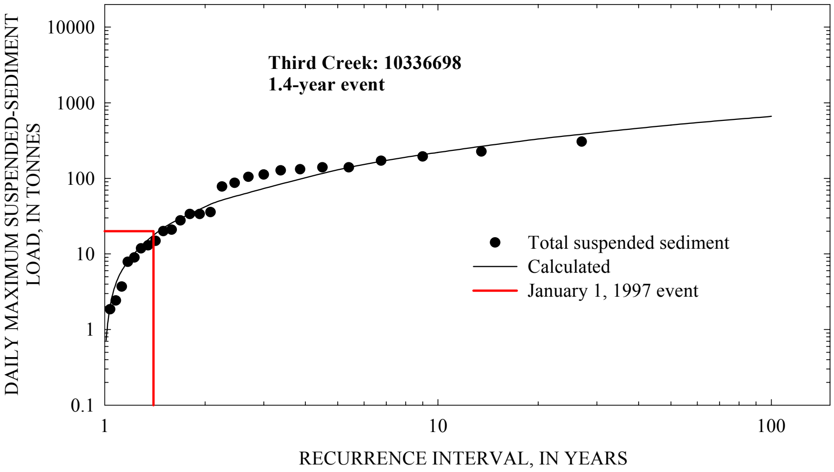


Figure 3-5. Magnitude-frequency analysis of annual, maximum-daily suspended-sediment loads for index stations on Blackwood Creek (10336660) and Incline Creek (10336700), showing widely varying return periods for the January 1, 1997 event.

3.4.4 Effect of January 1997 Runoff Event on Suspended-Sediment Transport Rates

With the relative magnitudes of flows and suspended-sediment loads resulting from the January 1997 runoff event varying widely across the Lake Tahoe Basin, analyses were conducted to determine what affects, if any, these had on future sediment transport rates. To accomplish this, mean-daily sediment loads for each station were separated into periods representing pre- and post-1997 data sets and regressed with mean-daily discharge to produce suspended-sediment transport rating relations before and after the runoff event.

Visual inspection of the plotted ratings showed generally lower sediment loads for a given discharge across the range of discharges for most stations. This indicates that the January 1997 event flushed stored sediment from the stream channels leaving less available for subsequent transport (Figure 3-6). However, given the amount of data scatter it was difficult in some cases to determine whether these differences were real and significant.

Using a combination of sum of squares (SS) statistical tests applied to the pre- and post-1997 rating relations, we evaluated whether the paired regressions are significantly different from one another. Only Second Creek (10336691), and Incline Creek (10336697) showed no discernable change. The Type I SS tests whether the slope of the rating is different than 0.0. The Type III SS tests whether the slopes or intercepts of the ratings are significantly different. Initial results showed that in most cases the SS tests indicated that either the slopes and/or intercepts of the paired regressions were significantly different at the 0.05 level. Still, these results were not convincing in that the statistics pertain to the confidence limits of the regression and not prediction limits. For example, SS results for pre- and post-1997 ratings for Blackwood Creek (Figure 3-6) indicate a statistically significant decrease in loads after January 1997 but inspection of the plot leaves this conclusion in doubt. To alleviate this problem we set stricter limits on the Type III SS measure (P-value) to 0.0001 and the ratio of explained to unexplained variance (F-value) to about 20 to discriminate those sites having significant sediment flushing after January

1997. Those stations determined to have lower transport rates across the range of discharges post January 1997 are shown in Table 3-6.

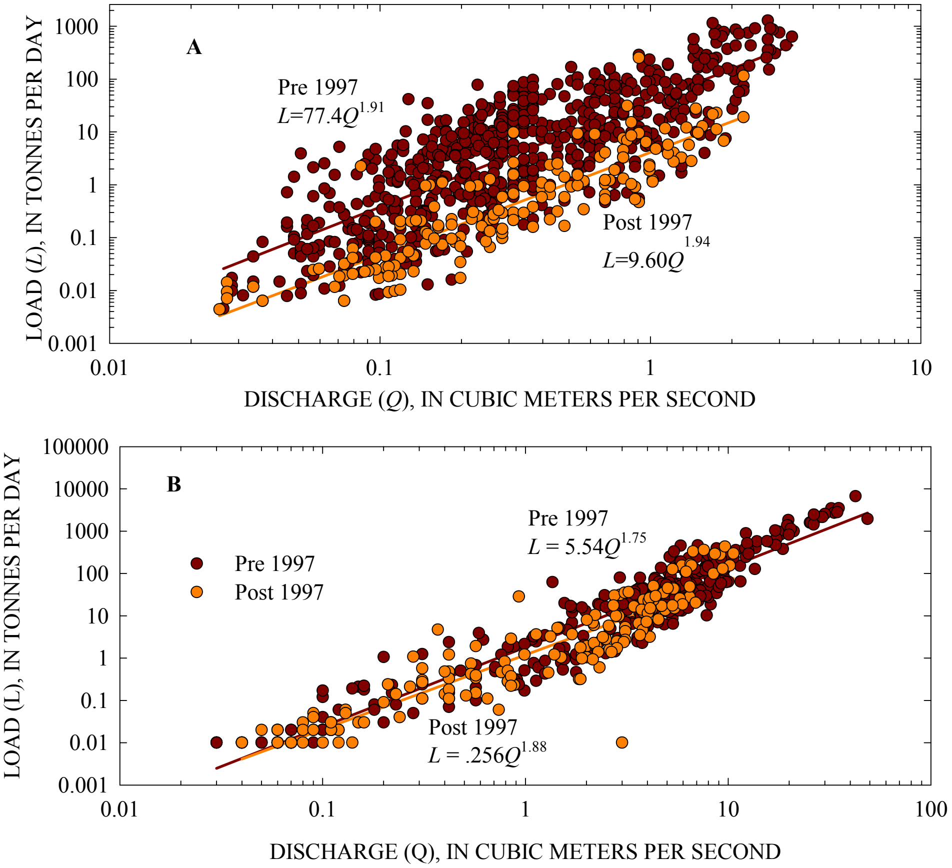


Figure 3-6. Examples of pre- and post-1997 suspended-sediment transport ratings for index station on Third Creek (10336698) showing flushing effect of January 1997 runoff event (A), and for Blackwood Creek (10336660) showing no discernable affect.

Table 3-6. Summary of significant statistical relations indicating decreasing suspended-sediment loads across the range of discharges following the January 1-2, 1997 runoff event.

Stream	Station	Quadrant	F- value	P-value	Post 1997 trend
UTR	10336610	S	24.1	<.0001	decreasing
Trout	10336790	S	27.7	<.0001	decreasing
Trout	10336775	S	26.5	<.0001	decreasing
Trout	10336770	S	34.0	<.0001	decreasing
Ward	10336676	W	38.1	<.0001	decreasing
Incline	10336700	N	136	<.0001	decreasing
Incline	103366993	N	45.9	<.0001	decreasing
Incline	103366995	N	50.8	<.0001	decreasing
Third	10336698	N	272	<.0001	decreasing
Wood	10336692	N	27.3	<.0001	decreasing

Wood	10336694	N	63.6	<.0001	decreasing
First	10336688	N	47.1	<.0001	decreasing
Logan House	10336740	E	20.3	<.0001	decreasing
Edgewood	103367585	E	47.4	<.0001	decreasing
Edgewood	10336765	E	24.9	<.0001	decreasing

3.5 Total Annual Suspended-Sediment Yields

Interpreting suspended-sediment transport rates as yields per unit of drainage area (in T/km^2) is a convenient way to discern differences in sediment production and delivery from different watersheds and from different sites within watersheds. Table 3-7 lists in descending order the median values of total annual suspended-sediment yields for all sites with historical data. As with Table 3-2, the 18 index stations are highlighted in green. Of the four highest yield values shown in Table 3-7, three are from the northern quadrant and were sampled only in the early 1970's, representing the dis-equilibrated conditions of that period and do not represent long-term conditions. The fourth, from Ward Creek also represents a very short period of record although it drains an erosive headwaters area of the basin. Notwithstanding these potential biases, the greatest median suspended-sediment yields emanate from Blackwood (66.4 T/y/km^2), Third (56.2 T/y/km^2), Ward (34.1 T/y/km^2), Upper Truckee (15.5 T/y/km^2), and Trout (12.5 T/y/km^2). The lowest yields in ascending order are Logan House (0.6 T/y/km^2), Glenbrook (0.8 T/y/km^2), Dollar (1.0 T/y/km^2), Quail Lake (1.5 T/y/km^2), and Edgewood (2.6 T/y/km^2). Note that most of these low-yielding index streams are located in the eastern quadrant of the basin.

Table 3-7. Total annual suspended-sediment yields. Stations shaded in green are index stations (Annual values are provided in Appendix E).

Stream	Station number	Annual Yield		Quadrant	Years of data	Drainage area (km^2)
		Average (tonnes/km^2)	Median (tonnes/km^2)			
Second[2]	10336691	319	300	N	4	4.7
First[2]	10336688	142.0	146	N	4	2.8
Ward	10336670	128	128	W	3	5.2
Wood[2]	10336692	89	93	N	4	5.3
Blackwood	10336660	105	66.4	W	40	29.0
Third	10336698	107	56.2	N	26	15.7
Ward	10336676	68.9	34.1	W	28	25.1
Ward	10336674	33.2	27.7	W	9	12.9
Ward	10336675	23.7	19.5	W	9	23.2
UTR	103366092	15.9	15.9	S	10	88.8
UTR	10336610	20.1	15.5	S	24	142
Incline	103366995	15.1	14.1	N	11	11.6
Incline	103366993	11.1	12.6	N	10	7.2
Trout	10336780	18.9	12.5	S	40	95.1
Incline	10336700	33.8	12.0	N	17	18.1
Grass[1]	10336593	10.9	10.9	S	3	16.6
UTR	10336580	10.0	9.2	S	10	36.5
General	10336645	14.7	9.1	W	20	19.3
Trout	10336770	8.2	5.7	S	10	19.1
Trout	10336775	6.1	5.4	S	10	61.4
Meeks[1]	10336640	3.6	3.6	W	3	22.2
Eagle[1]	10336630	3.4	3.4	W	3	20.4
Trout	10336790	3.4	3.4	S	5	105
Edgewood	10336760	2.4	3.2	E	8	14.2
Eagle Rock	103367592	3.6	3.0	E	10	1.5
Edgewood	103367585	3	2.6	E	11	8.1
Quail Lake[1]	10336650	1.5	1.5	W	3	4.2
Dollar[1]	10336684	1.0	1.0	N	3	4.7
Edgewood Trib.	10336756	0.9	0.9	E	2	0.6
Glenbrook	10336730	1.1	0.8	E	16	10.5
Logan House	10336740	1.0	0.6	E	17	5.4
Edgewood	10336765	0.6	0.6	E	2	16.2

1 = Data from Kroll (1976)
2 = Data from Glancy (1988); Data from disturbed high runoff period in 1970s.

The spatial distribution of annual suspended-sediment yields are somewhat similar to the loads distribution but with some important differences (Figure 3-7). Both of the disturbed western streams (Blackwood and Ward Creeks) are in the highest sediment producing class, reflecting the critical nature of human intervention on this side of the lake. In contrast, the relatively undisturbed General Creek has a median annual yield value of 9.1 T/y/km^2, thus providing a measure of the magnitude of the disturbances on Blackwood and Ward Creeks. The Upper Truckee River and Trout Creek although being among the largest contributors of suspended sediment to Lake Tahoe display only moderate suspended-sediment yields (15.5 and 12.5 T/y/km^2, respectively). This reinforces the notion that it is the sheer size of these watersheds relative to other basins in the Lake Tahoe watershed that is an important factor in the magnitude of their sediment contributions to the lake. This is not to say, however, that human intervention and other factors in the flatter alluvial sections of these streams has not led to accelerated bank erosion and suspended-sediment transport rates, but that yields from these two watersheds are not exceptional.

Eastern streams again generally display the lowest suspended-sediment transport values in the Lake Tahoe watershed (Figures 3-2, 3-3, and 3-7; Table 3-7); a direct function of low runoff rates and water yields. Median annual suspended-sediment yield from the index station located in the developed (disturbed) Edgewood Creek watershed are still relatively low (2.6 T/y/km^2).

When sorted by basin quadrant (Figure 3-8a), suspended-sediment yields for the 18 index stations appear to be dominated by the northern quadrant streams Second (300 T/y/km^2), First (146 T/y/km^2), and Wood Creeks (93 T/y/km^2). Because of a sampling period that coincided with rapid development and instability in these basins, values reported here are probably not representative of long-term averages for developed streams in this quadrant. Removing these three sites from the plot provides a more accurate picture of median suspended-sediment yields across the four basin quadrants (Figure 3-8b). However, comparing values from the eastern quadrant streams in Figures 3-8a and 3-8b does provide a means of comparing sediment production during development with long-term values. Yields from Third Creek, a watershed disturbed at various times over the 26-year sampling period by re-routing of channels, urbanization, and road construction has a high median suspended-sediment yield (56.2 T/y/km^2). This value is still 2 to 6 times less than median values between 1970 and 1974. Over the period of record, Third Creek produces as much sediment per unit area as unstable streams on the western side of the lake even though median annual water yield is about half (0.46 m^3/m^2).

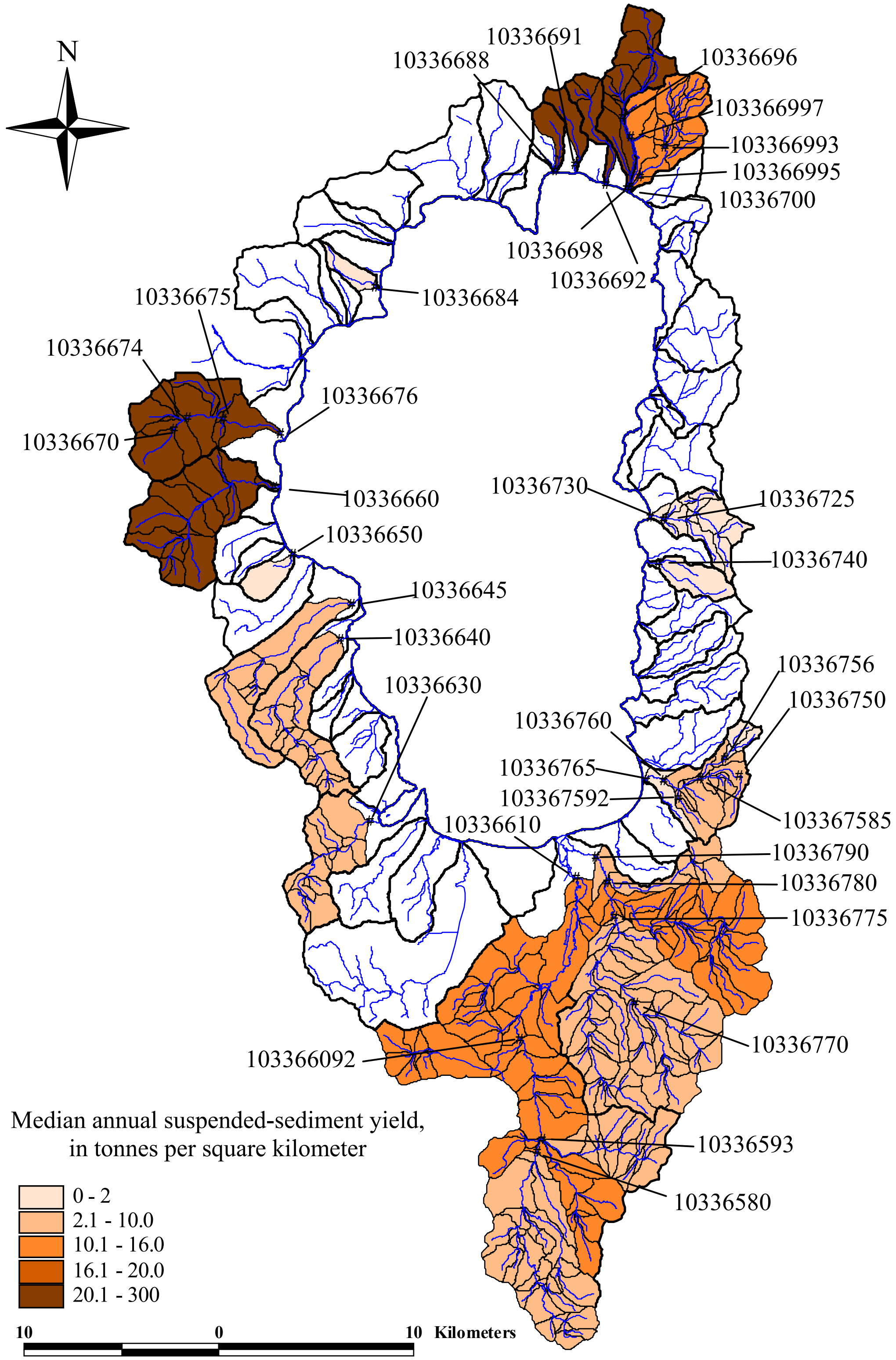


Figure 3-7. Median annual suspended-sediment yields.

It is believed that the combination of upland mass-wasting processes in the undeveloped, upstream part of the basin (Entrix, 2001), combined with erosion from cut slopes and streambanks in the downstream developed areas has resulted in the high long-term suspended-sediment yield. In comparison, the adjacent, developed Incline Creek watershed maintains considerably lower suspended-sediment yields (median = 12.0 $T/y/km^2$) even though the two basins have similar road densities (a measure of urbanization). The lower yields from Incline Creek are in part due to the fact that the basin does not cut through major unconsolidated debris flow and landslide deposits in its upper reaches as does Third Creek.

Similar spatial variations between watersheds are seen when expressing annual suspended-sediment loads per unit of runoff. Annual loads (in tonnes) are divided by annual runoff (in m^3) for each year of record to express annual yields or concentrations, in g/m^3 (Table 3-8). Within basin comparisons using annual concentration data can show variations in sediment production and sources within basins. This approach can be better than using loads per unit area because of the tendency for yield values expressed in T/km^2 to decrease with distance downstream because of greater opportunities for sediment storage.

A revealing result of the analysis of suspended-sediment loads per unit runoff is that production and delivery of sediment from the northern quadrant streams, on average, is about the same as the wetter, western streams if we neglect the data from Third Creek. This is most certainly due to higher unit-runoff rates from the developed areas in the northern quadrant, resulting in higher yields of sediment. However, subsequent analysis of the temporal trends of suspended-sediment transport will show that because of the natural attenuation of sediment loads following disturbance, as well as installation of erosion-control measures, that annual loads are decreasing faster here than in any other quadrant of the Lake Tahoe Basin.

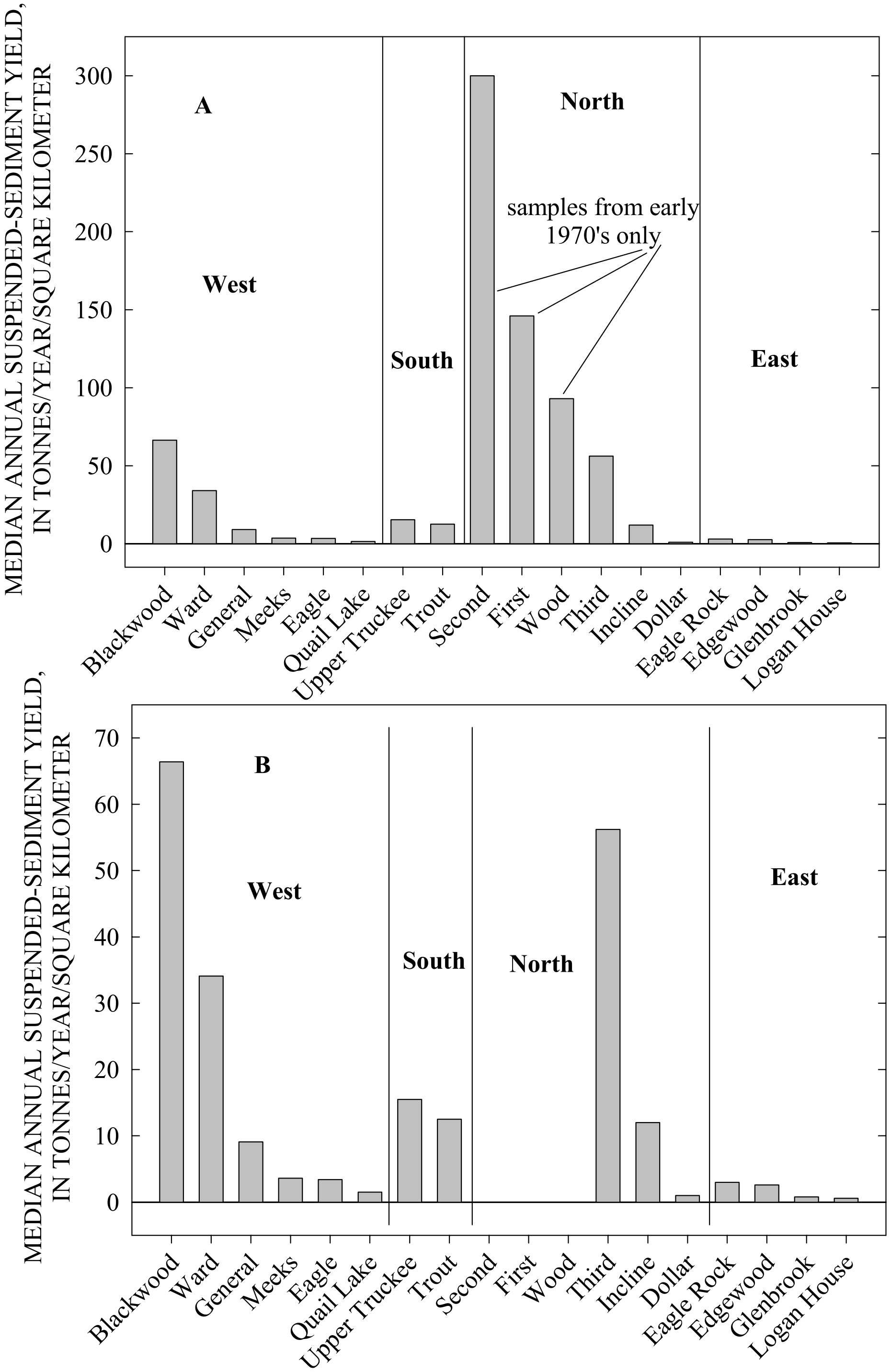


Figure 3-8. Median annual suspended-sediment yields for the 18 index stations (A), and without those northern streams sampled only in the early 1970's (B).

Table 3-8. Annual suspended-sediment loads per unit runoff (annual sediment concentrations). Rows shaded in gray have short periods of record and are not included in calculations of the median values for their respective quadrant. (* = index station)

Stream	Station	Quadrant	Annual sediment concentrations		Percent difference from median
			Median (g/m^3)	Average (g/m^3)	(g/m^3)
Eagle Rock*	103367592	E	6.50	7.18	-6.3
Edgewood	10336760	E	6.94	6.98	0.0
Edgewood	10336765	E	7.14	7.14	2.9
Edgewood*	103367585	E	12.6	14.6	81.6
Edgewood Trib	10336756	E	3.98	3.98	-42.7
Glenbrook*	10336730	E	6.94	7.44	0.0
Logan House*	10336740	E	6.16	7.36	-11.2
Median			**6.94**	**7.36**	
First	10336688	N	397	418	1424
Second	10336691	N	964	964	3601
Wood	10336692	N	261	241	902
Incline*	10336700	N	29.4	64.4	12.9
Incline	103366993	N	16.7	14.2	-35.9
Incline	103366995	N	22.7	26.4	-12.9
Third*	10336698	N	153	181	487
Median			**26.1**	**45.4**	
Grass	10336593	S	14	14	-6.7
Trout	10336770	S	7.8	11.4	-48.0
Trout	10336775	S	10.7	12.1	-28.7
Trout*	10336780	S	41.2	41.7	175
Trout	10336790	S	15.0	14.3	0.0
UTR	10336580	S	7.76	8.44	-48.3
UTR*	10336610	S	27.1	28.5	80.7
UTR	103366092	S	15.4	14.2	2.7
Median			**15.0**	**14.2**	
Blackwood*	10336660	W	54.6	74.2	225
General*	10336645	W	11.3	15.0	-32.7
Ward	10336670	W	83.4	81.5	396
Ward	10336674	W	16.8	17.55	0.0
Ward	10336675	W	15.5	18.2	-7.7
Ward*	10336676	W	30.7	56	82.7
Median			**16.8**	**18.2**	

3.6 Fine-Grained Suspended-Sediment Loads and Yields

In terms of lake clarity, the delivery of sands and gravels to Lake Tahoe is not a critical issue. Material finer than 0.062 mm, defined as silts and clays, have the ability to remain in suspension for longer periods of time and have a direct effect on lake clarity. Using calculated suspended-sediment loads in combination with relations derived herein between discharge and percent silt plus clay, fine-sediment loads and yields are calculated by multiplying the load for a given day by the percent of material finer than 0.062 mm. Examples of these relations are shown in Figure 3-9.

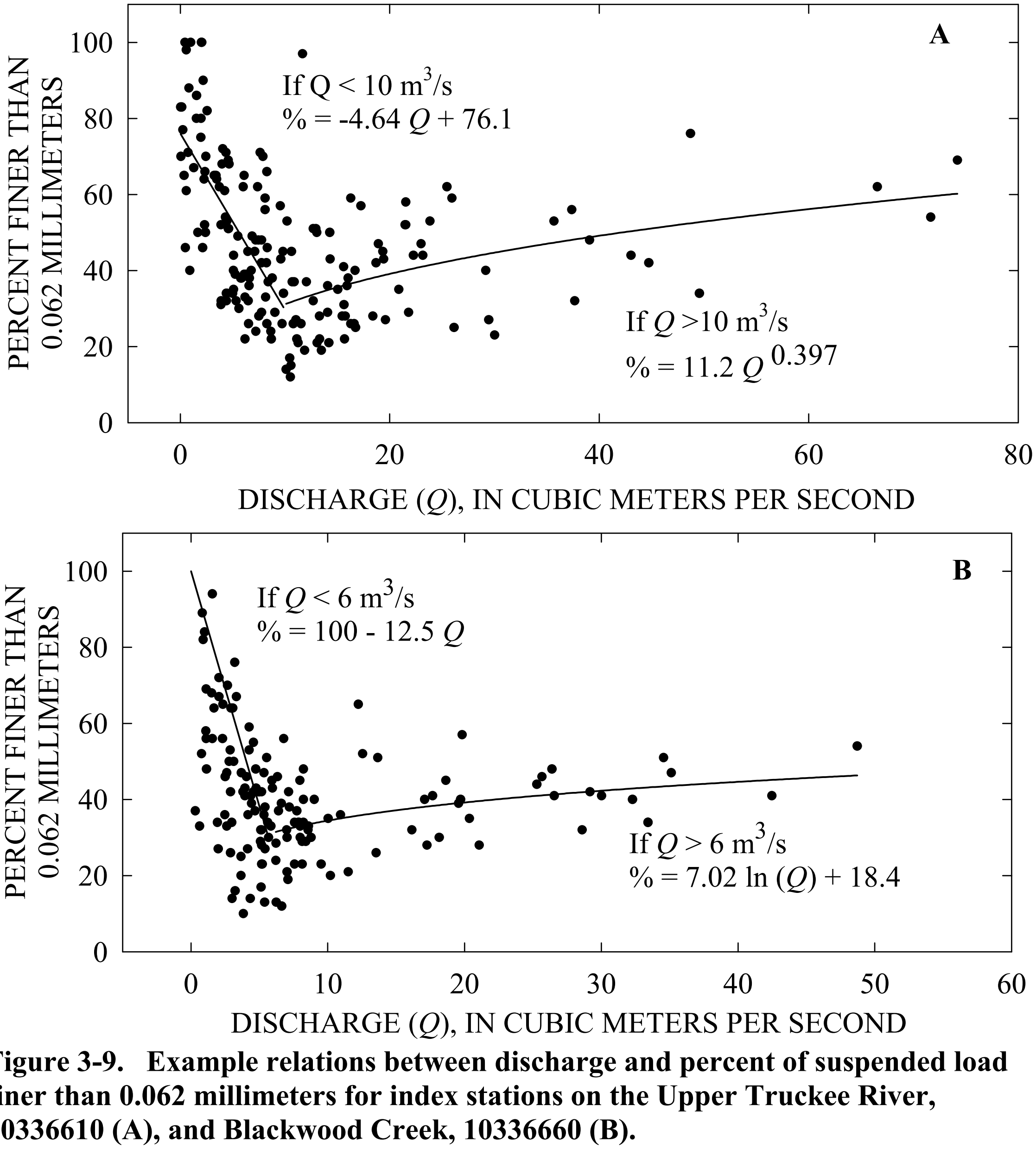


Figure 3-9. Example relations between discharge and percent of suspended load finer than 0.062 millimeters for index stations on the Upper Truckee River, 10336610 (A), and Blackwood Creek, 10336660 (B).

The largest contributors of fine sediment to Lake Tahoe on an annual basis are the Upper Truckee River and Blackwood Creek with median annual values of 1010 T/y and 846 T/y, respectively (Table 3-9). These values are about twice that of the next largest annual contributors Trout (462 T/y) and Ward Creeks (412 T/y). In comparison General Creek, delivers about 53 T/y. The greatest contributor from the eastern side of the lake is the index station on Edgewood Creek (11.4 T/y). Table 3-9 also provides an estimate of the relative contributions of fine load to total suspended-sediment load on an annual basis. Eastern streams such as Glenbrook, Logan House, and Edgewood Creeks display high percentages of fine loads as does Incline Creek on the north side of the basin; however, these values should be considered as estimates only because of the large degree of scatter in the discharge vs. percent finer relations. The spatial distribution of fine-grained loads is displayed in Figure 3-10.

Table 3-9. Summary of annual fine-grained suspended-sediment loads to Lake Tahoe calculated from measured data. Stations highlighted in green are index stations.

Stream	Station number	Annual Fine Load		Median relative contribution (percent)	Years of data	Drainage Area (km^2)
		Average (tonnes)	Median (tonnes)			
UTR	10336610	1261	1010	44	24	142
Blackwood	10336660	1347	846	45	40	29.0
Trout	10336780	624	462	38	40	95.1
Ward	10336676	658	412	47	28	25.1
Third	10336698	462	318	31	26	15.7
Ward	10336670	194	193	30	3	5.2
Trout	10336790	134	141	40	5	105
Incline	10336700	320	129	67	17	18.1
Incline	103366995	74.4	66.7	47	11	11.6
General	10336645	69.2	53.3	29	20	19.3
Grass	10336593	40.4	40.4	31	2	16.6
Incline	103366993	24.4	27.7	36	10	7.2
Eagle[1]	10336630		21.8		3	20.4
Meeks[1]	10336640		19.1		3	22.2
Edgewood	103367585	12.9	11.4	59	11	8.1
Edgewood	10336765	8.5	8.5	89	2	16.2
Glenbrook	10336730	8.8	7.0	80	16	10.5
Quail Lake[1]	10336650		3.2		3	4.2
Dollar [1]	10336684		2.6		3	4.7
Logan House	10336740	3.5	2.3	75	17	5.4

[1] = Data from Kroll (1976).

A direct relation between fine-grained loads as defined in this report (< 0.062 mm) and lake clarity may not be distinct because they may not be representative of the very-fine fraction <0.020 mm, particularly in terms of particle weight. This is because the contribution of particle weights of the 0.020 to 0.062 mm fraction are greater. Particle-size data in the range 0.9020 to 0.062 mm being currently collected as part of the Tahoe TMDL research program (J. Reuter, 2003, written com.) could ultimately be used to refine estimates of the delivery of very fine particles if they are associated with a corresponding water discharge.

Table 3-10. Summary of annual fine-grained suspended-sediment yields from Lake Tahoe watersheds. Stations highlighted in green are index stations.

Stream	Station number	Annual Fine Yield		Years of data	Drainage area (km^2)
		Average (tonnes/km^2)	Median (tonnes/km^2)		
Ward	10336670	37.4	37.1	3	5.2
Blackwood	10336660	45.4	21.5	40	29.0
Third	10336698	29.4	20.2	26	15.7
Ward	10336676	26.2	16.4	28	25.1
UTR	10336610	8.9	7.1	24	142
Incline	10336700	17.7	7.1	17	18.1
Incline	103366995	6.4	5.7	11	11.6
Trout	10336780	6.6	4.9	40	95.1
Incline	103366993	3.4	3.8	10	7.2
General	10336645	3.6	2.8	20	19.3
Grass	10336593	2.4	2.4	2	16.6
Trout	10336790	1.3	1.4	5	105
Edgewood	103367585	1.6	1.4	11	8.1
Eagle[1]	10336630		1.1		20.4
Meeks[1]	10336640		0.9		22.2
Quail Lake[1]	10336650		0.8		4.2
Glenbrook	10336730	0.8	0.7	16	10.5
Dollar [1]	10336684		0.6		4.7
Edgewood	10336765	0.5	0.5	2	16.2
Logan House	10336740	0.6	0.4	17	5.4

[1] = Original data from Kroll, 1976.

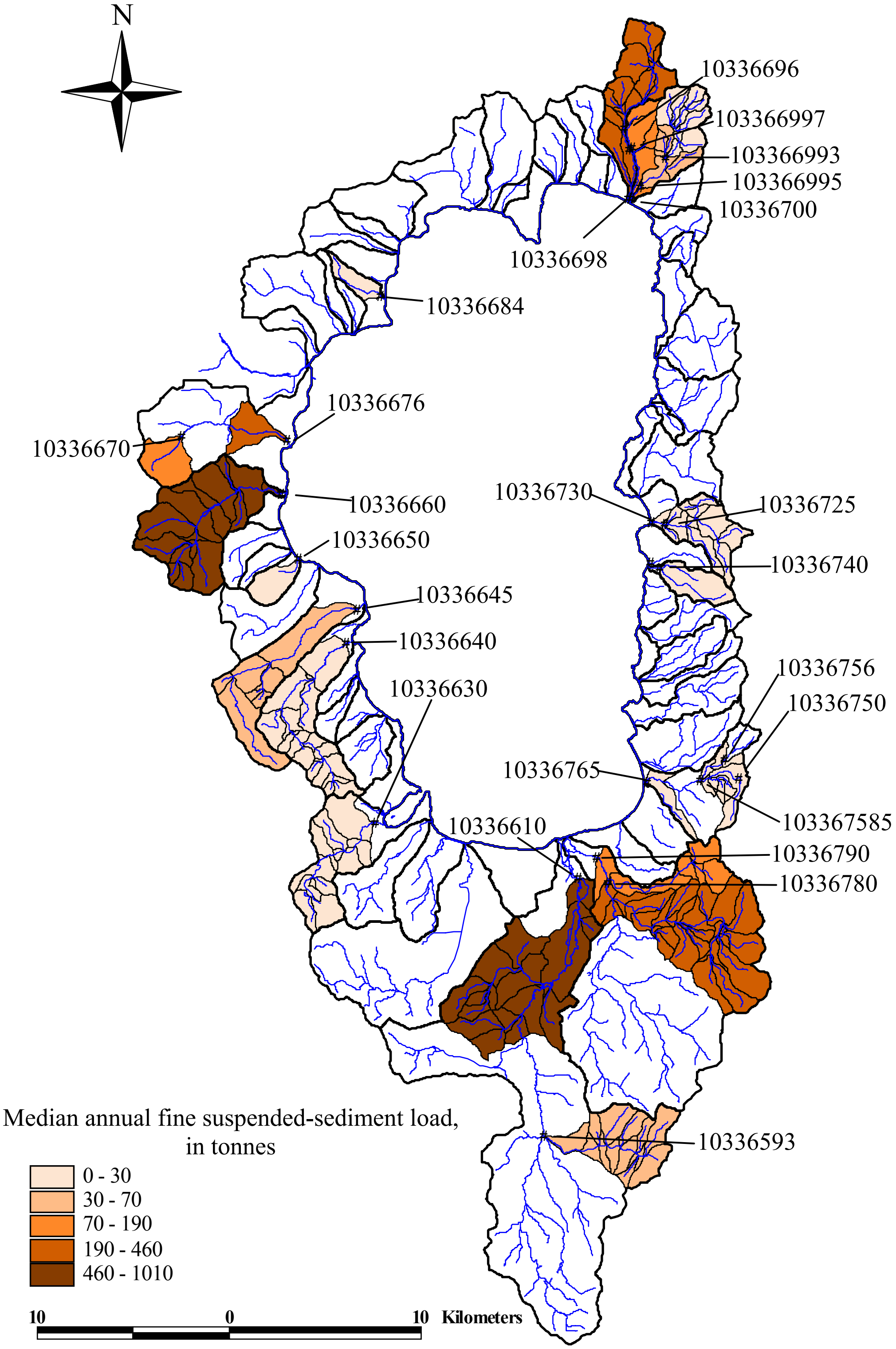


Figure 3-10. Spatial distribution of median, annual fine-grained suspended-sediment loads.

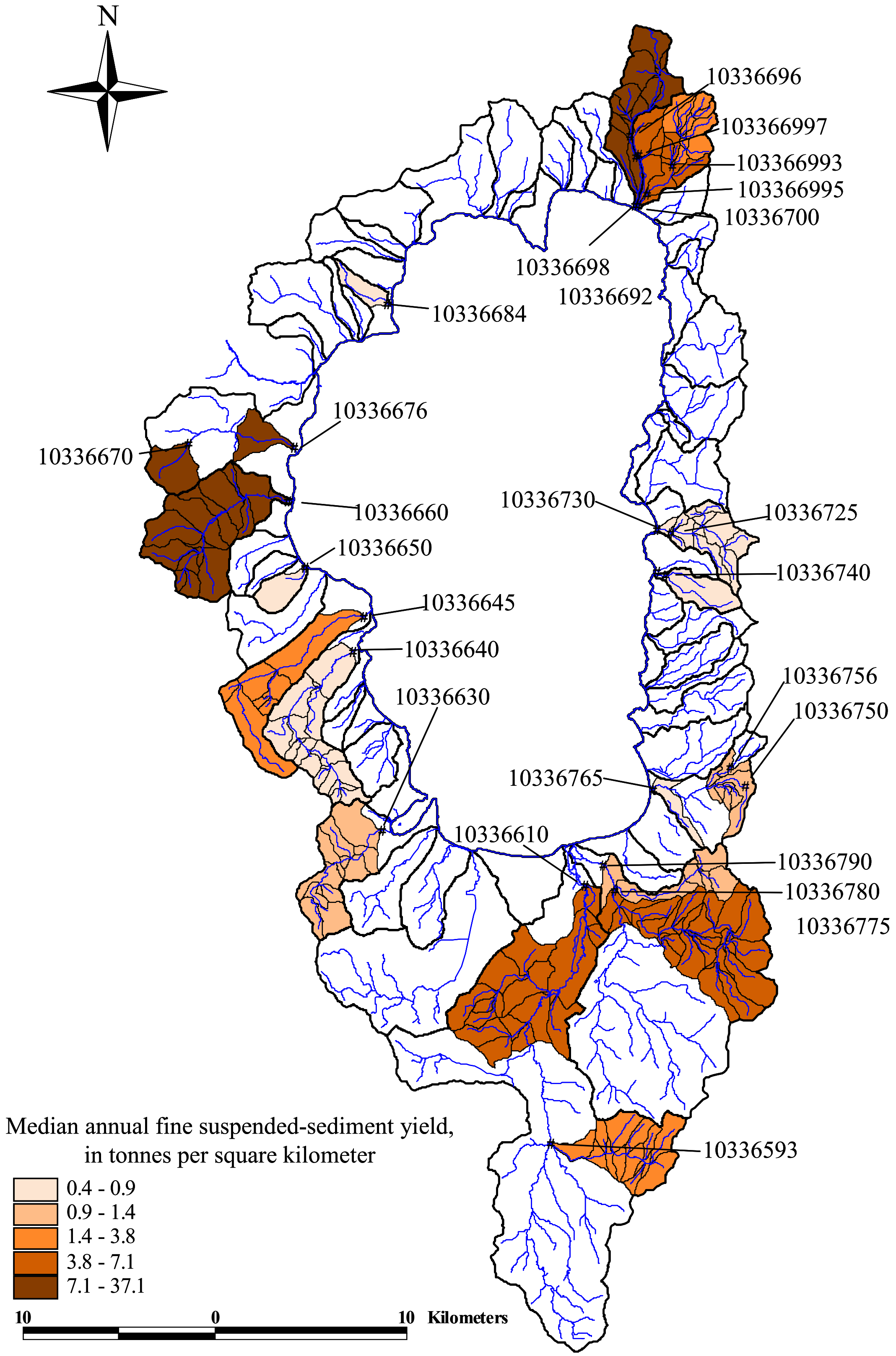


Figure 3-11. Spatial distribution of median, annual yields of fine-grained sediment.

A better understanding of the production and delivery of fine-grained suspended sediment is obtained from expressing transport as load per unit area (yield). Notwithstanding the 37 $T/y/km^2$ indicated from the headwaters station on Ward Creek (10336670) with only three years of record, it is the index stations representing disturbed streams that produce the most fine-grained sediment (Table 3-10). In descending order, they are: Blackwood (21.5 $T/y/km^2$), Third (20.2 $T/y/km^2$), and Ward Creeks (16.4 $T/y/km^2$). On average, the Upper Truckee River produces about as much fine-grained sediment per unit area as does Incline Creek, about 7 $T/y/km^2$. The effect of disturbances on fine-grained sediment production is evident by comparing yield values from relatively undisturbed western streams such as General, Meeks, and Eagle Creeks with those from Blackwood and Ward Creeks. On average the disturbed western watersheds produce about 10 times more silt and clay per unit area than the undisturbed basins (Table 3-10; Figure 3-11).

On the eastern side of the lake median, annual fine-grained suspended-sediment yields range from 0.4 $T/y/km^2$ from the undisturbed Logan House watershed to 1.4 $T/y/km^2$ in the developed Edgewood Creek watershed, a difference of three and one-half times. Data on yields from the north quadrant are limited to Third and Incline Creeks with Incline producing substantially less silt and clay per unit area than Third. Given the similar degrees of disturbance in these two watersheds, the difference is probably due to more intense erosion processes in the higher elevations of the Third Creek watershed.

3.7 Intra-Basin Variations

Several watersheds including Edgewood, Incline, Trout and Ward Creeks, and the Upper Truckee River contain more than one sampling station and thereby provide a mechanism to compare sediment production from different parts of each watershed (Table 3-11). With the exception of Edgewood and Trout Creeks, median-annual concentrations (yields per unit volume of water) are greatest at the downstream-most locations of the five watersheds indicating progressively more sediment being entrained from channel sources. Lower yields in the downstream direction along Edgewood and Trout Creeks indicate sediment storage in channels. Time-series cross sections along Edgewood Creek show average net deposition of about 14 $m^3/y/km$ (1984-2002) along 5.6 km of channels. In addition, sediment retention ponds below the downstream-most station on Edgewood Creek provide additional opportunities to reduce sediment loads before waters enter the lake.

Suspended-sediment loads per unit of runoff increase in the downstream direction along Incline Creek and the Upper Truckee River with sediment entrained from developed areas and eroding streambanks (Table 3-11). Along the Upper Truckee River this is particularly evident in the sinuous reach adjacent to the golf course where about 650 $m^3/y/km$ of bank materials has been eroded over 2.9 km between 1992 and 2002. That median annual concentrations for the upstream-most stations on Trout Creek and the Upper Truckee River are the same (7.8 g/m^3) is certainly coincidental, yet sediment-transport rates past these two “reference” stations are probably indicative of background rates of sediment production from predominantly forested upland sources in the southern quadrant of the basin.

The exceptionally high median-annual concentration from the upstream-most site on Ward Creek (Table 3-11) agrees with the observations of Reuter and Miller (2000) and Stubblefield (2002) that the badland area in the unvegetated headwaters contributes large quantities of sediment to the main stem where suspended-sediment transport is greatly reduced. However, results for this site (10336670) are based on only three years of record. Suspended-sediment transport increases again in the lower-most reaches with material entrained from eroding streambanks.

Results presented in this section and in Table 3-11 are in general agreement with the narrative on the subject by Reuter and Miller (2000) with the exception of the interpretation about the downstream-most reaches of Ward Creek. Figure 3-11 showing median annual suspended-sediment yields of fine-grained materials is useful in visualizing the trends discussed above.

Table 3-11. Median annual suspended-sediment concentrations for stations along five Lake Tahoe streams. All data expressed in grams of sediment per cubic meter of water (annual concentration). Numbers in parentheses are percent change from next station upstream.

Location	Stream and (Quadrant)				
	Edgewood (E)	**Incline (N)**	**Ward (W)**	**Trout (S)**	**Upper Truckee (S)**
Upstream	6.50	16.7	83.4[1]	7.8	7.8
Mid-basin 1		22.7 (36)	16.8 (-80)	10.7 (37)	15.4 (97)
Mid-basin 2	12.6 (94)		15.5 (-8)	41.2 (285)	
Downstream	6.94 (-45)	29.4 (30)	30.7 (98)	15.0 (-64)	27.1 (76)

[1] = Only three complete years of data.

3.8 Suspended-Sediment Transport from "Reference" and Disturbed Watersheds

Concerns over the role of development and other forms of human-induced disturbances on the delivery of suspended-sediment to Lake Tahoe has been justified on the basis of studies such as those by Glancy (1988) and others documenting erosion problems associated with these practices. Because of differences in rainfall-runoff characteristics, surficial geology, and land cover, stable, undisturbed watersheds located in the different basin quadrants are likely to have varied sediment-transport regimes.

To differentiate between "background" and "impacted" suspended-sediment loadings from for each of the four basin quadrants, "reference" stations or watersheds are selected. This procedure allows for comparison between relatively undisturbed watersheds and those that have been disturbed or altered by human intervention. Considerations in selecting these reference stations include length of flow and sediment record, amount of channel and watershed disturbance, and comparable drainage areas to the disturbed sites in the quadrant. The site on

Incline Creek (103366993) does not represent pristine conditions but probably represents the least disturbed site in the quadrant with sufficient data to compare with more disturbed locations. It is assumed that "reference" conditions, however, do not vary greatly within a quadrant. Reference stations are shown in Table 3-12.

Table 3-12. Reference stations selected for each of the four basin quadrants.

Basin quadrant	Stream	Station number	% Basin with high potential upland erosion[1]	Length of record (years)	Drainage area (km^2)
North	Incline	103366993	3.1	10	7.2
South	Upper Truckee	10336580	18.0	10	36.5
East	Logan House	10336740	0.0	17	5.4
West	General	10336645	1.8	20	19.3

[1] Methods and analysis described in Chapter 6.

Suspended-sediment yields per unit area from disturbed western streams Ward and Blackwood Creeks are 275% to 630% greater respectively, on an annual basis than the "reference" General Creek watershed. These values are comparable to those expressed in terms of yield per unit of runoff (g/m^3; Table 3-8). In the Upper Truckee River watershed, yields per unit area are roughly 75% greater in the flatter alluvial sections where bank erosion is active than at the upstream "reference" station. When compared in terms of median annual concentrations, the disturbed reaches of the Upper Truckee River pass about 250% more sediment per unit of runoff than reaches not experiencing bank erosion. In the eastern quadrant, the index station on Edgewood Creek passes about 330% more suspended-sediment per unit area (about 100% more per unit of water) than does the index station on Logan House Creek.

Comparisons in the north quadrant are difficult given that development in this part of the Lake Tahoe watershed has impacted most of the tributary streams draining the lake. The very high erosion rates from parts of the high elevation areas of Third Creek and comparisons between "reference" and representative, disturbed stations provide additional uncertainty. Still, the upstream-most site on Incline Creek (103366993) is considered a reference because it contains about half the density of unpaved roads compared to the area containing the index stations for Third and Incline Creeks, and few paved roads. Suspended-sediment yields per unit of runoff do show considerable differences with the index sites on Incline (73% greater) and Third Creeks (about 800% greater) that encompass more of the developed area.

3.9 Temporal Trends in Suspended-Sediment Delivery to Lake Tahoe

One of the most critical issues concerning degradation or recovery of Lake Tahoe water clarity is the question as to whether suspended-sediment loads are changing over time, and consequently, are restoration and erosion control efforts effective. Analysis of the temporal variations in sediment delivery to Lake Tahoe are based on the fundamental assumption that precipitation characteristics over the past 40 years have not changed substantially beyond the stochastic variations inherent in runoff production. Because temporal variations in annual suspended-sediment loads are dominated by annual changes in runoff, loads expressed per unit of runoff is a particularly sensitive parameter to interpret temporal trends. Three techniques were used with statistical testing to evaluate temporal trends in the hope of developing parallel lines of evidence. They are:

1. Annual variations in suspended-sediment loads per unit of runoff;
2. Daily variations in suspended-sediment loads per unit of runoff; and
3. Decadal (or less) shifts in the slope and intercept of suspended-sediment transport ratings.

The first two techniques were utilized where there was sufficient mean-daily flow data to calculate annual values for a minimum of five years. The third technique was used where there was no mean-daily flow data but only instantaneous values to develop sediment-transport ratings.

Annual suspended-sediment loads for 21 stations were divided by the total runoff for each year of record and plotted with time to obtain temporal trends of annual concentrations. Examples from ten index stations are shown in Figure 3-12. Statistical analysis of the data shown in Figure 3-12 and for the other 11 stations were conducted to determine the existence of any trends with time. Results of linear regression analysis are displayed in Table 3-13. Only three sites indicating decreasing annual loads have relations significant at the 0.10 level of significance: Upper Truckee River (10336610), Third Creek (10336698), and Trout Creek (10336790). Results for the latter site may be questionable in that there are only 5 years of flow record. In general the results listed in Table 3-13 are not particularly enlightening with extremely low r^2 values, indicating that very little if any of the variation in loads with time is explained. In an attempt to improve statistical significance and provide more reliable results, the analysis was recast using daily values to increase the number of observations (*n*).

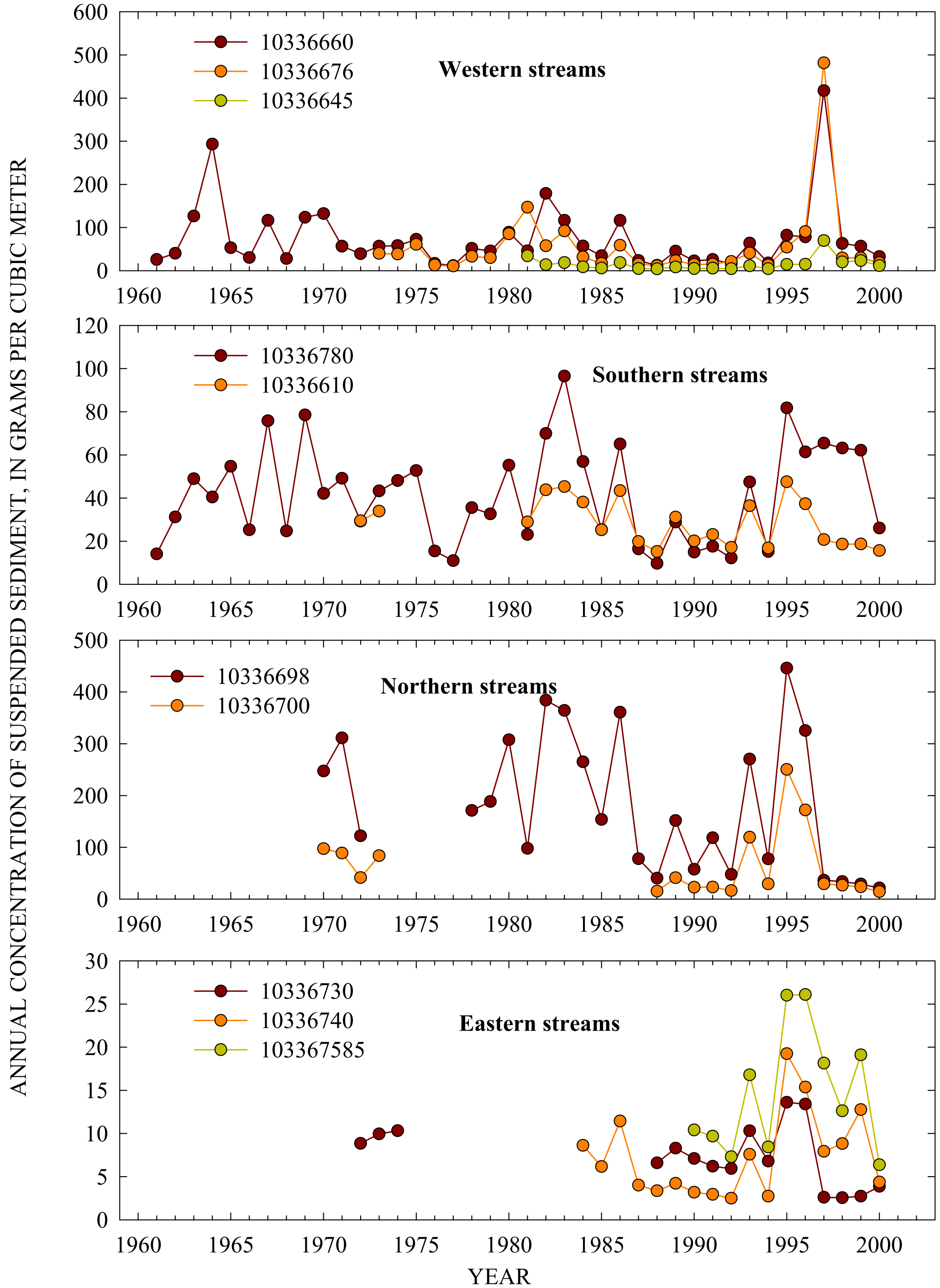


Figure 3-12. Annual concentrations of suspended sediment obtained by dividing annual suspended-sediment load by annual runoff.

Table 3-13. Summary statistics of analysis of temporal trends in annual concentration (in g/m^3).

Stream	Station	Equation	r^2	F-value	P - value	n	Significance and trend
Blackwood	10336660	y=347-0.12x	.0004	0.02	0.90	40	none
General	10336645	y=-907+0.46x	0.03	0.62	0.44	20	none
Ward	10336674	y=92.9-0.04x	.00015	.0009	0.98	8	none
Ward	10336675	y=-1082+0.55x	0.02	0.14	0.72	9	none
Ward	10336676	y=-3733+1.91x	0.03	0.83	0.37	28	none
Trout	10336770	y=298-0.14x	.0018	0.01	0.91	10	none
Trout	10336775	y=-171+0.09x	.0010	0.01	0.93	10	none
Trout	10336780	y=-150+0.10x	.0025	0.10	0.76	40	none
Trout	10336790	y=765-0.38x	0.67	6.21	0.09	5	some (-)
UTR	10336580	y=-330+0.17x	0.01	0.11	0.75	10	none
UTR	10336610	y=1071-0.52x	0.14	3.32	0.08	22	some (-)
UTR	103366092	y=-936+0.48x	0.03	0.26	0.62	10	none
Incline	10336700	y=1055-0.50x	0.01	0.10	0.76	17	none
Incline	103366993	y=-1331+0.67x	0.08	0.72	0.42	10	none
Incline	103366995	y=-3361+1.70x	0.12	1.08	0.33	10	none
Third	10336698	y=10807-5.35x	0.12	3.40	0.08	26	some (-)
Eagle Rock	103367592	y=-727+0.37x	0.18	1.73	0.22	10	none
Edgewood	10336760	y=189-0.09x	0.01	0.06	0.81	8	none
Edgewood	103367585	y=-962+0.49x	0.05	0.50	0.50	11	none
Glenbrook	10336730	y=317-0.16x	0.16	2.74	0.12	16	none
Logan House	10336740	y=-544+0.28x	0.08	1.33	0.27	17	none

Results using daily values show all but five sites with statistically significant trends of decreasing daily concentrations (based on the P-value of the regression) but the results are still considered suspect because of the exceedingly flat slopes indicated by the regression equation (Table 3-14). Although P-values suggest that the slope of the majority of regressions is significantly different than zero (flat, with no trend) this can be largely attributed to the very large sample size. Note the very low slopes of the regressions listed in Table 3-14. Restated, if any trend with time existed, it would show up in the analysis of daily values. That five sites still showed no statistically significant trend is important. These five locations all represent upstream and, or reference sites in the watershed and would, therefore, not be expected to display attenuation of sediment- transport rates in response to disturbance.

Table 3-14. Summary statistics of analysis of temporal trends in mean-daily concentrations (in g/m^3). Stations highlighted in pale yellow signify no discernable trend.

Stream	Station	Equation	r^2	F - value	P - value	n	Significance and trend
Blackwood	10336660	y=18.5-1.74e-4x	.0003	4.75	0.03	14975	definite (-)
General	10336645	y=4.33+7.43e-5x	.0003	2.39	0.12	7756	none
Ward	10336674	y=6.76-7.83e-4x	.006	20.5	0.0001	3652	definite (-)
Ward	10336675	y=6.45-3.47e-4x	.001	4.55	0.03	3653	definite (-)
Ward	10336676	y=14.0-3.84e-4x	.0009	9.41	0.0022	10592	definite (-)
Trout	10336770	y=5.54-2.42e-4x	.001	5.71	0.02	4150	definite (-)

Trout	10336775	y=619-8.87e-5x	.0002	0.94	0.33	4140	none
Trout	10336780	y=25.0+1.51e-4x	.0007	11.0	0.0009	14975	definite (+)
Trout	10336790	y=15.1-3.35e-3x	0.15	465	0.0001	2557	definite (-)
UTR	10336580	y=2.86-7.05e-5x	.004	1.77	0.18	4160	none
UTR	10336610	y=19.4-8.00e-4x	0.03	299	0.0001	9526	definite (-)
UTR	103366092	y=4.20-2.21e-4x	.001	5.55	0.02	4140	definite (-)
Incline	10336700	y=51.7-3.44e-3x	0.01	90.5	0.0001	6839	definite (-)
Incline	103366993	y=8.04-2.93e-4x	.002	6.96	0.01	4171	definite (-)
Incline	103366995	y=18.0-1.08e-3x	.009	37.3	0.0001	4295	definite (-)
Third	10336698	y=128-7.75e-3x	0.04	376	0.0001	10469	definite (-)
Eagle Rock	103367592	y=5.23+7.96e-4x	0.11	469	0.0001	3970	definite (+)
Edgewood	10336760	y=5.34-3.61e-5x	.00002	0.49	0.49	3287	none
Edgewood	103367585	y=10.2-2.54e-4x	.001	5.96	0.01	4383	definite (-)
Glenbrook	10336730	y=8.07-5.27e-4x	0.11	769	.0001	6529	definite (-)
Logan House	10336740	y=4.28+1.75e-6x	5.70E-07	0.004	0.95	6575	none

By using a combination of statistical measures from Table 3-14, we can perhaps extract additional useful information from the analysis. Arbitrarily setting stricter limits on the Type III sum of squares measure (P-value) to 0.0001 and the ratio of explained to unexplained variance (F-value) to near 100, we can discriminate the following five sites as having significant temporal trends of sediment-transport rates:

(1) Upper Truckee River, 10336610 (decreasing);
(2) Incline Creek, 10336700 (decreasing);
(3) Third Creek, 10336698 (decreasing);
(4) Glenbrook Creek, 10336730 (decreasing); and
(5) Eagle Rock Creek, 103367592 (increasing).

The watersheds draining all of these stations have experienced some level of disturbance over the past 40 years and the data indicate that the first four are recovering due to a combination of natural adjustment processes and erosion-control measures. The same cannot be stated conclusively for Ward and Blackwood Creeks where sediment-transport rates remain high. There is no statistical evidence from either the annual or daily analyses that index stations from the three main western streams (Blackwood, Ward, and General Creeks) have increasing rates of sediment transport as reported by Rowe *et al*. (2002). However, negative slopes of the regression equations (indicating the rate of decreasing sediment transport) are greatest for Incline and Third Creeks reflecting more rapid attenuation of transport rates.

3.9.1 Temporal Trends in Fine-Grained Loadings

Statistical analysis identical to that performed for total annual and total mean-daily suspended-sediment loads were carried out for the available fine-loads data. As expected, the analysis of temporal trends in annual, median concentrations of fine-grained suspended sediment mirrors that of total, annual with the Upper Truckee River and Third and Glenbrook Creeks displaying a significant decreasing trend of concentrations (Table 3-15). Aside from the downstream-most station on Trout Creek (10336790) which represents a short period of record, and therefore, a questionable trend, the remaining sites show no discernable trend in annual concentrations. Although two of the western streams (Ward and General Creeks) have positive regression slopes, neither of these relations are significant.

Table 3-15. Summary of statistical analysis of temporal trends in fine-grained median, annual concentrations of suspended sediment (in g/m^3).

Stream	Station	Equation	r^2	F-value	P – value	n	Significance
Blackwood	10336660	y=105-0.04x	.0001	0.005	0.94	40	none
Ward	10336676	y=-770+0.40x	0.02	0.48	0.50	28	none
General	10336645	y=-164+0.09x	0.05	0.87	0.36	20	none
UTR	10336610	y=443-0.22x	0.22	5.53	0.03	22	definite (-)
Trout	10336790	y=-50.3+0.03x	0.71	7.43	0.07	5	some (+)
Trout	10336780	y=-22.3+0.02x	0.001	0.05	0.81	40	none
Third	10336698	y=3206-1.59x	0.24	7.58	0.01	26	definite (-)
Incline	10336700	y=1508-0.74x	0.07	1.04	0.33	17	none
Incline	103366995	y=280-0.13x	.009	0.07	0.79	10	none
Incline	103366993	y=-3553+1.8x	0.09	0.82	0.39	10	none
Edgewood	103367585	y=294-0.14x	0.02	0.20	0.67	11	none
Glenbrook	10336730	y=251-0.12x	0.19	3.23	0.09	16	some (-)
Logan House	10336740	y=-154+0.08x	0.03	0.43	0.52	17	none

If we retain the stricter statistical limits on the Type I sum of squares measure used previously (P-value) to 0.0001 and the ratio of explained to unexplained variance (F-value) to near 100, the following sites as having significant trends of fine-grained suspended-sediment transport rates (Table 3-16):

(1) Upper Truckee River, 10336610 (decreasing);
(2) All of the sites on Incline Creek, (decreasing);
(3) Third Creek, 10336698 (decreasing);
(4) Glenbrook Creek, 10336730 (decreasing); and
(5) Edgewood Creek, 103367592 (increasing).

There is again, no indication of increasing sediment-transport rates from the western quadrant streams.

Table 3-16. Summary of statistical analysis of temporal trends in fine-grained daily concentrations of suspended sediment (in g/m^3).

Stream	Station	Equation	r^2	F – value	P – value	n	Significance
Blackwood	10336660	y=11.6-1.30e-4x	.001	15.4	.0001	14975	definite (-)
Ward	10336676	y=9.07-3.09e-4x	.006	64.0	.0001	10592	definite (-)
General	10336645	y=3.26-3.24e-5x	.0003	14.6	.0001	7756	definite (-)
UTR	10336610	y=10.4-3.90e-4x	0.05	544	.0001	9526	definite (-)
Trout	10336790	y=6.10+5.69e-5x	.0026	465	.0099	2557	definite (+)
Trout	10336780	y=11.0+3.34e-5x	.0007	7.22	.007	14975	definite (+)

Third	10336698	y=127-7.68e-3x	0.03	369	.0001	10469	definite (-)
Incline	10336700	y=34.0-2.85e-3x	0.04	264	.0001	6839	definite (-)
Incline	103366995	y=13.4-1.66e-3x	0.17	893	.0001	4295	definite (-)
Incline	103366993	y=4.69-5.37e-4x	0.08	351	.0001	4171	definite (-)
Edgewood	103367585	y=8.47-8.48e-4x	0.07	346	.0001	4383	definite (-)
Glenbrook	10336730	y=42.3-9.01e-4x	.0003	2.14	0.14	6529	none
Logan House	10336740	y=4.28-8.15e-5x	.0048	30.9	.0001	6575	definite (-)

3.9.2 Shifts in Suspended-Sediment Transport Ratings

The third line of evidence used to interpret temporal trends in sediment delivery to Lake Tahoe is an analysis of shifts in the sediment-transport rating relations. Mean-daily or annual data are not required for this analysis, only a series of statistical tests to determine whether the relation between instantaneous discharge and instantaneous suspended-sediment concentration is changing with time. An example using data from Third Creek is shown in Figure 3-13.

Regression data from at least three periods for northern quadrant streams (Third, Incline, and Wood Creeks) are provided as an example of this technique. Table 3-17 shows both generally decreasing intercepts (load at 1 m^3/s) and exponents (rate of increase of load with increasing discharge) for the three streams. This is indicative of trends towards lower production of suspended-sediment and is supported by Type I and Type III sum of squares (SS) tests shown in Table 3-18. The Type I SS tests whether the slope of the rating is different than 0.0. The Type III SS tests whether the slopes or intercepts of the ratings are significantly different from one another. The decision matrix is shown in Table 3-18 for five stations on four northern streams with the conclusion that these streams are experiencing reductions in sediment loads across the range of discharges (Figures 3-13 and 3-14a). Particular attention is given to the northern quadrant because of published accounts of historically high suspended-sediment loads.

Results for Blackwood Creek (10336660), although statistically significant are extremely subtle in comparison to the northern quadrant (Figure 3-14b). The same can be said for the Upper Truckee River index station (10336610) where suspended-sediment loads over the range of discharges first increased during the 1983-1992 period but then decreased during the 1993-2002 period to values below the 1972-1982 period. Ward Creek, the other large sediment contributor also does not show conclusive evidence that loads are decreasing across the range of flows over the entire period, particularly at high discharges. Results for Blackwood and Ward Creeks, and the Upper Truckee River indicating lower suspended-sediment loads during the period 1993-2002 probably reflect the enormous flushing of stored sediment that took place during the January 1997 event.

Table 3-17. Comparison of suspended-sediment transport ratings for different periods for index stations on three north quadrant streams.

Stream	Period	Intercept	Exponent	n
Third	1965-1974	103	2.84	248
	1975-1984	18.3	2.02	74
	1985-1994	46.7	2.05	235

	1995-2002	6.3	2.10	267
Incline	1965-1974	85.9	2.51	229
	1975-1984	no data	no data	-
	1985-1994	18.4	2.12	224
	1995-2002	5.0	2.09	203
Wood	1969-1970	967	2.76	50
	1991-1996	69.5	1.96	54
	1997-2002	31.2	2.22	40

Table 3-18. Decision matrix using Type I and III sum of squares tests to determine if shifts in suspended-sediment transport ratings are statistically significant for four northern quadrant streams.

Stream	Station	Sum of Squares Test	Testing	F - value	P- value	Result	Conclusion
First	10336688	Type I	slope = 0	141	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	6.55	.0003	Slopes are not equal	Ratings are not = and not parallel
		Type III	Intercepts =	26.8	<.0001	Intercepts are not equal	Ratings shift (mix) First and Last Rating Shift (-)
Wood	10336692	Type I	slope = 0	189	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	5.65	0.0043	Slopes are not equal	Ratings are not = and/or not parallel
		Type III	Intercepts =	36.8	<.0001	Intercepts are not equal	Ratings shift (-)
Third	10336698	Type I	slope = 0	489	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	1.49	0.215	Slopes are equal	Ratings = and/or parallel
		Type III	Intercepts =	185	<.0001	Intercepts are not equal	Ratings shift (mix) First and Last Rating Shift (-)
Incline	10336700	Type I	slope = 0	514	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	4.61	0.0102	Slopes are not equal	Ratings are not = and/or not parallel
		Type III	Intercepts =	260	<.0001	Intercepts are not equal	Ratings shift (-)
Incline	103366995	Type I	slope = 0	298	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	1.72	.1816	Slopes are equal	Ratings = and/or parallel
		Type III	Intercepts =	53.5	<.0001	Intercepts are not equal	Ratings shift (mix) First and Last Rating Shift (-)

Convincing evidence of reductions in sediment-transport rates is also available from this analysis for the index station on Edgewood Creek (1093367585), showing parallel shifts to lower suspended-sediment loads significant at the 0.0001 level.

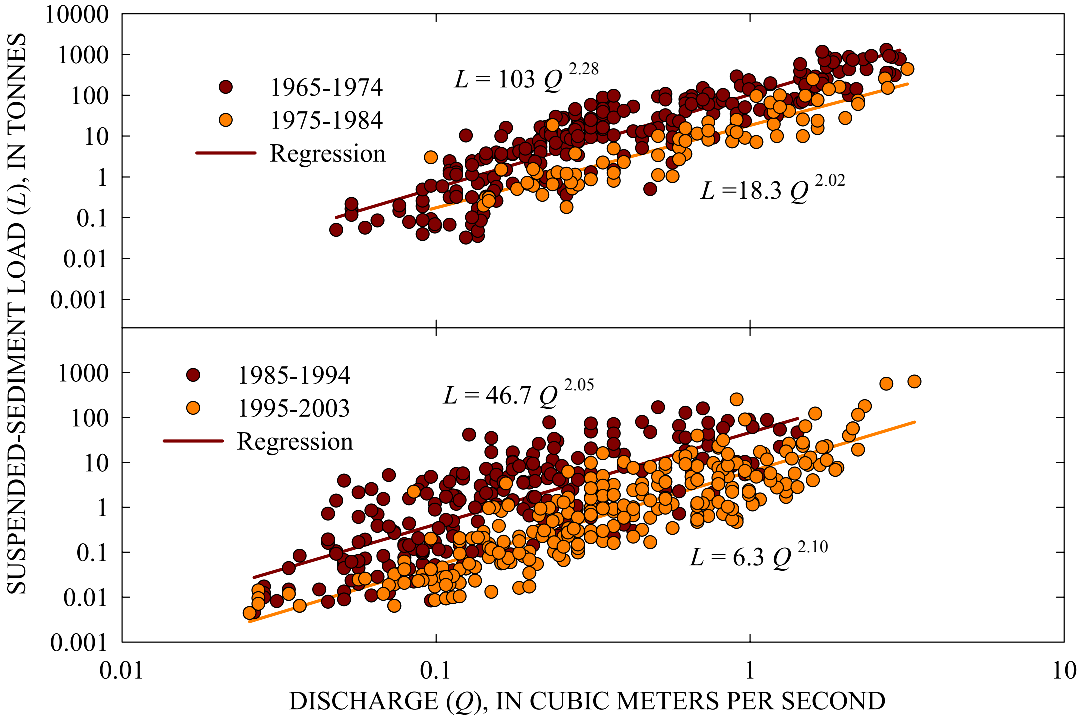
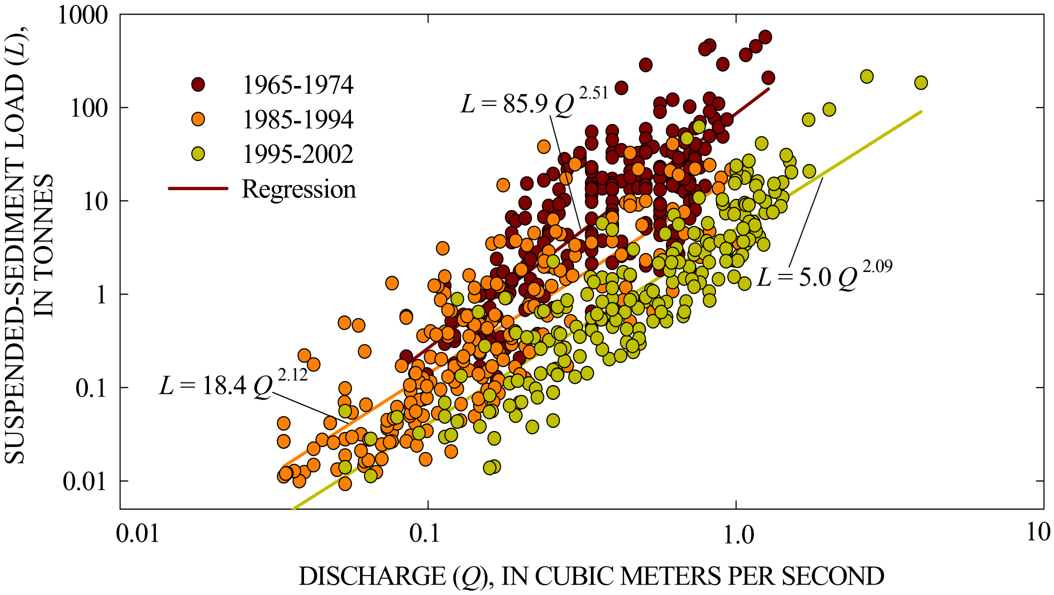


Figure 3-13. Shift in suspended-sediment transport ratings to lower loads at a given discharge across the range of discharges for the index station on Third Creek (10336698).



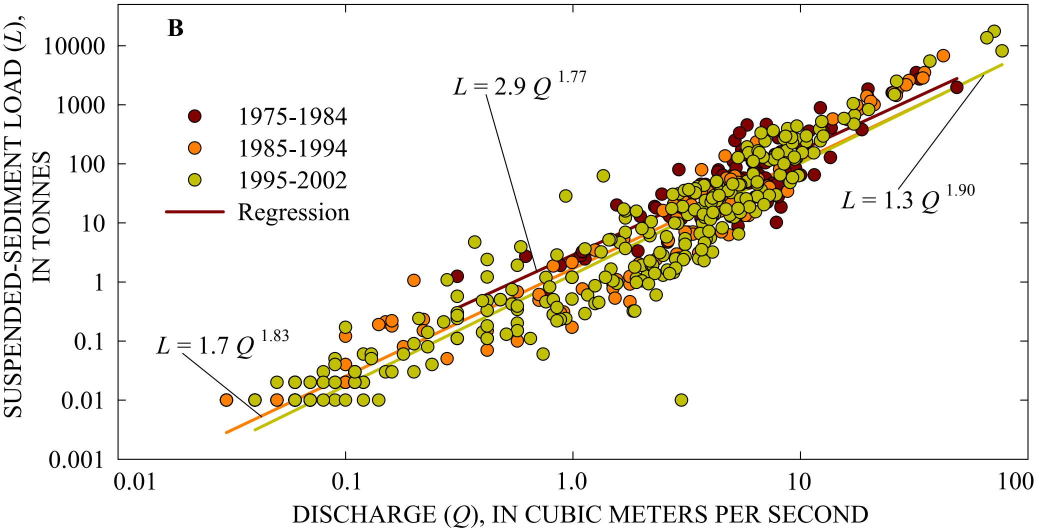


Figure 3-14. Shift in suspended-sediment transport ratings to lower loads at a given discharge across the range of discharges for the index station on Incline Creek (10336670) (A), and no discernable shift for index station on Blackwood Creek (10336660) (B).

3.10 Summary of Temporal Trends Analysis

Parallel lines of evidence have been provided that show significant reduction in sediment production and delivery from index stations draining developed watersheds in the north quadrant of the basin. Streams such as Third, Incline, and Wood Creeks produce much less suspended-sediment today than they did 30 to 40 years ago. In part this is probably due to natural adjustment processes that cause sediment-transport rates to reduce non-linearly with time following disturbance (Simon, 1992). Erosion control measures have probably also played an important role in these documented reductions in suspended-sediment transport rates. Evidence from other large sediment-producing watersheds such as the Upper Truckee River and Blackwood and Ward Creeks is mixed. Data for the Upper Truckee River does indicate that suspended-sediment transport to Lake Tahoe is decreasing based on annual trends of sediment load per unit of runoff (Tables 3-13 to 3-16). Sediment delivery from Blackwood and Ward Creeks has probably not changed significantly over the past 40 years, in contrast to the increases in loads reported by Rowe *et al*. (2002).

3.11 Relations Between Suspended Sediment Loads and Secchi Depth

The degrading clarity of Lake Tahoe's waters has been quantified through measurements of secchi depth (Figure 1.1) that have conclusively shown a reduction over the past 35 years. With fine-grained suspended-sediment transport loads being a primary suspect of this reduction in water clarity, an attempt was made to correlate fine-grained loadings with secchi depth.

Secchi-depth data were supplied from Reuter (2003, U. California at Davis, written commun.) for two locations in Lake Tahoe. The first disk was located near the shoreline, 0.3 km southeast of Tahoe Pines, California (close to the mouth of Ward Creek); the second disk was located mid-lake. Both monthly average and annual average secchi-depth data was provided. The duration of available data are summarized in Table 3-19.

Table 3-19. Duration of secchi-disk data.

Disk location name	Longitude	Latitude	Period of record	Duration (years)
LTP (Lake Tahoe Productivity)	39 05.630 N	120 09.000 W	Jul 1967 – Dec 2002	35.5
MLTP (Mid-Lake Tahoe Productivity)	39 09.220 N	120 02.120 W	Jul 1969 – Dec 2002	33.5

After initial data analysis with data from both disks, only the nearshore gage was used for correlation analysis. Regression analyses were carried out between both the actual secchi depth in meters, and the change in secchi depth from the previous record (as an overall decreasing trend in secchi depth was evident over the period of record), for various combinations of suspended-sediment load parameters:

(1) Annual and monthly data;
(2) Total load and fine load; and
(3) Loads for Ward Creek and the sum of loads for Ward Creek, Upper Truckee River and Blackwood Creek.

These streams were selected for inclusion in the analysis because they represent some of the largest sediment contributors to the lake (particularly fine-grained sediments) and with the exception of the Upper Truckee River, are in general proximity to the nearshore secchi disk.

Relations between annual load and secchi depth, and all monthly load and secchi depth did not exhibit strong correlations. However, when the suspended-sediment load data from the spring melt period were isolated, several of the relations with secchi depth were shown to be statistically significant at the 0.05 level.

3.11.1 Suspended-Sediment Loads During May and June

Non-organic material (suspended sediment, as opposed to algae) made up a greater proportion of suspended matter during the spring-melt months of April to July, particularly May and June when snowmelt is greatest (J. Reuter, 2003, U. California at Davis, per. commun.). Additional regression analyses were conducted, therefore, between secchi depth and total monthly loads for these months. Examination of the mean-monthly discharge statistics for major sediment-producing index stations indicated flows consistently peaked in the months of May and June for all gaging stations analyzed (Table 3-20). These months were, therefore, used for spring analysis.

Table 3-20. Average peak flows for May and June.

Stream	Station	Mean Discharge	
		May (m^3/s)	June (m^3/s)
Upper Truckee	10336610	8.69	7.30
Blackwood	10336660	3.62	2.86
Ward	10336676	2.60	2.12
Third	10336698	0.56	0.66
Trout	10336780	2.22	2.62
Incline	10336700	0.48	0.44

Although none of the r^2 values were extremely promising, the relation between secchi depth, or change in secchi depth produced several statistically significant relations (Table 3-21). Regression statistics were generally stronger for the change in secchi depth rather than the absolute magnitude of the depth. The number of pairs of data was 25 (degrees of freedom: 24). Using a 95% confidence level (single class), the critical F-value (ratio of explained to unexplained variance) is 4.26. As the calculated F-value is greater than this in all eight cases, all correlations are shown to be statistically significant. Example relations are plotted in Figure 3-15.

Table 3-21. Summary statistics for relations between two secchi-depth parameters and several sediment-load parameters using the sum of loads during May and June.

Parameter	Secchi depth			Change in secchi depth		
	r^2	F-value	p-value	r^2	F-value	p-value
Sum (Ward, Blackwood, UTR): Total Load	0.249	7.63	0.011	0.412	16.1	<0.001
Ward Creek: Total Load	0.185	5.24	0.032	0.340	11.8	0.002
Sum (Ward, Blackwood, UTR): Fine Load	0.236	7.43	0.012	0.408	16.5	<0.001
Ward Creek: Fine Load	0.266	8.71	0.007	0.390	15.4	<0.001

Table 3-22. Summary statistics for relations between two secchi-depth parameters and several sediment-load parameters using June data only.

Parameter	Secchi depth			Change in secchi depth		
	r^2	F-value	p-value	r^2	F-value	p-value
Sum (Ward, Blackwood, UTR): Total Load	0.424	16.9	<0.001	0.461	19.6	<0.001
Ward Creek: Total Load	0.357	15.0	<0.001	0.389	17.2	<0.001
Sum (Ward, Blackwood, UTR): Fine Load	0.365	15.5	<0.001	0.391	17.3	<0.001
Ward Creek: Fine Load	0.395	15.6	<0.001	0.507	24.7	<0.001

Regression statistics using the June-load regressions tend to be consistently higher than those using loads for May plus June load (Table 3.22). Perhaps this related to the observation that even though peak loads generally occur in May, it may take some time for the fine-grained sediments to make their way out into the lake, thereby affecting the disks offshore. Again using 95% confidence level (single class), for 24 degrees of freedom, the critical F-value is 4.26. With the calculated F-values for each June regression being greater than the critical value, in all eight cases there is no reason to reject that hypothesis that there is a significant relation between the pairs of variables shown in Table 3-22. Two examples of this are shown in Figure 3-16. It is also interesting to note that relations for fine sediment emanating from Ward Creek have among the strongest statistical significance of all those attempted owing to the creek's proximity to the nearshore disk.

3.11.2 Discussion

It appears that low and moderate flows do not have a strong influence on secchi depth/change in secchi depth, as there is consistently considerable scatter in values for these variables when suspended loads are low. However, large snowmelt discharges causing large suspended-sediment loads, subsequently have been observed to cause notable declines in secchi depth. Because of the great inherent complexities in delivery and mixing processes that are masked by these simple regression techniques, they are probably conceptually accurate but quantitatively, contain a reasonable degree of uncertainty. Still, the fact that the tested regressions are statistically significant beyond the 0.05 confidence level indicate that:

1. suspended-sediment loads, particularly those during the spring melt season can be used as an indicator of lake clarity, and
2. maintenance of the long-term monitoring station at the mouth of Ward Creek (10336676) that includes sampling for suspended-sediment and suspended particle-size distribution is justified as a basis of comparison with secchi depth data (Figures 3-15b and 3-16b).

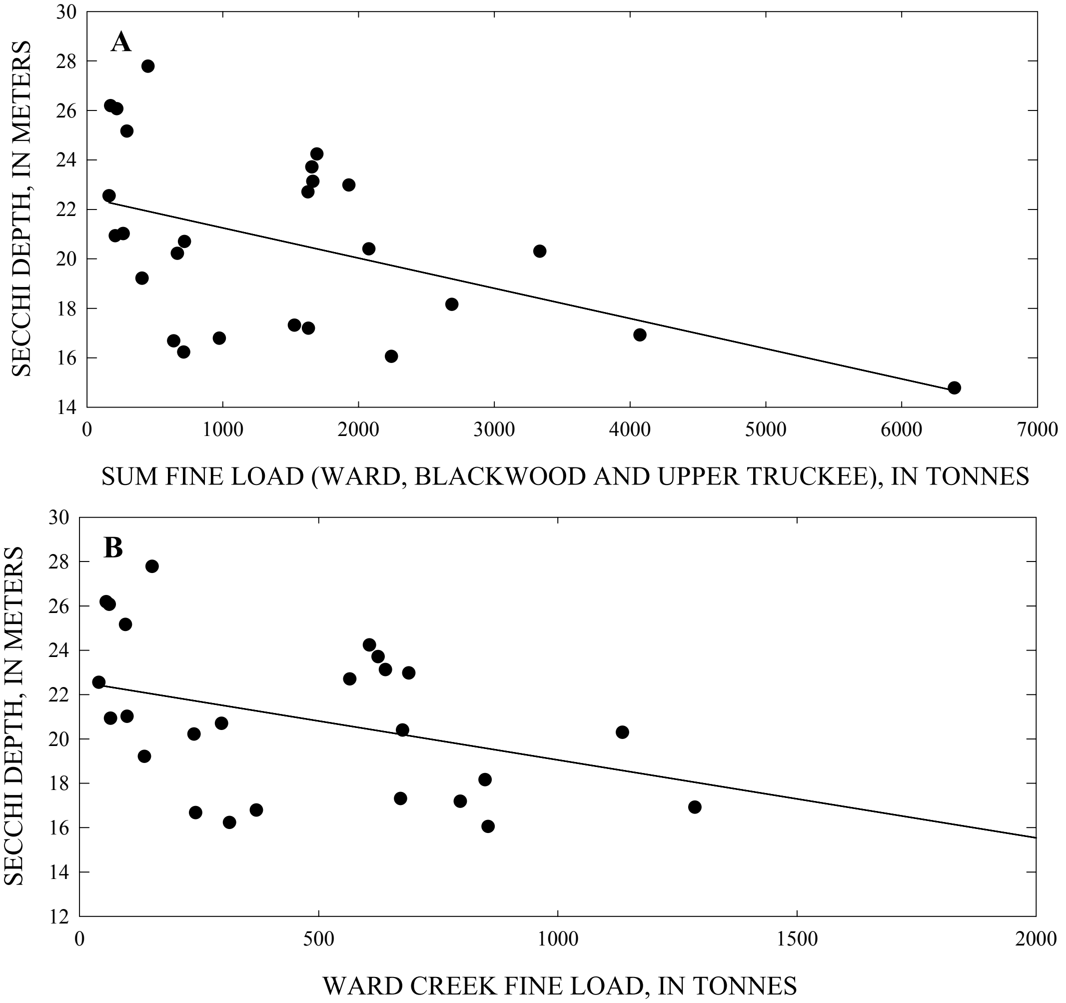


Figure 3-15. Linear regressions between fine suspended-sediment load and secchi depth for May and June using sum of the fine load for Ward Creek, Blackwood Creek and Upper Truckee River (A), and Ward Creek fine load only (B).

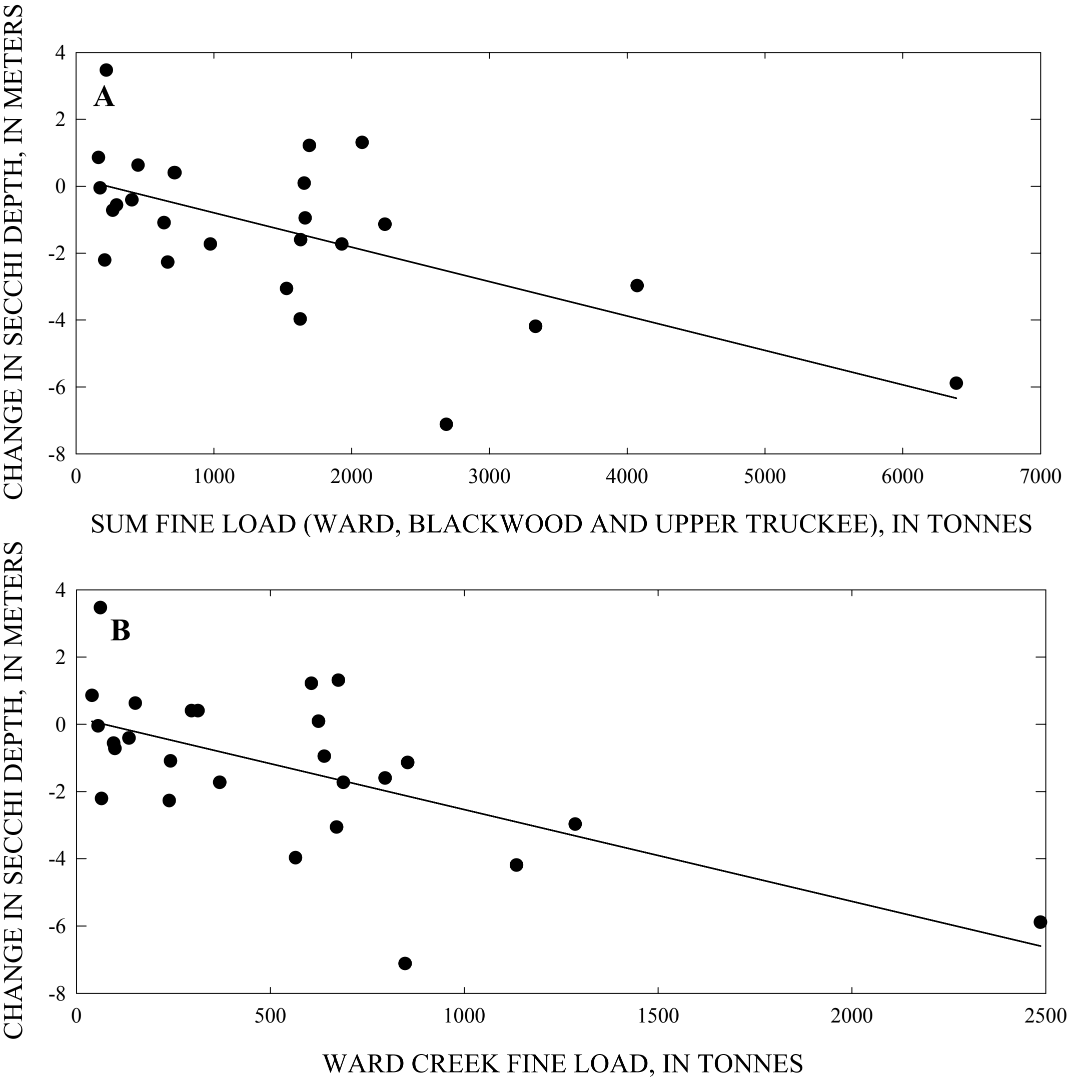


Figure 3-16. Linear regression between fine load and change in secchi depth for May and June using sum of the fine load for Ward Creek, Blackwood Creek and Upper Truckee River (A), and Ward Creek fine load only (B).

4 CHANNEL EROSION AND BASIN GEOMORPHOLOGY

4.1 Introduction

Erosion of materials from channel boundaries has been named as a leading contributor to water clarity problems in Lake Tahoe. Increased algal production in the lake has been linked to an increase in the delivery of nutrients from tributary streams (Goldman and Byron, 1986; Goldman, 1988) adsorbed onto fine-grained sediments (Leonard *et al*., 1979). Aside from anecdotal evidence and studies of short duration (Hill and Nolan, 1991 for example) little quantitative information is available on the magnitude of sediment contributions, particularly fine-grained materials, from channel boundaries. The Hill *et al*. (1990) and Nolan and Hill (1991) study on Blackwood, General, Logan House, and Edgewood Creeks stands as an exception, as does some of the recent work by Stubblefield (2002) on Ward and Blackwood Creeks. The current study owes a debt of gratitude to both Mike Nolan (U.S. Geological Survey; USGS) and Andrew Stubblefield (U. California at Davis) for their assistance in re-occupying monumented cross sections in the study watersheds, and to Cynthia Walck (California State Parks) for making past surveys on the Upper Truckee River available to the authors.

The magnitude and extent of channel erosion was determined using three methods:

(1) Direct comparison of monumented, historical cross-section surveys with surveys conducted in 2002 on Blackwood, Edgewood, General, and Logan House Creeks, and the Upper Truckee River (Figure 4-1);
(2) Identification of unstable reaches contributing fine-grained sediment via bank erosion during reconnaissance surveys (stream walks) of geomorphic conditions along Blackwood, Edgewood, Logan House, Incline, General, and Ward Creeks, and the Upper Truckee River (Figure 4-1); and
(3) Rapid geomorphic assessments (RGAs) at 304 locations across the Lake Tahoe Basin.

This chapter uses field observations and data to evaluate channel erosion while Chapter 5 uses numerical modeling techniques to address channel contributions.

4.2 Direct Comparison of Measured Cross Sections

One of the simplest but most powerful ways of calculating rates and volumes of channel erosion is by direct comparison of time-series cross-sections. To obtain a relatively good degree of accuracy it is critical to be able to locate the historical cross-section location in both the horizontal and vertical dimensions.

4.2.1 Availability of Data

Cross sections on Blackwood, General, Logan House, and Edgewood Creeks were monumented with metal fence posts and labeled with brass plates (Hill *et al*. 1990) by the U.S. Geological Survey in 1983 and 1984. Original survey notes were obtained from the USGS and new surveys were conducted at as many of these sites as could be located during the fall of 2002. Time-series cross sections of the Upper Truckee River were originally surveyed in 1992 and had been recently re-surveyed (2001 or 2002), thus providing a ten-year record of channel changes (C. Walck, 2003, written commun.). A summary of the historical cross-section data is provided in Table 4-1.

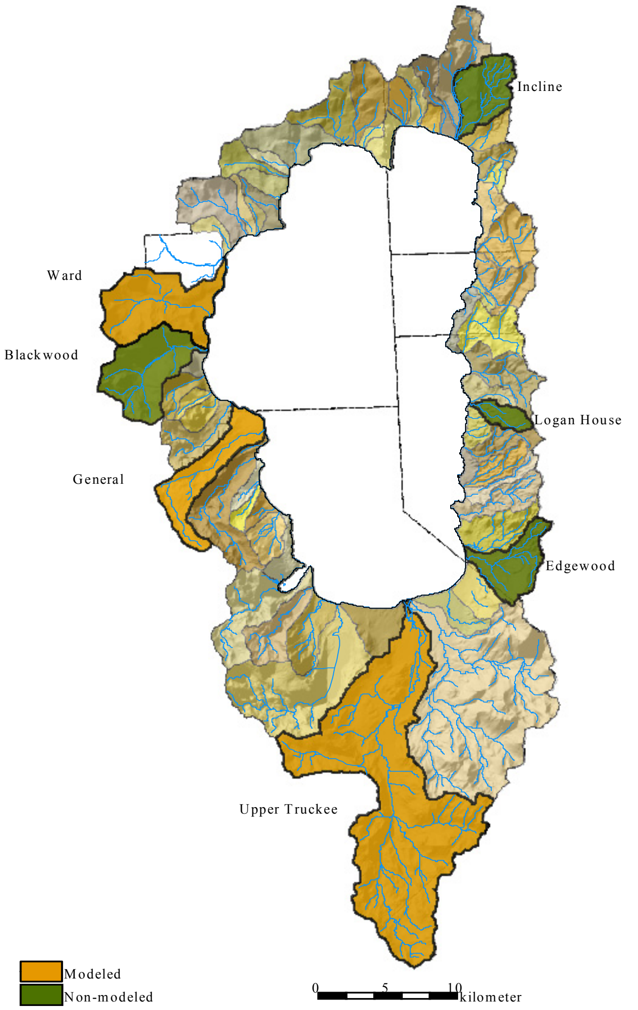


Figure 4-1. Denoted watersheds were the subject of detailed surveying and geomorphic assessments.

Table 4-1. Summary of historical cross-section data available for this study.

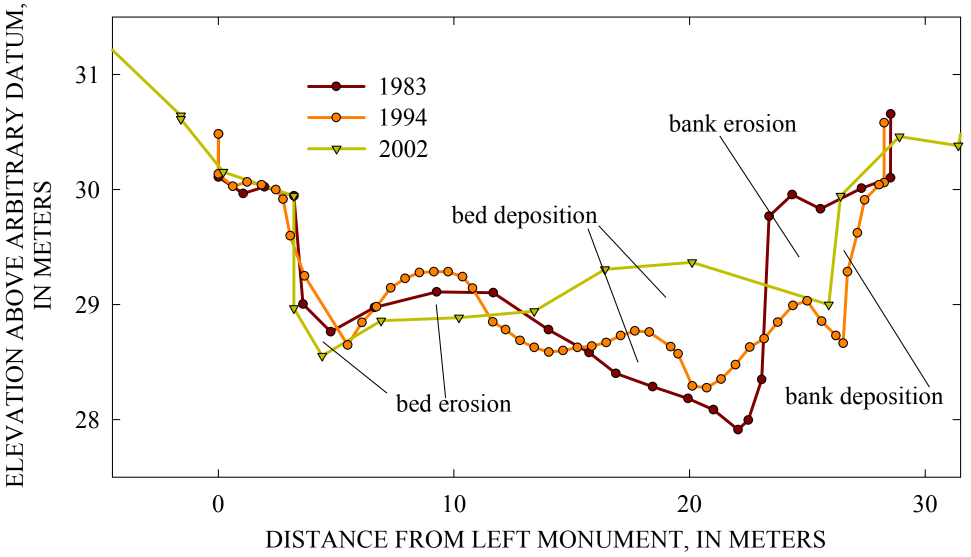
Stream	Date of first survey used	Number of sections matched	Total matched length (km)	Source of historical data
Blackwood	1983	17	8.3	USGS[1]
Edgewood	1983	23	5.6	USGS[1]
General	1983	12	8.5	USGS[1]
Logan House	1984	10	3.3	USGS[1]
Upper Truckee	1992	24	2.9	Calif. Parks[2]

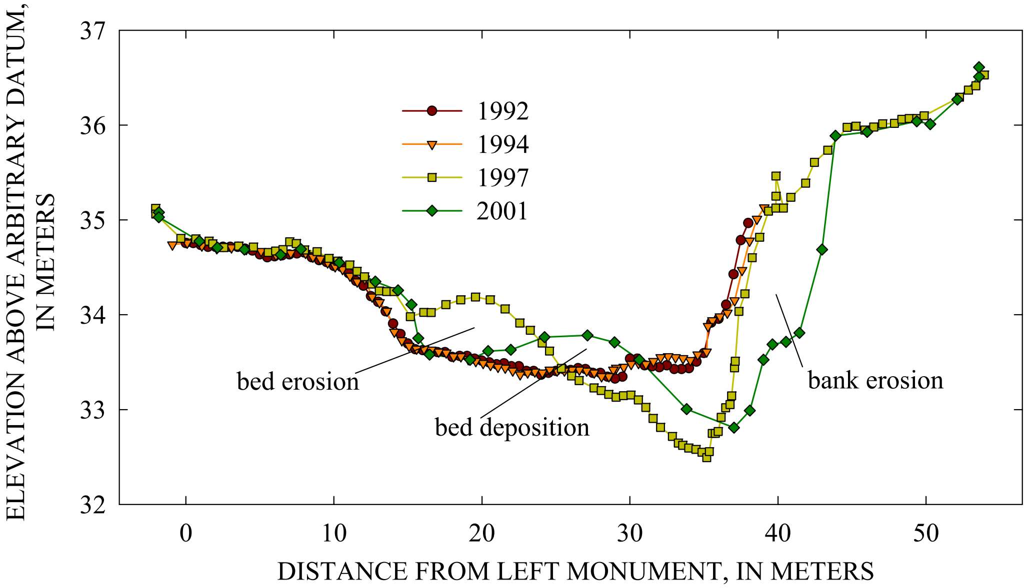
[1] Data from K.M. Nolan (2003 written commun.)

[2] Data from C.M. Walck (2003 written commun.).

4.2.2 Calculation of Volumes Eroded or Deposited

The change in cross-sectional area for a given time period was determined by overlaying time-series cross sections and calculating the area between the plotted lines. The location of the bank toe was determined for the original and 2002 surveyed sections and used to discriminate between erosion or deposition from the bed and banks. Examples are shown in Figure 4-2. Values between adjacent cross sections were averaged and then multiplied by the reach length to obtain a volume in m^3. Results are expressed as a rate (in m^3/y) and as a yield (in $m^3/y/km$ of channel length). The average percentage of fines determined from samples of bank material (Appendix B) was multiplied by the volume of material eroded from the channel banks to determine rates and yields of fine-grained materials delivered by streambank erosion. Because fines were not found in measurable quantities on streambeds, bed erosion was neglected as a contributor of fine sediments.





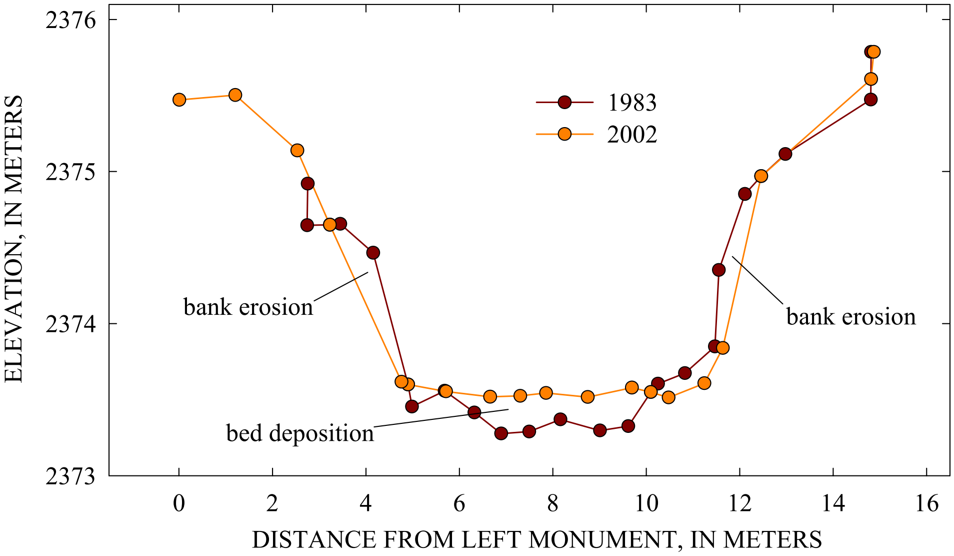


Figure 4-2. Examples of overlain surveys from Blackwood Creek, Upper Truckee River and General Creek.

4.3 <u>Reconnaissance Level Geomorphic Evaluations of Channel Erosion Areas</u>

4.3.1 Evaluation of Continuous Stream Lengths (Stream Walks)

To augment sediment load data and re-surveying of historical cross sections, the seven intensely studied streams were evaluated throughout their study lengths. From September through November 2002 seven stream channels (Figure 4-1) were assessed to provide direct field evidence of stream stability trends throughout each of the intensely studied watersheds. Streams included the Upper Truckee River, General Creek, Blackwood Creek, Ward Creek, Incline Creek, Logan House Creek, and Edgewood Creek.

Evaluations were carried out through stream walks of each main-stem channel. Typically the lower 80% of the main channel length was covered during each walk. At approximate 100 m intervals, notes and photographs were taken to document eroding reaches and assess their potential for supplying fine sediment. The levels of erosion are divided into four classes: none to negligible, low, moderate, and high. The classes were determined through an objective evaluation based on bank height, length of bank instability, vegetation root density, and relative amount of fine-grained materials. The eroding reaches for each stream were then tabulated and mapped to show bank erosion “hotspots” and overall geomorphic trends along the channel. These data were combined geomorphic data derived from rapid geomorphic assessments (RGAs) of point locations that were conducted not only along the seven intensely studied streams, but throughout the entire Lake Tahoe Basin as well. Since the purpose of these evaluations was to identify potential sources of eroding streambank materials, non-contributing streambanks were not specifically notated.

4.3.2 Rapid Geomorphic Assessments (RGAs)

To determine the relative stability and stage of channel evolution for all of the sites with available sediment data in the Lake Tahoe Basin, rapid geomorphic assessments (RGAs) were conducted. RGA techniques utilize diagnostic criteria of channel form to infer dominant channel processes and the magnitude of channel instabilities (Figure 4-5). They have been used successfully in a variety of physiographic environments to rapidly determine system-wide geomorphic conditions of large fluvial networks. Because they provide information on dominant channel processes rather than only channel form, they can be used to identify disturbances and critical areas of erosion and deposition. This is the justification for classifying streams by "stage of channel evolution" (Figure 4-5), which uses diagnostic characteristics of channel form to infer dominant channel processes that systematically vary over time and space. Of specific interest to practitioners in the Lake Tahoe Basin are stages IV and V, which represent channel instabilities marked by mass failures of streambanks.

In some classification schemes the "reference" condition simply means "representative" of a given category of classified channel forms or morphologies (Rosgen, 1985) and as such, may not be analogous with a "stable", "undisturbed", or "background" rate of sediment production and transport. With stages of channel evolution tied to discrete channel processes and not strictly to specific channel shapes, they have been successfully used to describe systematic channel-stability processes over time and space in diverse environments subject to various disturbances such as stream response to: channelization in the Southeast US Coastal Plain (Simon, 1994); volcanic eruptions in the Cascade Mountains (Simon, 1992); and dams in Tuscany, Italy (Rinaldi and Simon, 1998). Because the stages of channel evolution represent shifts in dominant channel processes, they are systematically related to suspended-sediment and bed-material discharge (Simon, 1989b; Kuhnle and Simon, 2000), rates of channel widening (Simon and Hupp, 1992), and the density and distribution of woody-riparian vegetation (Hupp, 1992).

Conditions along a reach of an alluvial channel reflect upland processes as well as channel-adjustment processes upstream and downstream. Stream channels act as conduits for energy, flow, and materials emanating from upland and upstream channel sources. As such, they reflect a balance or imbalance in the delivery of flow and sediment. Considering the large area of the Lake Tahoe Basin, it was not feasible to perform detailed, time-consuming surveys at every site. However, RGA's provide an efficient alternative for determining stability conditions and dominant processes delivering sediment along channel networks.

The RGA procedure for sites in the Lake Tahoe basin consisted of three steps, which collectively took about one hour to complete over a reach of about 6 – 20 channel widths in length:

(1) Take photographs looking upstream, downstream and across the reach;
(2) Take samples of bed and bank material. This could be a bulk sample, a particle count if the bed is dominated by gravel and coarser fractions, or a combination of the two;
(3) Make observations of channel conditions and diagnostic criteria listed on the combined stability ranking scheme.

RGAs were conducted at 304 sites across the Lake Tahoe watershed in the three-month period between September and November 2002 (Figure 4-3). RGA data collected at these locations are included in Appendix F. Particle-size data for these sites are in Appendix B.

4.4 Combined Stability Index

A simple field form containing twelve criteria was used to record observations of field conditions in an objective manner (Figure 4-4). The field form was modified somewhat from those that have been used elsewhere to include the important characteristics of potential side-slope erosion in the sub-alpine watersheds. Thus, the original channel-stability index includes the first nine questions on the field for, with potential sediment contributions from adjacent side slopes included with questions 10 – 12. Each criterion is ranked, and all values are then summed to obtain an index of channel and near-channel stability. A higher ranking indicates greater instability. The rankings, however, are not weighted and for example, a ranking of twenty does not mean that the site is twice as unstable as a site with a value of ten. Experience has shown that values of twenty or greater are indicative of significant instability; values of ten or below are indicative of relative stability.

To differentiate between potential contributions from channels and adjacent slopes, results are shown as a combined index, a channel index, and potential side-slope erosion. These are plotted on individual maps for the seven intensely studied watersheds and on Lake Tahoe Basin maps for sites in the remaining watersheds. The index of side-slope erosion potential is not meant as a measure of general upland contributions from the entire watershed, only those direct contributions from slopes adjacent to channels. In addition, sites where channel processes are dominated by streambank erosion and channel widening (stages IV or V; Figure 4-5) and the percentage of all banks in a reach that are contributing sediment are also mapped.

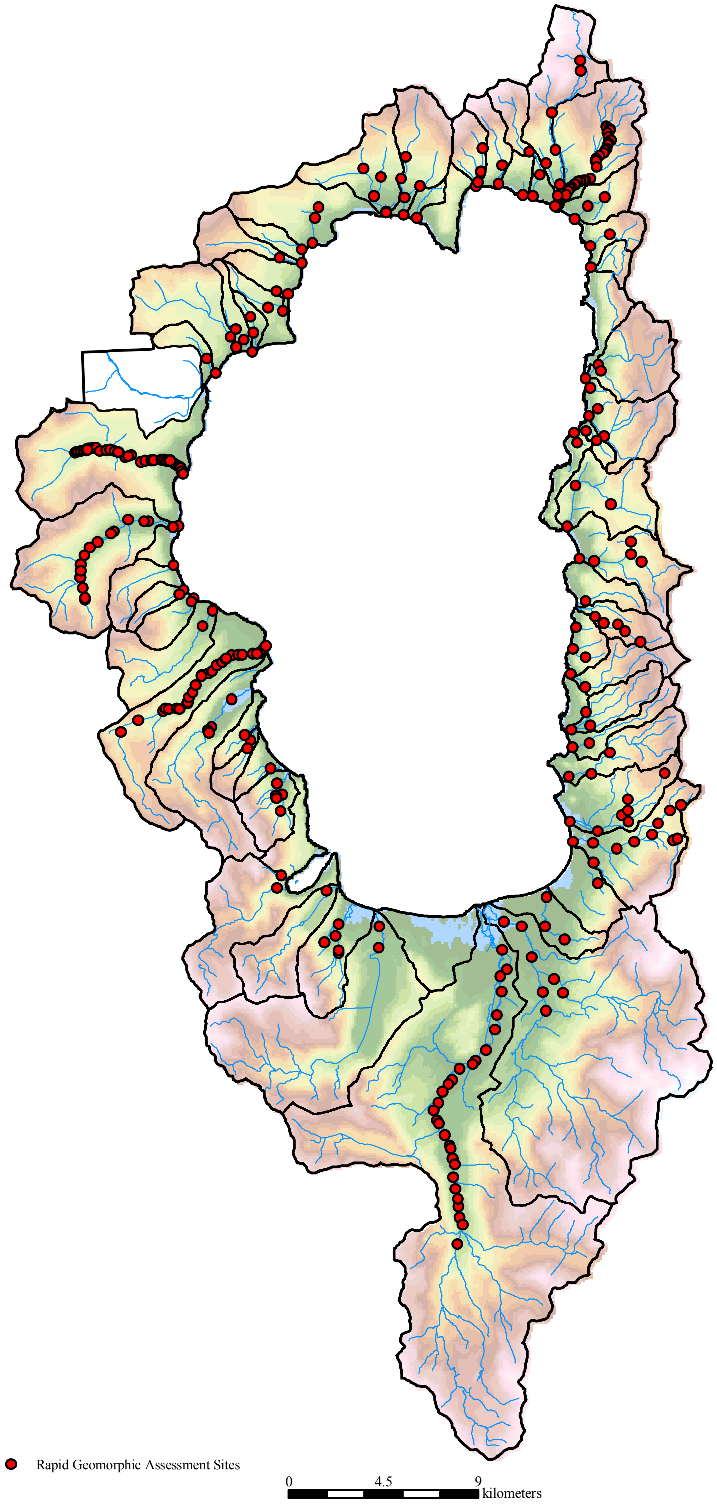


Figure 4-3. Map showing locations of the 304 rapid geomorphic assessments (RGAs) conducted in the Lake Tahoe Basin between September and November, 2002.

COMBINED-STABILITY RANKING SCHEME

Station #__________________ **Station Description**__________________________________

Date _____________ **Crew** _______________ **Samples Taken**________________________

Pictures (circle) U/S D/S X-section **Slope**__________ **Pattern:** Meandering
Straight
Braided

1. Primary bed material

Bedrock	Boulder/Cobble	Gravel	Sand	Silt Clay	
0	1	2	3	4	____

2. Bed/bank protection

Yes	No	(with)	1 bank protected	2 banks	
0	1		2	3	____

3. Degree of incision (Relative ele. Of "normal" low water; floodplain/terrace @ 100%)

0-10%	11-25%	26-50%	51-75%	76-100%	
4	3	2	1	0	____

4. Degree of constriction (Relative decrease in top-bank width from up to downstream)

0-10%	11-25%	26-50%	51-75%	76-100%	
0	1	2	3	4	____

5. Streambank erosion (Each bank)

	None	fluvial	mass wasting (failures)	
Left	0	1	2	____
Right	0	1	2	____

6. Streambank instability (Percent of each bank failing)

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	0	0.5	1	1.5	2	____
Right	0	0.5	1	1.5	2	____

7. Established ripirian woody-vegetative cover (Each bank)

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	2	1.5	1	0.5	0	____
Right	2	1.5	1	0.5	0	____

8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	2	1.5	1	0.5	0	____
Right	2	1.5	1	0.5	0	____

9. Stage of channel evolution

I	II	III	IV	V	VI	
0	1	2	4	3	1.5	____

10. Condition of adjacent side slope (circle)

N/A	Bedrock	Boulders	Gravel-SP	Fines	
0	1	2	3	4	____

11. Percent of slope (length) contributing sediment

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	0	0.5	1	1.5	2	____
Right	0	0.5	1	1.5	2	____

12. Severity of side-slope erosion

None	Low	Moderate	High	
0	0.5	1.5	2	____

TOTAL ____

Figure 4-4. Combined-stability index field form and ranking scheme.

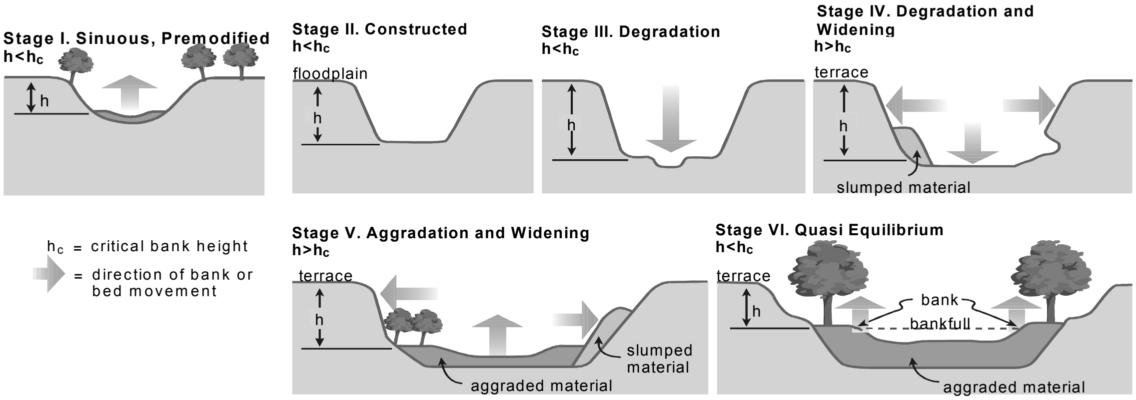


Figure 4-5. Six stages of channel evolution from Simon and Hupp (1986) and Simon (1989) identifying Stages IV and V as those dominated by bank widening.

4.5 Channel Changes With Time: Rates and Volumes of Streambank Erosion

Rates of bank erosion in the five streams ranged from net deposition of 51 m^3/y along Edgewood Creek to about 1860 m^3/y along the Washoe Meadows reach (by the golf course) of the Upper Truckee River (Table 4-2). Four of the five streams surveyed are net sinks for sediment with Edgewood and Logan House Creeks also showing net deposition on the channel banks. All of the streams with the exception of the Upper Truckee River are aggradational. Because different lengths of channel and time were considered in this analysis, data expressed in m^3/y/km are used to make comparisons between streams. Thus, Blackwood Creek provides roughly 14 times the amount of streambank sediment on an annual basis than General Creek; about 700% more fines per unit length of channel even though streambanks of General Creek contain, on average, more fine-grained material than do streambanks along Blackwood Creek (Table 4-2). This is significant because it quantifies the effects of disturbance on the magnitude of streambank erosion rates on the wetter, western side of the Lake Tahoe watershed.

The combination of net deposition on the channel bed (negative values in Table 4-2) and net erosion from the banks is not uncommon. Material deposited on the channel bed is predominantly coarse grained. Of particular interest is the net amount and rate of fines eroded from the channel banks on an annual basis. Since virtually no fine-grained materials are found on streambeds, is can be safely assumed that the bulk of this eroded material is transported to the lake.

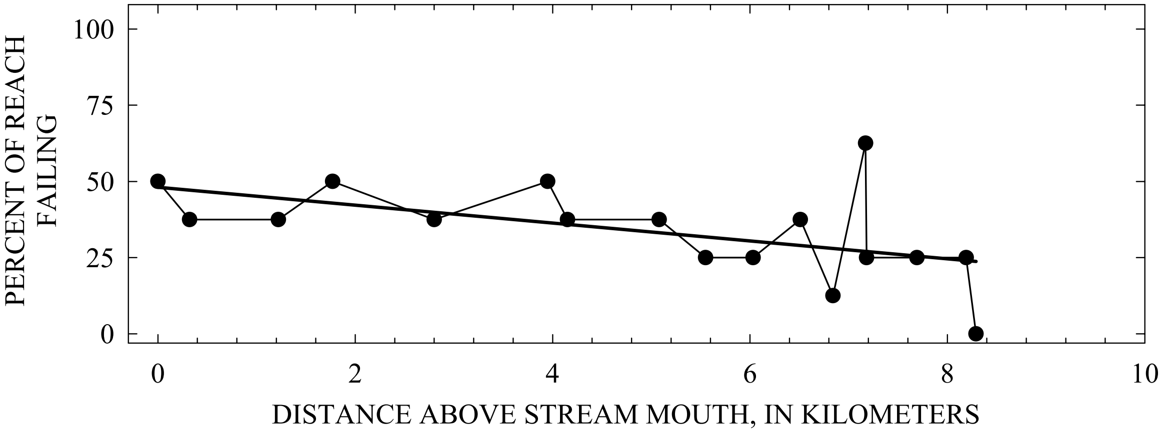
Geomorphic assessments of 17 reaches over the lower 8.2 km of Blackwood Creek show that:

(1) except for the upstream-most site which is upstream of a headcut, 25-50% of the longitudinal extent of all assessed banks were unstable;
(2) there is a general trend of decreasing bank instability with distance upstream (Figure 4-6); and
(3) a knickpoint at about km 8.1 marks the headward advance of an instability moving through the Blackwood Creek network.

Points 2 and 3 above are typical of streams responding to disturbance. Combined, all of the evidence from Blackwood Creek, including the exceptionally high suspended-sediment yields suggests that the consistently high sediment loadings are the result of not only the gravel mining operations downstream but also land surface disturbance over 100 years ago. We speculate that alluvial valley fills dating from the period of intense logging operations provides the source of much of the sediment eroding from channel banks along Blackwood Creek.
Compare Figure (4-6) for Blackwood Creek, with RGA results from Logan House Creek, where extremely low sediment yields and net bank deposition have been calculated from past and present surveys (Figure 4-6), and the importance of streambank erosion in delivering suspended sediment can be appreciated.

Table 4-2. Results of analysis of historical and contemporary channel cross-section surveys for the five streams with historical data. Positive values denote erosion; negative values denote deposition.

Stream	**Total (m^3/y)**	**Bank (m^3/y)**	**Bed (m^3/y)**	**Silt-clay in banks (%)**	**Bank erosion rate ($m^3/y/km$)**	**Bank erosion of fines (m^3/y)**	**Bank erosion of fines ($m^3/y/km$)**
Blackwood	-413	1800	-2220	6	217	101	12.2
Edgewood	-78	-51	-28	2	-	-	-
General	-237	125	-362	10	14.6	13.0	1.5
Logan House	-21	-8	-13	-	-	-	-
Upper Truckee	2340	1860	476	14	645	261	90.3



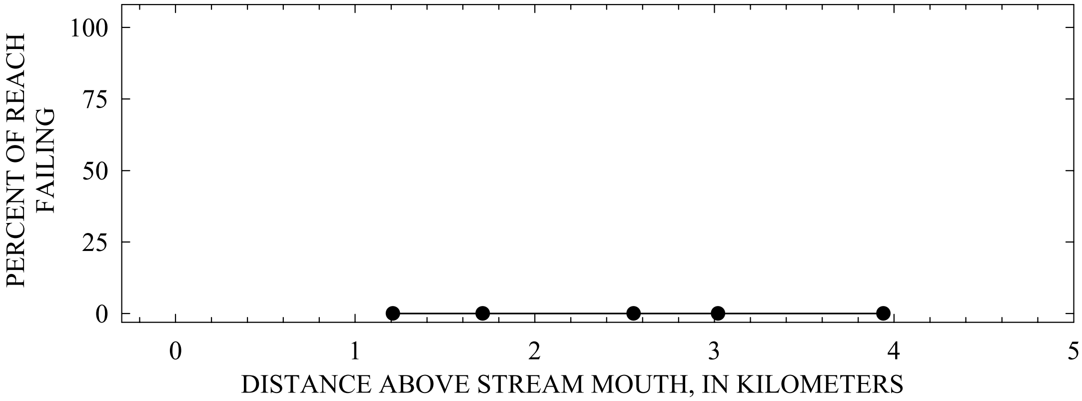


Figure 4-6. Percentage of left and right banks that are unstable along Blackwood Creek (upper) and along Logan House Creek (zero) (lower).

4.5.1 Upper Truckee River

Comparison of time-series cross sections indicates that the Upper Truckee River delivers about three times the amount of streambank sediment per river kilometer than Blackwood Creek. However, because streambanks along the Upper Truckee River tend to be more fine-grained (14%) then along Blackwood Creek (6%), the Upper Truckee produces 640% more fine-grained bank material (90 m^3/y/km) than Blackwood Creek (12.2 m^3/y/km) over the measured reaches. Although the matched cross sections on the Upper Truckee River represent only 2.9 km of a total study length of about 24 km, RGAs conducted along the entire 24 km length indicate that bank erosion is prevalent in all of the non-boulder reaches.

In the sinuous reaches of Washoe Meadows and further downstream, the outsides of meander bends are particularly active. This is evident from RGA data on the percent of each reach having failing banks (Figure 4-7). Here, the recurrence of 50% values reflect a geotechnically stable inside bend and an outside bend that is unstable along its entire length. Values of 0% failing reflect boulder reaches and other protected areas. Bank-erosion rates compared between 1992-1994 and 1997-2002 have increased 2 to 3 times, most likely a function of toe scour and lateral retreat of bank toes during the large January 1997 flow event. In fact, the 1997 surveys in the reach post-date the rain on snow event indicating that hydraulically-induced channel changes during the event resulted in geotechnical instabilities that have affected channel processes for at least the next five years. To place these results in a historical perspective, analysis of the lateral migration of this reach of river was conducted.

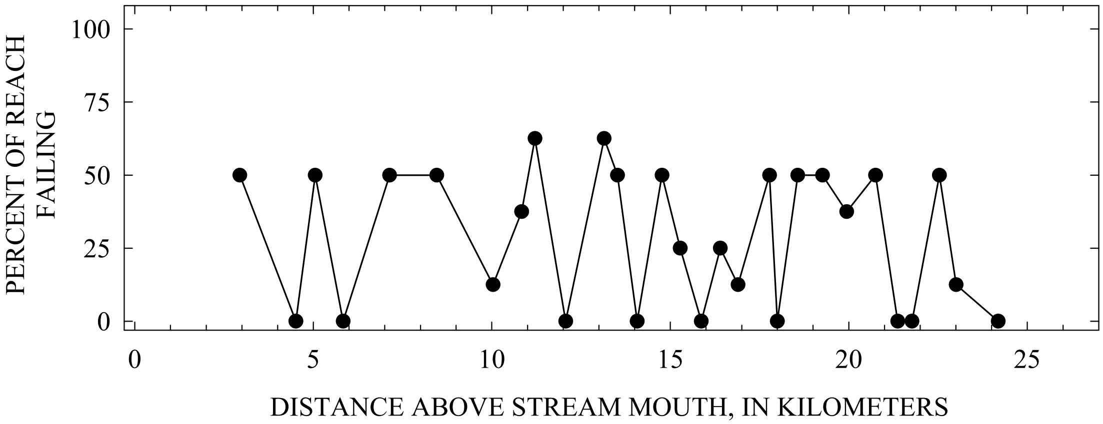


Figure 4.7. Percentage of left and right banks failing along the Upper Truckee River.

4.5.2 Data for Analysis of Channel Migration (1940-1994)

Channel centerlines of the Upper Truckee River were obtained from four sets of aerial photographs supplied by California State Parks: 1941, 1952, 1971 and 1994 in ArcView shapefile format (C. Walck, 2003, written commun.). Because the centerlines had different starting and ending points, upstream and downstream boundaries were established for the reach that was included in the four shapefiles. River centerlines were then cut at these points, isolating the common reach. The study reach extended from 1.7 km downstream of the first Highway 50 bridge (upstream boundary) to the second Highway 50 bridge (downstream boundary). This reach length following the valley profile was 3.07 km (the direct “as the crow flies” distance was 2.31 km). The downstream 73% of the reach runs through the Lake Tahoe Golf Course. Figure 4-8 illustrates the four channel centerlines.

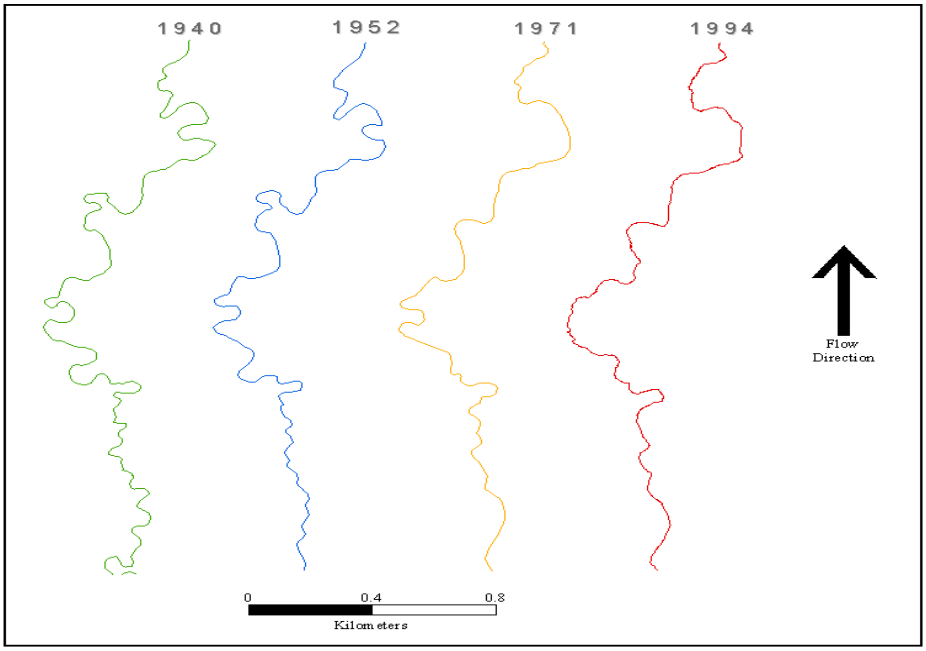


Figure 4-8. Successive centerlines of the Upper Truckee River, 1941 – 1994.

4.5.3 Analysis of Channel Lengths and Channel Activity

The lengths of the four cut-line coverages were calculated using ArcView. More detailed analysis was also performed for the section of the channel adjacent to the golf course and the remaining section upstream.

Channel activity is defined by Shields *et al.* (2000) as: *"the mean rate of lateral migration along a river reach in dimensions of length, per unit time" (pg. 58)*. Calculation of channel activity over various time periods enabled the historical stability of the Upper Truckee River to be quantified. The active area of the channel was computed for each temporally adjacent pair of channel centerlines. An ArcView extension was downloaded to converted polylines to polygons. This was utilized to create a polygon enclosing the area of channel between each pair of centerlines which had been worked; the three polygons are detailed in Table 4-3. The area of these polygons was divided by both the length of the valley length and the earlier centerline used to produce them. These values were subsequently divided by the period between the start and end points giving the channel-activity value. Figure 4-9 contains a map of the polygons generated by this centerline analysis, both individually and all superimposed onto a 1998 aerial photograph. Channel-activity values were also calculated for the golf course reach and remaining reach upstream of the golf course. The colored polygons shown in Figure 4-9 provide a concise picture of rates and magnitudes of lateral migration and instability over the subject reach.

Table 4-3. Time periods of polygons used in Upper Truckee River area analysis.

Polygon number	Start date	End date	Duration (y)
1	1940	1952	12
2	1952	1971	19
3	1971	1994	23

Sinuosity decreased initially during the record period, but has risen slightly in the 1971 to 1994 period. Over the 53-year period, the length of the Upper Truckee River in this reach has decreased 26%. The channel length and ratio of channel length to valley length (sinuosity) for each of the four periods are summarized in Table 4-4 and illustrated in Figure 4-10.

Table 4-4. Upper Truckee River channel-lengths.

Year	Length (m)	Channel length / valley length
1940	4720	1.54
1952	3950	1.29
1971	3370	1.10
1994	3500	1.14
Valley distance	3070	-

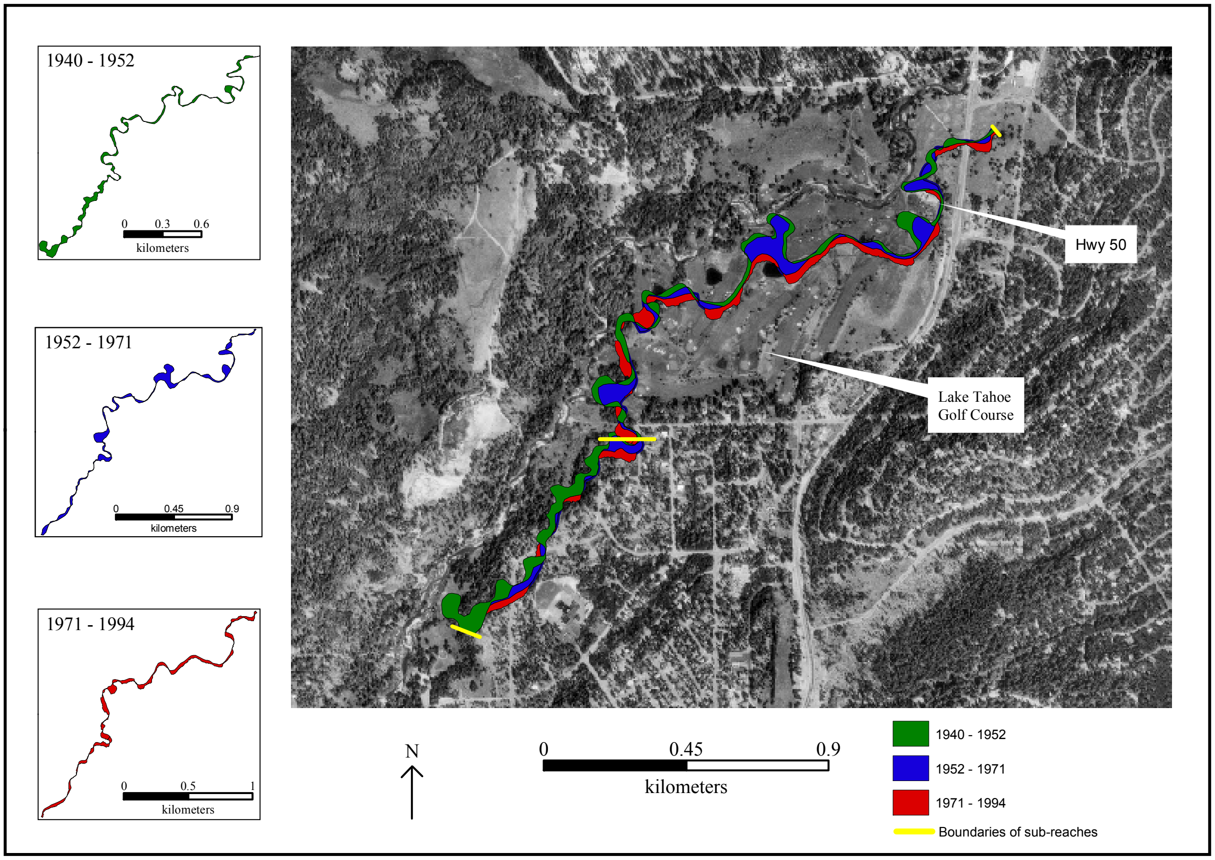


Figure 4-9. Channel activity for time periods along a reach of the Upper Truckee River.

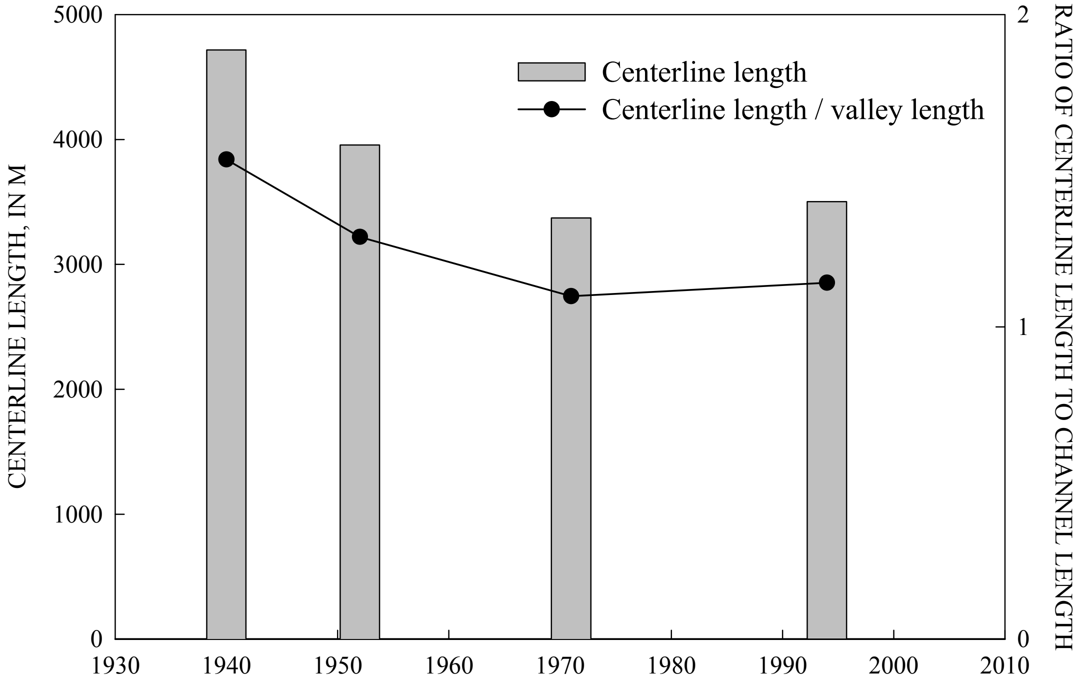


Figure 4-10. Upper Truckee River channel length results, 1941 – 1994.

The active area of this section of the Upper Truckee River has decreased since the years 1940 to 1952, to present (Table 4-5; Figure 4-11). This can be attributed in part to the construction of cutoffs by local landowners and channel incision related to these and other cutoffs constructed near the airport. Although this reach of the Upper Truckee River had a more stable planform between 1971 and 1994 then it did previously, it is currently still quite active. If we assume that this reach is representative of adjacent alluvial reaches, particularly those downstream from the golf course, these data also support the contention that fine-grained suspended-sediment loads emanating from streambanks of the Upper Truckee are high, but decreasing with time. A regression of annual, fine-grained concentrations with time for the index station on the Upper Truckee River (10336610) was found significant at the 0.03 level over the past 22 years.

Table 4-5. Upper Truckee River active-area analysis.

Period	**Interval (years)**	**Worked area (m^2)**	**Worked area per valley length per time interval (m^2/km/y)**	**Worked area per centerline length per time interval (m^2/km/y)**
1940-52	12	60857	1.65	1.08
1952-71	19	54796	0.94	0.73
1971-94	23	51266	0.73	0.66

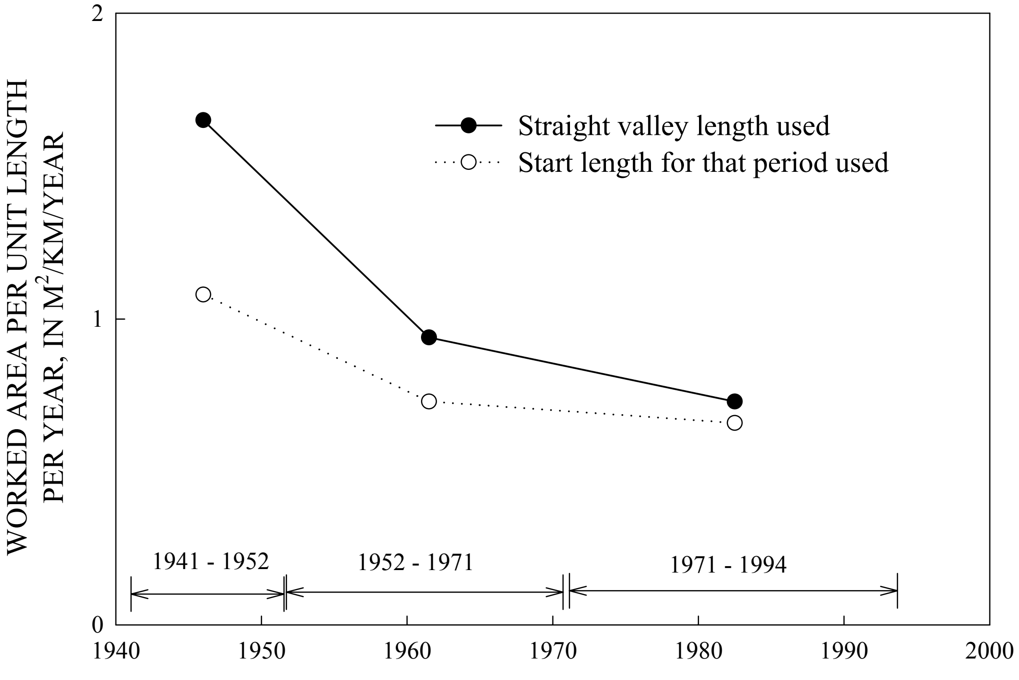


Figure 4-11. Upper Truckee River channel-activity results, 1941 – 1994.

4.5.4 Sub-Reach Channel Activity Results

Comparison of reaches adjacent to and upstream of the golf course also show decreasing channel activity with time. Figures 4-12 and 4-13, and Table 4-6 summarize results of analysis of the golf course reach and remaining upstream. High values for the reach upstream of the golf course for the 1940-1952 period are probably a function of the construction of channel cutoffs.

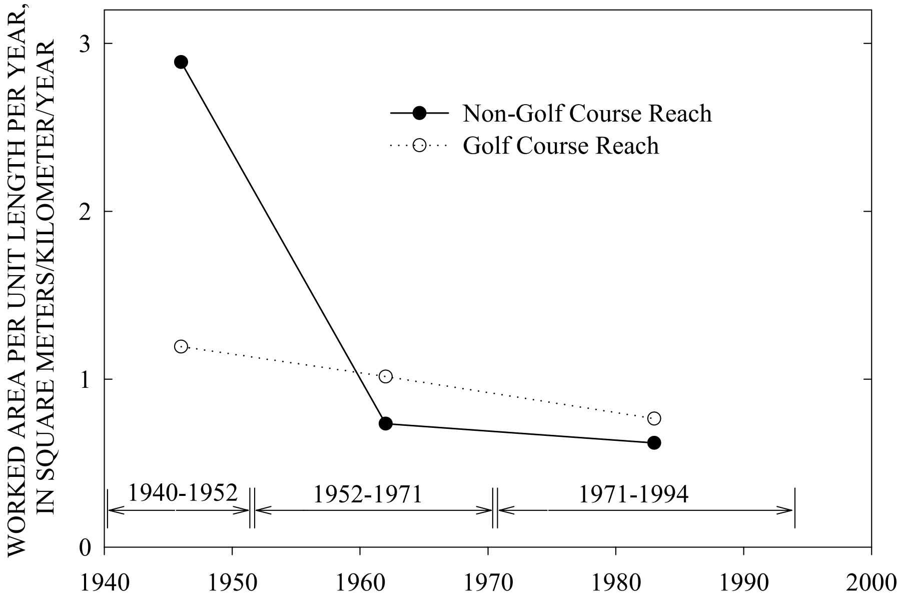


Figure 4-12. Channel activity by sub-reach using valley length.

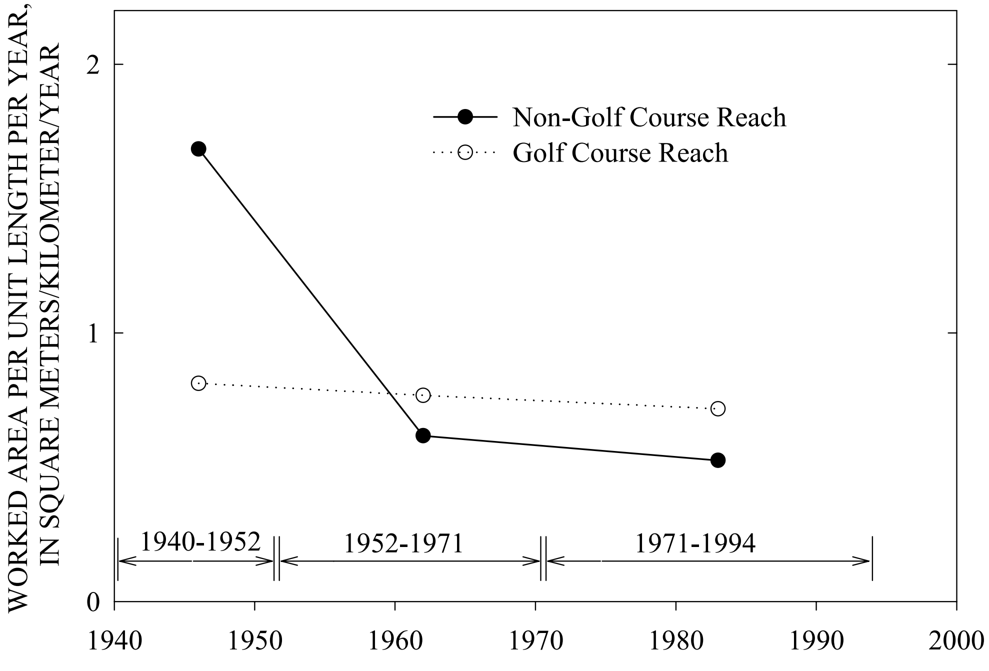


Figure 4-13. Channel activity for golf course and upstream sub-reaches, using

centerline start length.

Table 4-6. Channel activity in sub-reaches of the Upper Truckee River.

Period	**Reach**	**Worked area (m^2)**	**Worked area/valley length per time interval (m^2/km/y)**	**Worked area per (start) length per time Interval (m^2/y/km)**
1940-52	Upstream of Golf Course	28700	2.89	1.68
1952-71	Upstream of Golf Course	11600	0.735	0.617
1971-94	Upstream of Golf Course	11800	0.620	0.525
1940-52	Golf Course	32100	1.19	0.812
1952-71	Golf Course	43220	1.02	0.767
1971-94	Golf Course	39400	0.765	0.717

The first period of the reach upstream of the golf course possessed the largest active area value. The active area of the golf course reach is also comparatively high during this period. Between 1952 and 1971, and 1971 and 1994, the reach upstream of the golf course showed slightly lower activity values than the reach in the golf course. This may be attributable to the construction of a sheet-pile grade control structure in the upstream reach, which serves to arrest further channel incision. Still, activity rates for both reaches show a decline over the 53-year time period, further supporting the view that sediment loads from the Upper Truckee River are decreasing. From these data it is not possible to differentiate between reductions due to natural adjustment processes and those due to restoration efforts.

4.6 Ground Reconnaissance: Results of RGAs and Stream Walks

4.6.1 Upper Truckee River

The assessed portion of the Upper Truckee River spans 21 km from the Highway 50 bridge above Truckee Marsh to the USGS stream gage located 0.1 km below the Alpine Campground (10336580) (Figure 4-14). The length of assessed channel has been divided into six major reaches: the lower meadow, airport channelization, upper meadow, golf course, meandering gravel pool-riffle, and alternating moraine/meadow.

The lower meadow is a 2.5 km meandering reach. Streambanks are typically 1.5 m-high and composed of silt and fine sand. The stream meanders near the east valley wall thereby creating occasional escarpments. The escarpments contain a mix of materials including cohesive clays, cemented sands, and loose sand and gravel. Vegetation consists of grasses and alder on the flat meadow banks and sagebrush and pine on the escarpment banks. The overall bank erosion potential for the reach is rated high with sloughing banks considered to be the dominant fine sediment source.

In 1968 the Upper Truckee River was realigned to make way for modifications to the airport runway (Resources Agency, 1969). The present channel form is a 1.2 km reach with 20 cm diameter rip-rap lining the banks. Alders, grass, and small pines cover the banks. The erosion potential of the banks is negligible. The reach falls between hotspots 17 and 18 (Table 4-7).

Table 4-7. Summary of reconnaissance-level evaluation of areas of streambank instability and delivery of fine-grained sediments along the Upper Truckee River.

Erosion hotspot	Hotspot Location (UTM)		Source of Fine Sediment	Relative erosion magnitude
	Easting	Northing		
USGS stream gage 10336610				
1	760870	4312260	1.5 m high sloughed silt bank	moderate
2	760920	4312250	1.5 m high sloughed silt bank	moderate
Hwy 50 bridge at South Lake Tahoe, CA				
3	760970	4312230	1.5 m high sloughed silt bank	high
4	761070	4312226	1.5 m high sloughed silt bank	high
5	761110	4312230	1.5 m high sloughed silt bank	high
6	761155	4312223	1.5 m high sloughed silt bank	high
7	761256	4312156	1.5 m high sloughed silt bank	high
8	761371	4311919	1.5 m high sloughed silt bank	high
9	761503	4311704	1.5 m high sloughed silt bank	high
10	761468	4311521	1.5 m high sloughed silt bank	high
11	761441	4311376	5 m high escarpment below dam	moderate
Dam				
12	761304	4311214	6 m high escarpment	moderate
13	761219	4311170	6 m high escarpment	high
14	761133	4311094	4 m high escarpment	high
15	761020	4310981	1.2 m high undercut bank of silt/sand	moderate
16	760960	4310835	1.2 m high undercut bank of silt/sand	moderate
17	761029	4310789	1.2 m high undercut bank of silt/sand	moderate
			channelized and rip-rapped	negligible
18	760940	4309060	6 m high escarpment	moderate
19	760924	4308810	1.5 m high sloughed silt bank	moderate
20	760871	4308448	1.5 m high sloughed silt bank	moderate
21	760732	4308262	1.5 m high sloughed silt bank	moderate
22	760641	4308068	2.0 m high sloughed silt bank	moderate
Hwy 50/89 bridge north of Meyers, CA				

23	759662	4306745	3 m high slumped bank	moderate
24	759376	4306658	2 m high slumped bank	moderate
25	758927	4306417	2 m high eroding bank	moderate
26	758910	4306450	1.5 m high eroding bank	moderate
27	758672	4306417	2 m high eroding bank	moderate
28	758694	4306026	2.3 m high scalloped R bank	moderate
End of golf course				
29	758523	4305851	2.5 m high eroding R bank	moderate
Hwy 50 bridge south of Meyers, CA. USGS stream gage 103366092				
30	758062	4303989	3 m high eroding bank affected by LWD	major
USGS stream gage 10336600 downstream of Kata Road				
31	758579	4303011	eroding L bank	low
32	758685	4302967	LWD jam causing bank scour	moderate
33	758642	4302801	1.5 m high eroding silt/fine sand bank	moderate
34	758800	4302180	1.5 m high slumped L bank	moderate
35	758805	4302080	1.5 m high slumped L bank	moderate
36	758776	4301770	1.5 m high sloughed silt overlying sand bank	moderate
37	758775	4301618	1.5 m high sloughed silt overlying sand bank	moderate
38	758864	4300887	3 m high slumped bank	moderate
39	758936	4300508	2 m high eroding bank	moderate
Portal Road bridge				
40	758975	4300020	1.5 m high eroding L bank	low
41	759073	4299718	1.5 m high undercut/slumped L bank	low
42	759072	4299677	5 m high escarpment	moderate
43	759078	4299581	2 m high slumped bank	moderate
USGS Stream Gage 10336580				

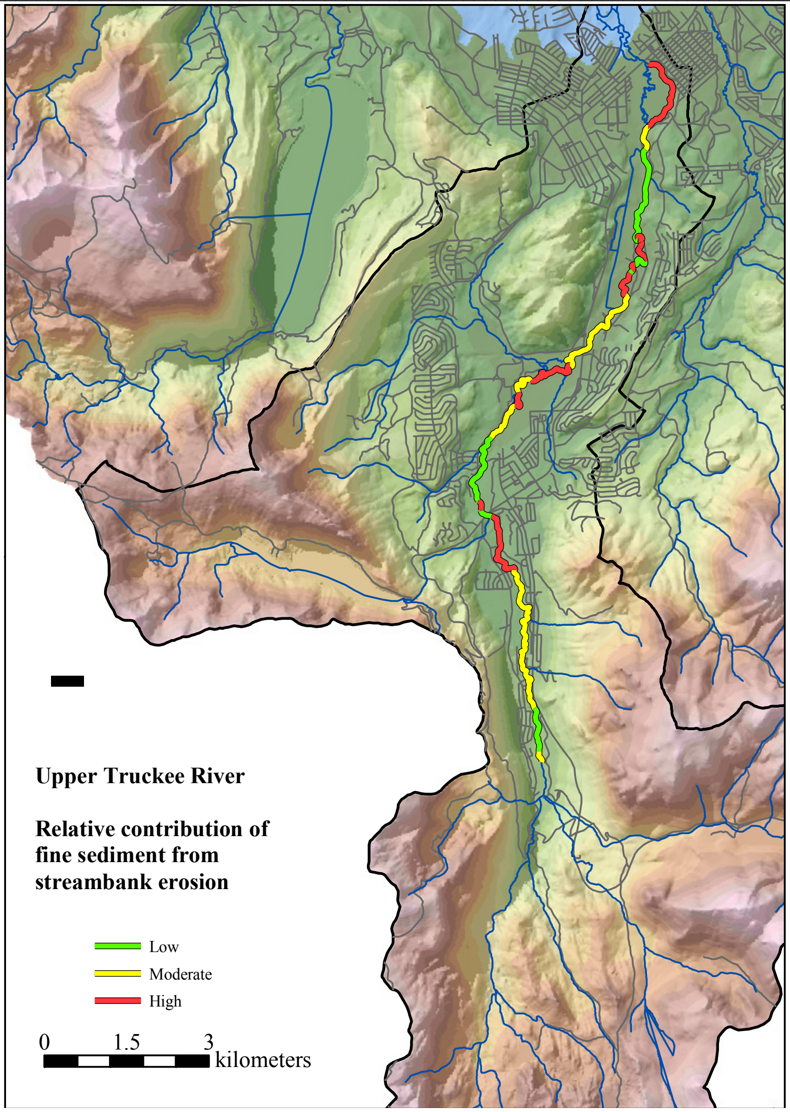


Figure 4-14. Map of the relative contribution of fine sediment from streambank erosion for the Upper Truckee River main stem.

The upper meadow reach is similar to the lower meadow. It is a 3.9 km sinuous reach with 1.5 m-high grassed banks composed of silt/fine sand. The outside bends are being undercut, and the upper portions are sloughing off (Figure 4-15). As woody vegetation levels increase in the upstream part of the reach, the frequency of sloughing cut-banks drops off, indicative of the potential role of woody plants in strengthening streambanks. The overall bank erosion potential of the reach is considered to be major (Hotspots 18-22, Table 4-7).

Figure 4-15. A typical reach rated "high" for fine-sediment contribution due to high silt containing banks and extensive failure length. The upper-meadow reach of the Upper Truckee River.

The river meanders 3.0 km past the golf course. It is typically gravel bedded with 1.5 to 3 meter-high banks of silt and fine sand layers overlying layers of coarse sand and gravel. Short grass is the dominant vegetation. Outside bends of non-cohesive materials have become undercut and are sloughing off. Some of the fine-grained bank materials are cemented thereby making the banks more resistant to erosion. Several different bank protection measures had been implemented. Rootwads, boulder sized rip-rap, and buried logs have all been placed along banks to reduce toe erosion and undercutting. The success of the protection measures is questionable due to the amount of bank scour taking place around many of the installations. The overall bank erosion potential of the golf course reach is considered to be intermediate. (Hotspots 23-28, Table 4-7).

The meandering pool riffle reach from the golf course upstream to the Highway 50/89 bridge (Hotspots 29 to Highway 50 bridge, Table 4-7) has been rip-rapped and re-vegetated starting in 1958 as part of a stream bank erosion control project. This is an aggradational reach with an active channel ranging from 20 to 40 m-wide where point bars take up two-thirds of the width (Figure 4-16). Young willows and pines are starting to grow high on the bars indicating they have only recently started to stabilize. Large woody debris partially exposed in sand/gravel bars indicates recent channel migration. The large woody debris also influences the pools and riffle formation by controlling grade whenever a log blocks a large portion of the channel. Bed and bank materials are well sorted with sand and gravel predominant in this reach. Near the upper end of the reach bank materials transition to silt and fine sand which appear to be beaver pond deposits. Channel widening is causing undercutting and bank failure of these fine grained banks, however the bank heights, at about 1 m, and the shortness of the reach indicates this area is probably not a great supplier of fine grained material. Overall the fine-sediment availability in this reach is considered to be low due to the coarseness of available material and aggradational nature of the reach.

Figure 4-16. Gravel-bedded aggrading reach composed of well sorted above gravel is rated "low" due to low bank heights, and coarse bed and bank material. Middle of the meandering pool-riffle reach above the golf course.

The stream crossing a moraine marks the intersection of the Upper Truckee River and Highway 50 above Meyers the beginning of the alternating meadow/moraine reach. The channel contains boulders up to 5 m in diameter immediately upstream of the bridge. The 0.5 km upstream contains sporadic locations of high bank erosion, where boulders have eroded out of the till, but do not defend the banks from high flows (hotspots 30 to 32, Table x). The banks at these locations tend to be high, 3 to 4 m, and the boulders also serve to catch large woody debris which exacerbates local scour. Transitioning from the upper end of the moraine to the meadow reach, bank heights become lower and the channel is predominantly bedded with gravel with fewer boulders.

The channel is bordered by broad relatively flat flood plains (Hotspots 32 to 37, Table 4-7). Land use is residential and pasture. Banks range from 1 to 2 m-high. Their composition varies from silt and sand to sand and gravel. Occasionally outside bends are sloughing and occasional large woody debris initiates bank scour. Due to the coarseness of material and low banks the overall fine-sediment availability is considered moderate (Figure 4-17).

Figure 4-17. Typical bank rated "moderate" in fine-sediment contribution due to large portion of coarse material in the bank.

The stream passes though a series of small moraines over the first kilometer below the Portal Road bridge (Hotspots 38 to 43, Table 4-7). The channel along this reach varies from boulder controlled step pool to gravel pool-riffle meadows above each moraine. The bouldery banks along the moraines are well protected from erosion by the large grain size material. The pool-riffle reaches have erodable silt/sand banks formed as either beaver ponded sediment or as lacustrine deposits behind the moraines. Fine-sediment availability is rated low in the boulder step-pools and moderate along pool-riffle meadows.

4.6.1.1 Summary

The Upper Truckee River exhibits a significant amount of bank erosion, particularly in the Washoe Meadows reach. This has been quantified earlier in the chapter and the reader is directed to Table 4-2. There exists a general trend of increasing stability with distance upstream, indicative of a channel undergoing adjustment to disturbance(s) (Figure 4-20 A). The lowest reaches, from the Upper Truckee Marsh to the golf course, have a greater available supply of fine sediment due to bank heights being high enough to slough off when undercut, the lack of root penetration through to the bank toe, and the lack of coarse material to protect the bank toes. Upstream of the golf course the channel has little fine sediment as it passes through a moraine. The meadow reaches between moraines provide silt/sand sediments from banks that are susceptible to erosion by sloughing. However, unlike from golf course downstream, the banks in this reach are not as high, and they contain greater quantities of sand and gravel, thereby reducing the available amount of erodible fine sediment.

Geomorphic interpretations made during the stream walk and evaluated during RGAs are further summarized spatially with maps depicting the:

(1) combined-, channel-, and side-slope erosion indexes (Figure 4-18), and

(2) the occurrence of bank failures combined with fine-grained content of the streambanks (Figure 4-19).

In addition, results are shown graphically, displaying these data relative to distance above the stream mouth (Figure 4-20).

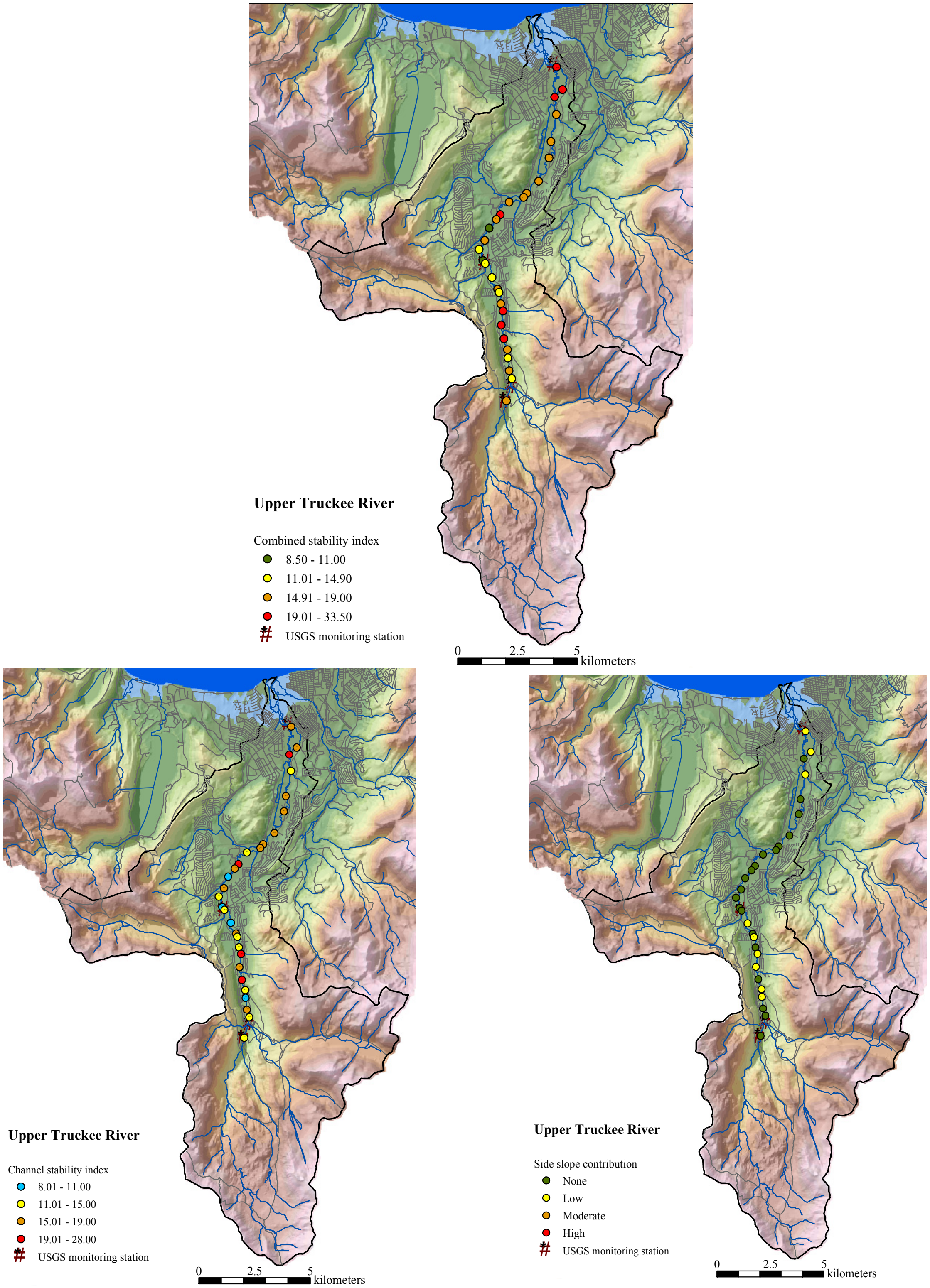


Figure 4-18. Results of rapid geomorphic assessments of the Upper Truckee River showing the relative contributions of channel- and side-slope indexes to the combined stability index, and critical erosion areas.

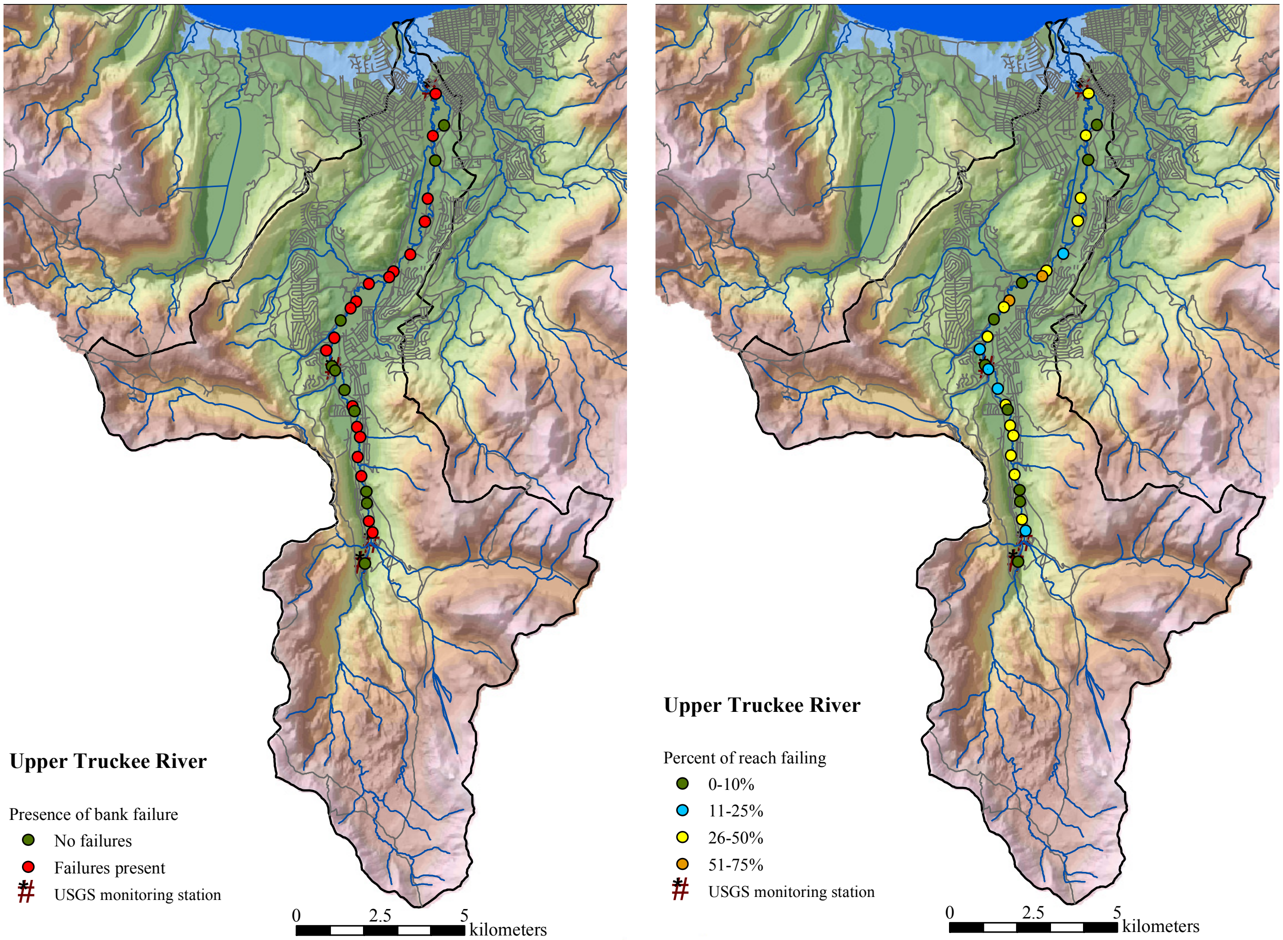


Figure 4-19. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along the Upper Truckee River.

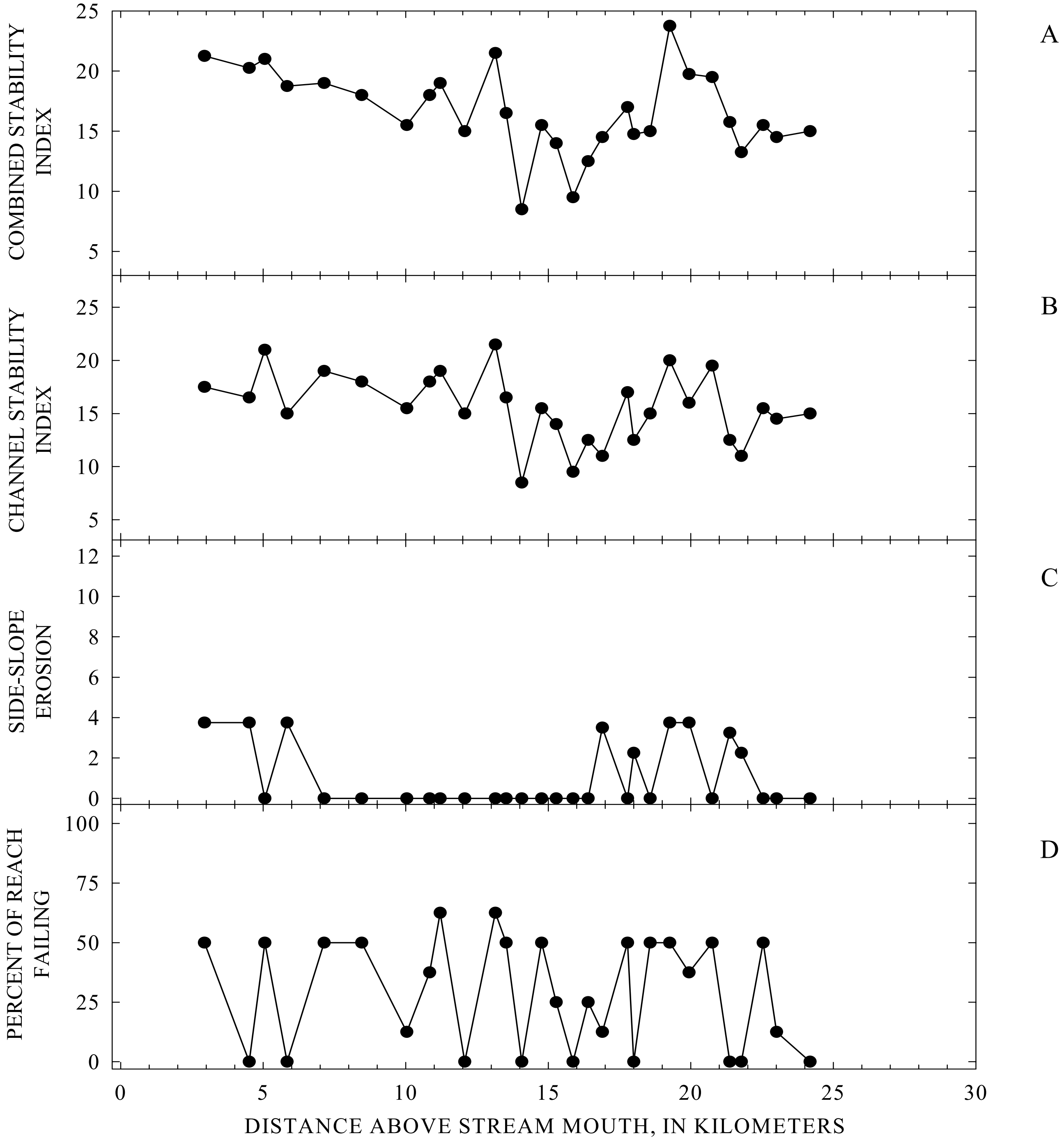


Figure 4-20. Results of RGAs conducted along the Upper Truckee River showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank bank failures.

4.6.2 Blackwood Creek

The morphology of the assessed 8 km of Blackwood Creek can be broken into four distinct reaches. Heading upstream, the initial 4 km contains fluvial deposits. The next 1.8 km is characterized by alterations from gravel mining; the next 1.2 km contains the combined alluvium of the four major tributaries; and the final km is a bedrock canyon. The reach comprising the lowest 4 km of Blackwood Creek from the mouth to the Barker Pass Road bridge (Figure 4-23) was assessed via RGAs at five locations. The remaining 4 km between the Barker Pass Road bridge to where the eastern most stream fork crosses the road to Barker Pass were assessed by stream walk (Figure 4-23).

Within the 0.5 km nearest the lake sea walls have been constructed along the stream, thereby helping to reduce sediment delivery from bank failures. The remaining 3.5 km of the initial reach (Hotspots 1-5, Table 4-8) is primarily a gravel- bedded sinuous channel. There are one to three m-high banks primarily silt and sand at the RGA sites. Measured quantities of silt/clay content for each site are given in Appendix B, with an average bank composition of 6%. The vegetation ranges from pine forests to grass meadows, however the outside bends are sufficiently high to prevent roots from protecting the full height of the banks (Figure 4-21).

Figure 4-21. Typical failing outside bend along the lower 4 km of Blackwood Creek. This site is rated "high" in fine-sediment availability due to the bank height and length of reach failing. Similar sites, with lower banks, are rated "moderate."

The reach affected by mining spans the next 1.8 km (Hotspots 6 to 9, Table 4-8) above the Barker Pass Road bridge. It is the lowest portion of the broad alluvial valley where alluvium from the upper four tributaries has been deposited. This reach was historically mined for gravel during the 1960's, with the channel being diverted during the active mining period and then restored in 1978 (Stubblefield, 2002). The channel along this reach consists of braided cobbles with low (0.5 to 2 m-high) unconsolidated silt/gravel/cobble banks and a 20 m-wide active bed.

Vegetation density is mixed with some grasses, dogwoods, and willows becoming established on the banks, especially along the lower end of the reach.

Table 4-8. Summary of reconnaissance-level evaluation of areas of streambank instability and delivery of fine-grained sediments along Blackwood Creek.

Erosion hotspot	Hotspot location (UTM)		Source of fine sediment	Relative erosion magnitude
	Easting	Northing		
1	745432	4332351	failing outside bends	high
2	744965	4332563	failing outside bends	moderate
3	744247	4332594	failing outside bends	moderate
4	743275	4331986	2.5 m high failing L bank	high
5	742485	4331986	1 m high eroding bank	low
6	741717	4331444	1.5 m high eroding banks at high flows	moderate
7	741583	4331268	1.5 m high eroding banks at high flows	moderate
8	741509	4331187	2.2 m high eroding L bank at high flows	high
9	741500	4331148	3 m high failing R bank	moderate
10	741471	4331146	2 m high eroding R bank	moderate
11	741201	4330981	1.7 m high failing bank	moderate
12	741172	4330808	1.7 m high failing bank	moderate
13	741003	4330682	2 m high eroding bank	moderate
14	741113	4330657	2 m high failing R bank	high
15	741029	4330104	2.5 m high failing L bank	high
16	741094	4330014	6.5 m high failing R bank	high
17	741062	4329868	3 m high failing L bank	high
18	741063	4329779	3 m high eroding L bank	moderate
19	741083	4329646	5 m high eroding L bank	moderate
20	741005	4329833	2 m high eroding bank	moderate
21	741188	4329342	1 m high eroding bank	low

The next 1.2 km reach (Hotspots 9 to 17, Table 4-8) above the mined reach spans the convergence of the south, middle, and north forks and the channel where the cobble and boulder portion of their sediments loads are deposited. The channel form varies between boulder controlled step-pools and boulder/cobble runs. This alluvial valley becomes narrower as one travels upstream. The channel, when in the middle of the valley, has primarily low cobble-gravel banks with little fine sediment available for erosion. However, cut banks 2 to 5 m-high form when channel meanders cut into the valley walls. Vegetation on these cut banks is typically sparse. A knickpoint exists about 100 m below the confluence of the Middle Fork and the easternmost fork. The bed above the knickpoint is a cemented glacial till consisting of gravel encased in a hard, yet erodible, clay matrix. The bed drops about 0.5 m crossing the knickpoint to a cobble bedded channel, and undercuts a bare, high terrace slope that contributes a significant amount of sediment to the channel during high flows.

The eastern fork reach, upstream from its confluence with the Middle Fork (Hotspots 17 to 21, Table 4-8), transitions from a boulder/cobble bed to a bedrock controlled channel. Banks are steep with essentially no sediment available for erosion (Figure 4-22). However, near the Barker Pass Road crossing, the channel banks are covered by a layer of colluvial material with a high silt/clay content.

Figure 4-22. Bedrock channel with a "low" fine sediment rating typical of the canyon reach of Blackwood Creek.

4.6.2.1 Summary

Grain size analysis of bed and bank materials indicate that the overall silt/clay content of the bed makes up essentially 0% of the bed material whereas the measured silt/clay content of the banks varied from 1 to 13% (average of 6%). This can be significant given that Blackwood Creek has historically been shown to provide quantities of material from its banks (Table 4-2). The lower clay/silt materials typically came from fluvial or glacial outwash deposits whereas the higher clay/silt percentages typically came from side slopes where the stream channel was cutting into the valley wall. This is reflected in the spikes in the channel-stability index between km 5 and 7 (Figure 4-26 B) and in the "high" rating along the same reach in Figure 4-23). Overall the channel tends to become more stable moving upstream with scattered peaks until river km 7.2 (Figure 4-26 A, B, C and D) where the overall fine-sediment availability from the channel drops to low (Figure 4-23) with the exception of just downstream of the Barker Pass Road crossing (river km 8.1 Figure 4-23).

Geomorphic interpretations made during the stream walk and evaluated during RGAs are further summarized spatially with maps depicting the:

(1) combined-, channel-, and side-slope erosion indexes (Figure 4-24), and

(2) the occurrence of bank failures combined with fine-grained content of the streambanks (Figure 4-25).

In addition, results are shown graphically, displaying these data relative to distance above the stream mouth (Figure 4-26).

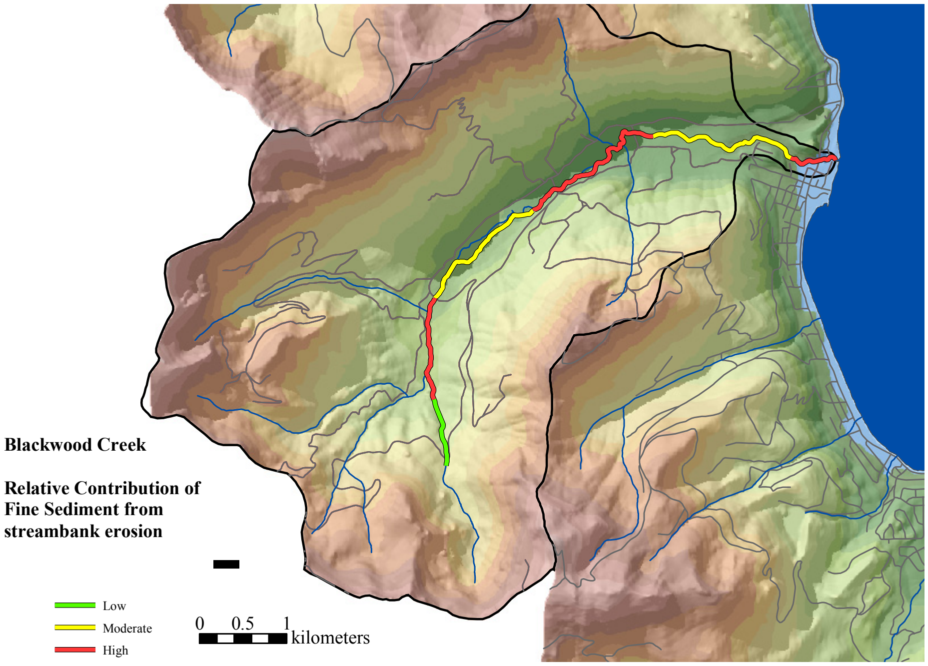


Figure 4-23. Map of the relative contribution of fine sediment from streambank erosion for Blackwood Creek.

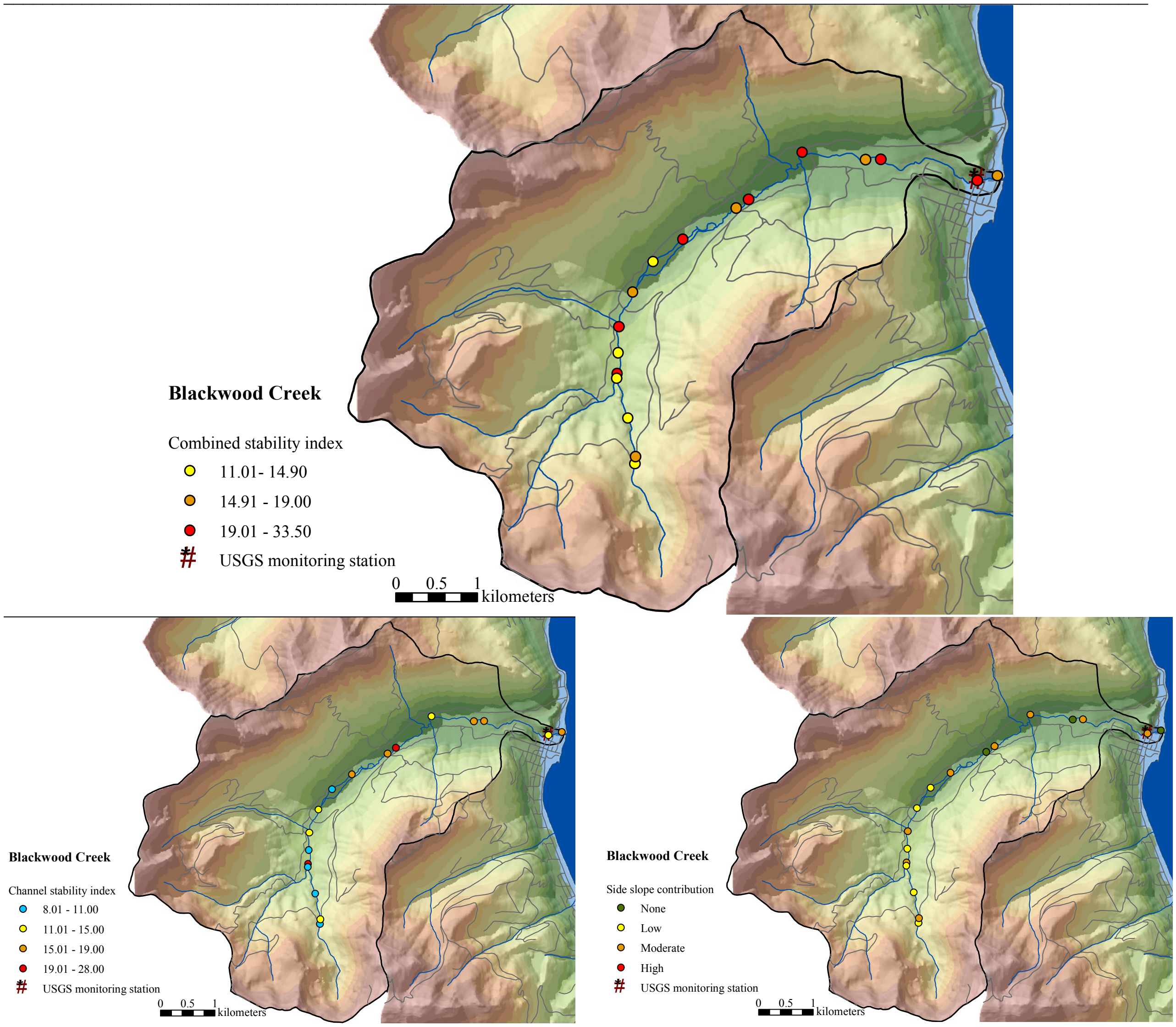


Figure 4-24. Results of rapid geomorphic assessments of Blackwood Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

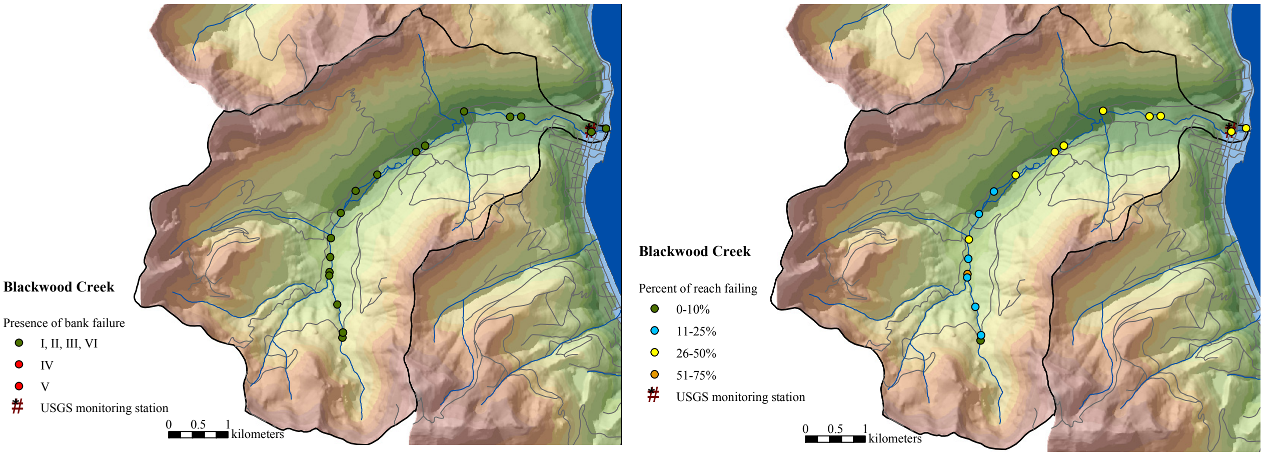


Figure 4-25. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along Blackwood Creek.

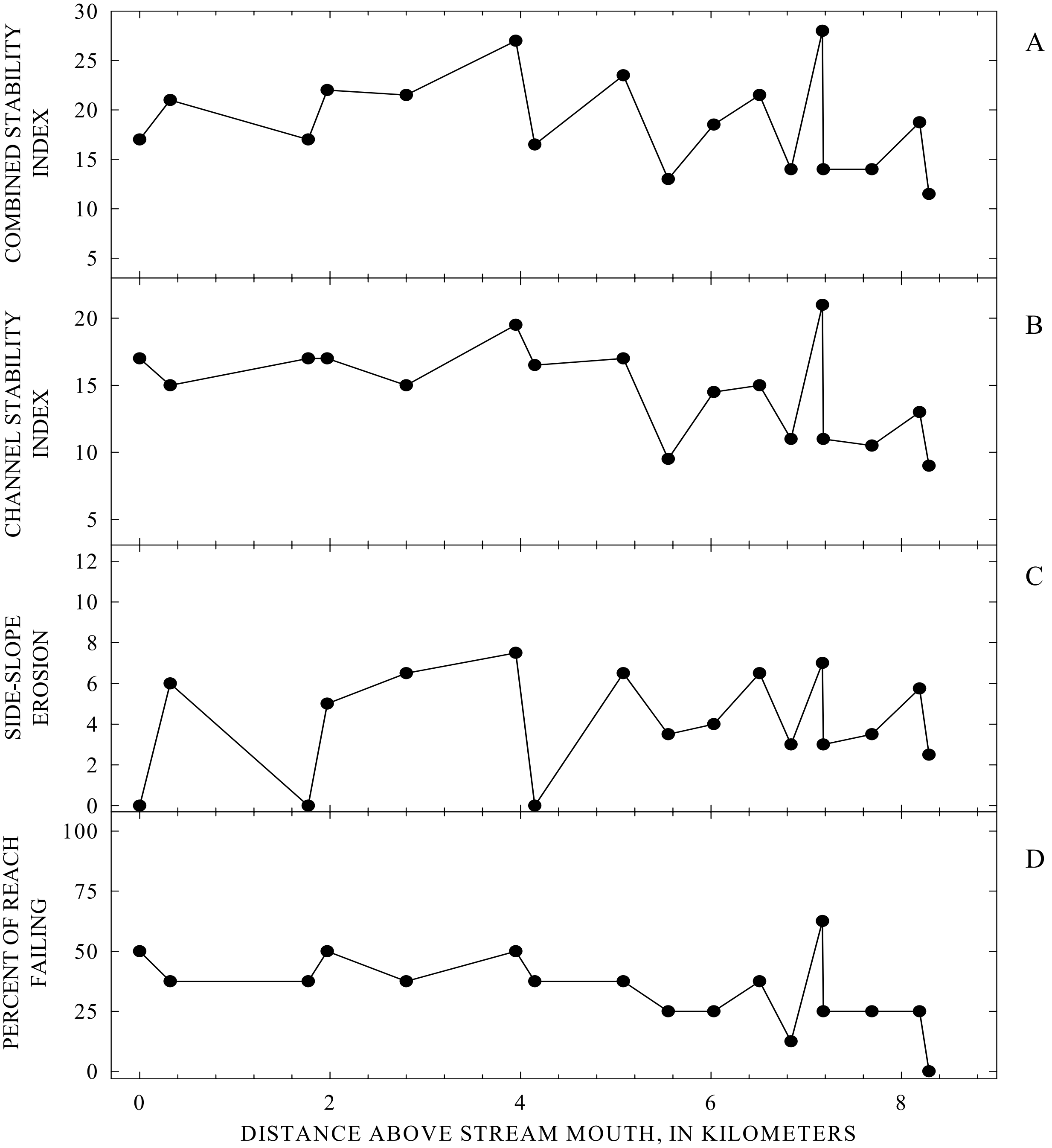


Figure 4-26. Results of RGAs conducted along Blackwood Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

4.6.3 Ward Creek

The assessed portion of Ward Creek consists of three major reaches spanning the lower 6.6 kilometers of the watershed (Figure 4-29). These reaches can be divided morphologically into three sections: The alluvial fan, the volcanic canyon, and the glacial till/beaver meadow. The alluvial fan covers 1.8 km between the canyon and the lake, where a sand/gravel delta has formed at the mouth. The gradient from base level at the lake increases to about 0.02 m/m. The stream appears stable, however the depth of scour pools and scour into cut banks indicates the channel may have recently been incising and widening, perhaps during the January 1997 flood. Cut banks have lenses of silty material and clast supported gravels, cobbles, and boulders. The top 0.3 meter is typically root bound. Cut banks range from 2.5 to 7 m-high. The stream borders a residential neighborhood; however the landowners have done little to alter the stream or stream bank vegetation. Exceptions occur where rip-rap has been placed along a bend, and where a home has been built over hanging the stream thereby forming a high flow constriction. Overall, the bank-rosion potential appears to be low to moderate. There are four areas of moderate to high fine-sediment availability noted, however they make up a small portion of the 1.8 km reach (Hotspots 1 to 4, Table 4-9).

Table 4-9. Summary of reconnaissance-level evaluation of areas of streambank instability and delivery of fine-grained sediments along Ward Creek.

Erosion hotspot	Hotspot location (UTM)		Source of fine sediment	Relative erosion magnitude
	Easting	Northing		
1	745862	4334956	2.3 m high failing R bank	moderate
2	745816	4335040	2.6 m high failing R bank	moderate
Hwy 89 bridge. USGS stream gage 10336676				
3	745643	4335227	6 m high failing R bank	high
4	745117	4335472	2 m high failing R bank	moderate
5	744784	4335534	12 m high failing R bank	high
6	744545	4335515	1.5 m high failing R bank	moderate
7	744215	4335462	7 m high failing R bank	high
8	744064	4335444	4 m high failing R bank	high
9	743707	4335478	7 m high failing R bank	high
10	743666	4335517	4 m high failing R bank	high
11	743481	4335671	reworking fluvial deposits	low
12	743283	4335672	15 m high failing bank	high
13	743202	4335667	1.7 m high failing bank of reworked fluvial deposits	moderate

14	743139	4335718	1.7 m high failing bank of reworked fluvial deposits	high
15	743109	4335744	LWD directs flow into bank	moderate
16	743000	4335768	12 m high escarpment fails only at high flows	moderate
17	742956	4335807	reworking fluvial deposits erosion control net	low
18	742831	4335868	6 m high escarpment fails only at high flows	moderate
19	742689	4335908	2 m high failing bank	moderate
20	742651	4335947	3 m high failing bank	high
21	742602	4335916	reworking fluvial deposits	moderate
22	742373	4335962	fluvial eroding glacial deposit	moderate
23	742266	4335965	2 m high failing L bank	high
24	742161	4335926	0.5 m high failing R bank	moderate
25	742055	4335911	1.5 m high failing L bank	high
26	741991	4335898	4 m high failing R bank	low
27	741908	4335964	1.5 m high failing R bank	low
28	741785	4336085	1.8 m high failing L bank	moderate
29	741737	4336040	2.5 m high failing R bank	moderate
30	741599	4336074	1 m high failing R bank	low
31	741539	4336069	1.2 m high eroding R bank	low
32	741438	4336029	2 m high eroding R bank	moderate
33	741333	4336018	1.3 m high eroding R bank	low
USGS stream gage 10336674				
34	740788	4335813	2.3 m high failing R bank	moderate

The valley narrows through the 0.8 km volcanic canyon section, and the stream gradient increases to about 0.027 m/m. Basalt bedrock outcrops near the upper end of this section, thereby restricting channel migration and creating a grade control. The channel cuts into valley walls creating escarpments in glacial deposits 4 to 12 meters high. Several of these escarpments have their toes on gravel bars several meters away from the thalweg, thereby preventing erosion from taking place except during high flows (Hotspots 4 to 9, Table 4-9). Overall the canyon section appears to have a moderate amount of fine sediment available and exposed for erosion.

The glacial till/beaver meadow reach spans 3.1 km from the exit of the canyon until the confluence near the USGS stream gage approximately 4.7 km above the mouth meadow

(Hotspots 9 to 34, Table 4-9). This reach channel meanders through a flat valley several hundred meters wide. The channel has mixed forms: cobble/boulder runs, cobble/gravel pool riffles, braided gravel/cobbles, and beaver ponds. Banks in the middle of the valley range from 0.5 to 2.0 m-high, however they become 4 to 12 m-high escarpments where the stream cuts into the valley walls. Stable reaches consist of banks less than 0.5 m-high composed of gravel with dogwood and alder growing to the water's edge. Stable reaches can also be braided with poorly vegetated cobble bars. It is assumed that the cobble bars formed during the January 1997 flood. Unstable reaches have 0.5 to 1.5 m-high vertical banks composed of organic rich silt (old beaver pond deposits). These banks are typically being undercut with frequent sloughing of the upper grass root-bound layer. They are considered to have low to moderate fine-sediment erosion potential depending on the length of the exposed bank (Figure 4-27). Areas considered to have high erosion potential are cut banks of beaver pond deposits higher than 1.5 m or escarpments where the stream is cutting into valley walls of glacial till. Overall, the glacial till/beaver meadow reach has a moderate amount of fine sediment available for erosion.

Figure 4-27. Failing bank of fine beaver-pond deposits is rated "low" in fine sediment availability due to low bank height and dense roots fully penetrating bank. The ice axe is 0.75 m tall. Till plain/beaver meadow reach of Ward Creek.

4.6.3.1 Summary

The alluvial fan reach has few areas actively eroding, and those that are appear to be composed of coarse material. Collectively this reach is probably not a great contributor of fine sediment. The canyon/moraine reach has several escarpments where the channel has cut into the morainal valley. These show up as side-slope erosion peaks between river km 0.7 and 3.5 (Figures 4-32 C and 4-29). Individually these locations offer a high potential to contribute fine sediment due to large area exposed. Most of this reach is well protected by vegetation and the bedrock portion simply erodes at an imperceptibly slow rate compared to the unconsolidated reaches. The lower part of the glacial till/beaver meadow reach has several "high" erosional areas associated with escarpments from 6 to 12 m-high. The remainder of the erosion is rated moderate due to the high vegetation level or greater density of large particles in the making up the banks. The middle of the reach is rated high overall due to the length, height, and composition of sloughing beaver pond deposits. Bank heights are lowest along the upper third of the reach and vegetation is well established and, therefore, side-slope erosion drops off from river km 4.3 to 6.7 (Figure 4-32 C). Erosion, therefore, is primarily "low" along the upper part of this reach.

Side slope erosion increases from rkm 2 to 3.5 (Figure 4-32 C) where the valley begins to narrow. The stream contacts the valley walls with a greater frequency creating escarpments with exposures up to 12 m-high and 100 m-long (Figure 4-28). Further upstream, river the broadening valley and shrinking bank heights serve to reduce the range in stability variation with diminished contributions from steep slopes (Figure 4-32 A, B, C, D).

Figure 4-28. Example of "high" erosion area along Ward Creek where stream has created a 12 m-high escarpment by meandering into the glacial till valley wall.

Geomorphic interpretations made during the stream walk and evaluated during RGAs are further summarized spatially with maps depicting the:

(1) combined-, channel-, and side-slope erosion indexes (Figure 4-30), and

(2) the occurrence of bank failures combined with fine-grained content of the streambanks (Figure 4-31).

In addition, results are shown graphically, displaying these data relative to distance above the stream mouth (Figure 4-32).

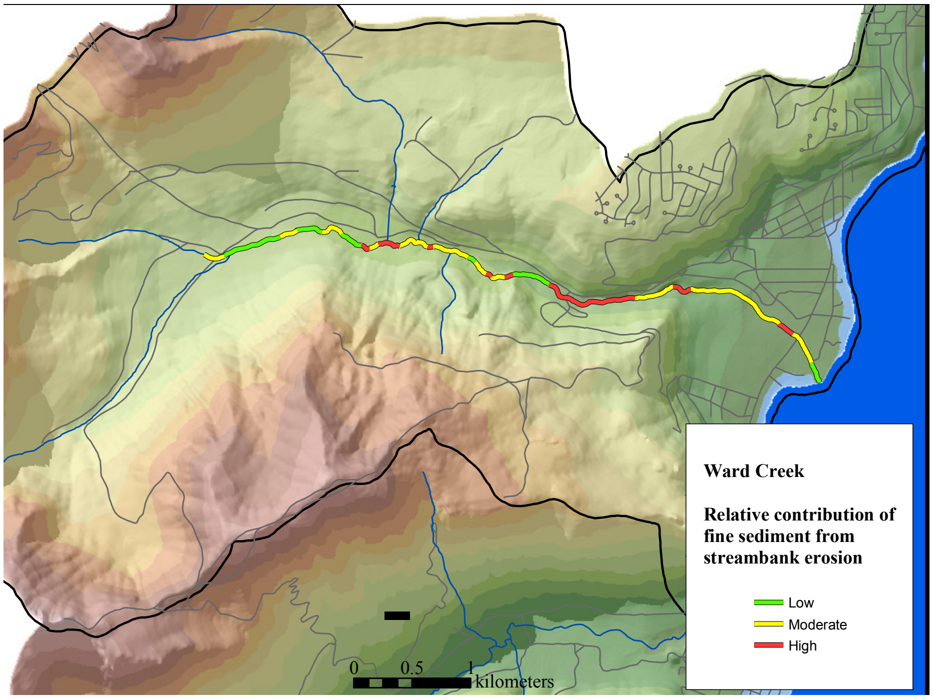


Figure 4-29. Map of the relative contribution of fine sediment from streambank erosion for Ward Creek.

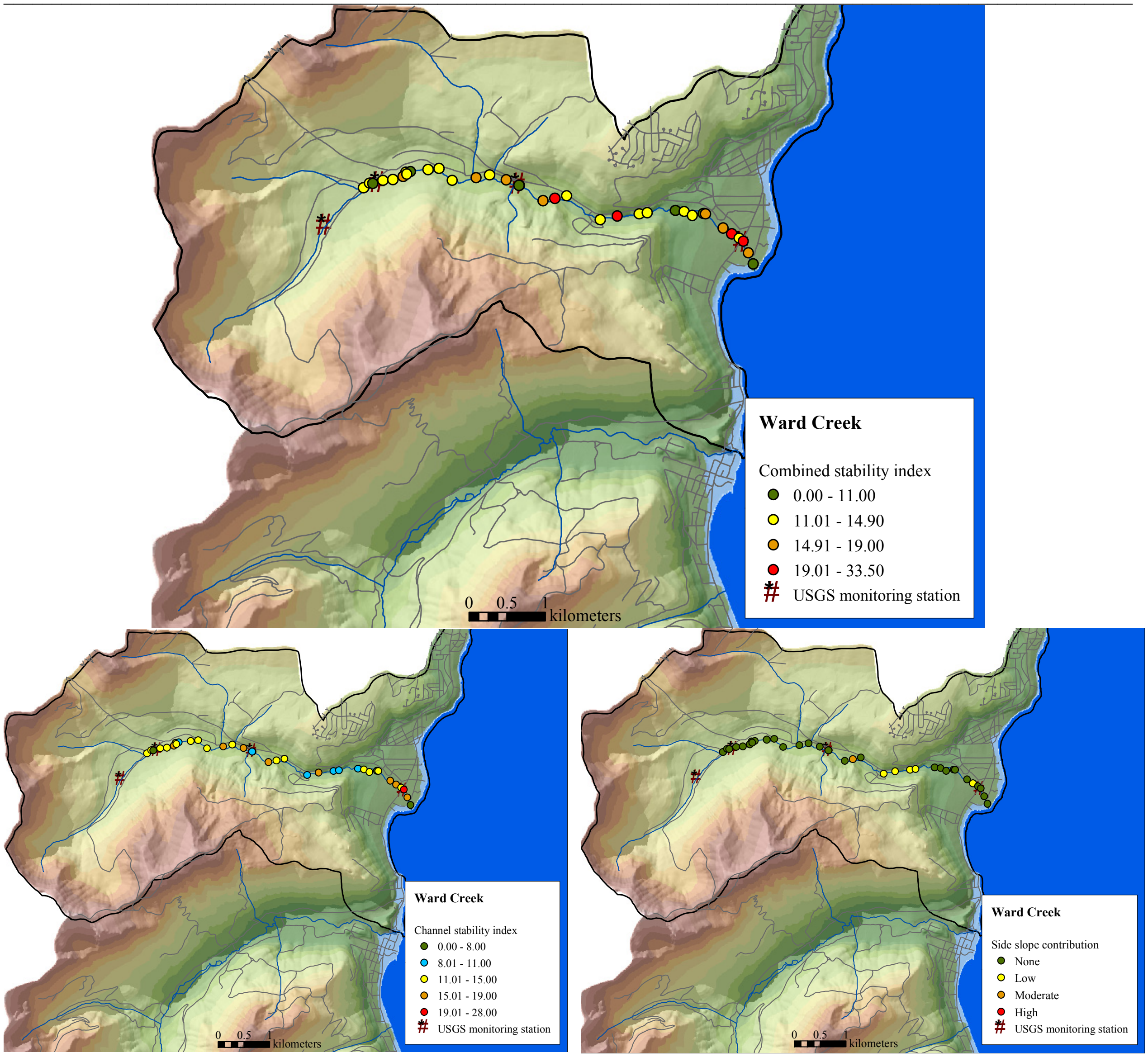


Figure 4-30. Results of rapid geomorphic assessments of Ward Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

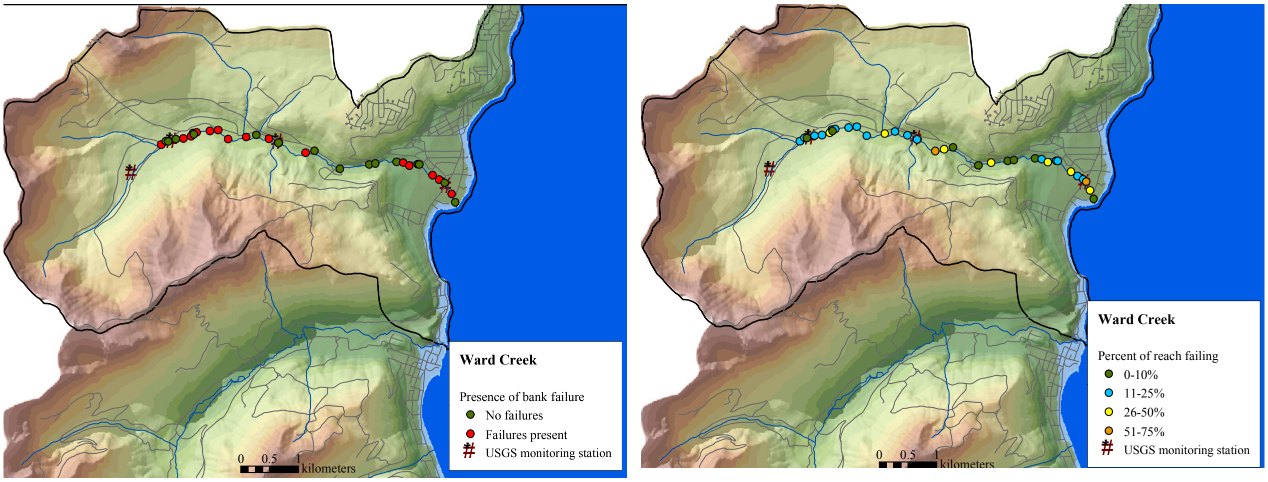


Figure 4-31. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along Ward Creek.

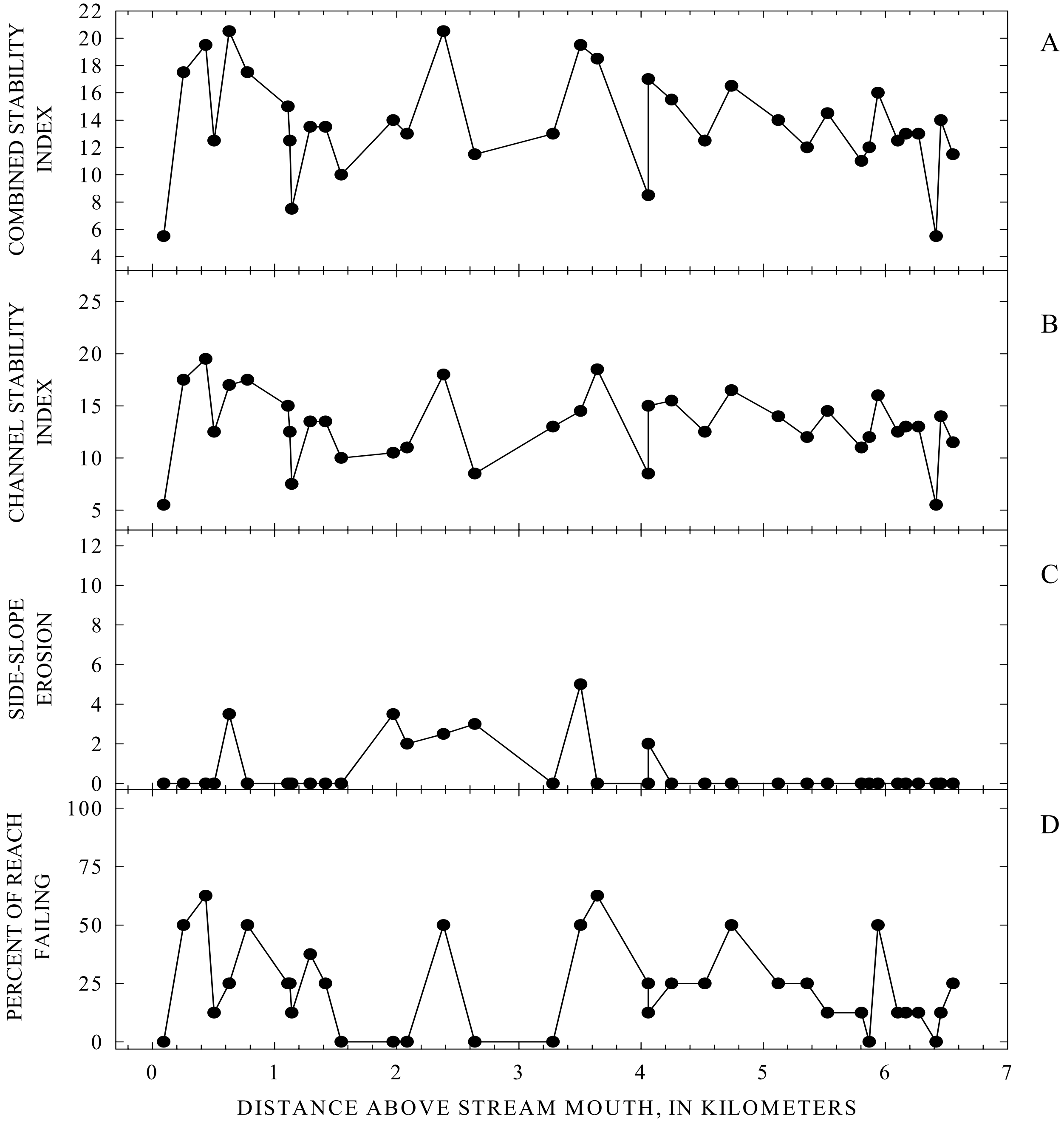


Figure 4-32. Results of RGAs conducted along Ward Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

4.6.4 General Creek

The assessed length of General Creek spans 8.3 km from the mouth to the junction with the upper valley. This creek has been divided into five major reaches: delta, incised till, aggrading gravel bed, boulder step-pool, and canyon.

The delta reach encompasses the 0.7 km reach from the mouth to 100 m above Highway 89. Near the mouth, coarse sand is being deposited in 1.5 meter high bars. Bank materials include fluvially deposited coarse sand, fluvially deposited silt/sand layers overlying gravel/cobble, and organic rich silt/clay lake deposits. Bank heights vary from 0.1 m in the pool of a beaver dam to about 1.0 m below the dam. Alders, dogwood, and grasses densely cover the banks. Bank erosion is greatest at two locations where large woody debris is causing bank scour. Erosion is also occurring through the undercutting of the silt/sand overlying gravel. The lake deposits are cohesive and appear to be a minor sediment contributor. The overall fine-sediment erosion potential of the reach is low (Hotspots 1 to 4, Table 4-10).

The incised-till reach spans 3.0 km from 100 m above Highway 89 to the furthest upstream U.S. Forest Service bridge. This reach is characterized by a meandering channel incised through a downstream thickening glacial till deposit (Figure 4-33). The result is a channel with 1 meter high floodplains between high till terraces. Escarpments form where the stream engages the terrace wall. Escarpments near the upper end of the reach are less than 3 m-high. Approaching the lower end of the reach, the escarpments reach to an estimated 20 m-high (Figure 4-33). All these escarpments are considered to be major sources of fine sediment. As they continue to erode, large trees become undercut and fall into the channel. The resulting large woody debris exacerbates erosion through scour by directing flows into the banks (Hotspots 5 to 19, Table 4-10).

Figure 4-33. Escarpment where stream has cut into high till terrace is rated as "high" in fine-sediment availability. Incised till reach, General Creek.

The aggrading gravel-bed section begins above the upper bridge and ends 2.4 kilometers upstream or about 0.3 km below the confluence of General Creek and the tributary from Lost Lake. The reach is split into upper and lower halves where it crosses a moraine by a short boulder riddled steep gradient reach. The downstream half is characterized by low banks well vegetated by alder and dogwood. The riparian zone in the lower half of the reach is well shaded by pines. Ferns and other plants requiring low-sunlight form the undergrowth. The forest thins in the upper part of the reach leaving banks exposed to the sun. Dense alder and dogwood form a canopy over the channel. Grasses and annual vegetation cover portions of the flood plains. The channel has aggraded a gravel and cobble bed into a braided channel along the upper quarter the section. The channel is actively widening through undercutting its banks. Banks are typically less than 1.5 meters high and are composed of fluvially deposited silt/sands overlying coarse sand and gravel. The banks in the moraine reach are well protected by boulders (Figure 4-34) therefore fine sediment production appears to be negligible along this reach (Between hotspots 22 and 23, Table 4-10). Overall the fine sediment erosion level appears to be moderate where the primary erosion processes are bank undercutting and large woody debris initiated scour (Hotspots 20 to 29, Table 4-10).

Table 4-10. Summary of reconnaissance-level evaluation of areas of streambank instability and delivery of fine-grained sediments along General Creek.

Erosion hotspot	Hotspot location (UTM)		Source of fine sediment	Relative erosion magnitude
	Easting	Northing		
1	749831	4326678	failing LB	low
2	749829	4326641	undercutting RB	low
3	749770	4326559	LWD directs flow into bank	low
4	749609	4326427	undercutting LB	low
5	748895	4326329	20 m high failing bank	high
6	748772	4326278	20 m high failing bank	high
7	748671	4326305	LWD directs flow into bank	moderate
8	748351	4326221	1 m high failing RB	moderate
9	748066	4326128	5 m high failing RB	high
10	747815	4325894	8 m high failing RB	high
11	747663	4325847	reworking fluvial deposits	moderate
12	747546	4325803	7 m high failing R andLB	high
13	747419	4325686	2 m high failing LB	moderate
14	747351	4325529	2 m high failing RB	moderate
15	747124	4325348	2 m high failing RB	high
16	747003	4325339	3 m high failing RB	moderate
17	746883	4325295	undercutting RB	low
18	746822	4325269	4 m high failing RB	high
19	746795	4325174	2 m high failing RB	moderate

20	746522	4324617	undercutting bank RB	low
21	746465	4324516	2 m high failing bank	moderate
22	746343	4324405	undercutting bank	low
23	745847	4323738	LWD directs flow into bank	high
24	745844	4323719	reworking fluvial deposits	moderate
25	745754	4323657	LWD directs flow into bank	high
26	745700	4323704	undercutting bank	moderate
27	745629	4323739	reworking fluvial deposits	moderate
28	745619	4323681	reworking fluvial deposits	moderate
29	745249	4323685	reworking fluvial deposits	moderate
30	744241	4323216	LWD directs flow into bank	moderate
Hwy 89 bridge. USGS stream gage 10336645				
31	743921	4323169	steep upland slope connected to channel	low
32	743282	4322916	steep upland slope connected to channel	low
33	743197	4322926	steep upland slope connected to channel	low
34	742970	4322627	failing RB	moderate

Figure 4-34. Typical bank rated "low" in fine-sediment availability. Bank is composed of cobble and boulder sized clasts with well established woody vegetation holding banks in place. General Creek.

The boulder step-pool section begins about 0.3 km below the confluence of General Creek and the tributary from Lost Lake and runs 1.5 kilometers to a trail crossing which marks the boundary into the canyon section. The boulder step-pool section is characterized by a steep gradient, bed and bank material varying in size from gravel to 3 m in diameter, dense dogwood and alder on the banks, and upland slopes attached to the channel without a floodplain. The overall fine sediment erosion potential from the banks is considered negligible due to the lack of fines available (Hotspots 29 to 34, Table 4-10).

The canyon section spans 1.3 kilometers from the trail crossing up to a second trail crossing near the mouth of the upper valley. The steep gradient channel is dominated by bedrock and boulder step-pools. Banks consist of cobble/boulder deposits, durable granite and diorite bedrock, and decomposing granite bedrock. Alders and willows grow on narrow flood plains in the pool areas. Upland slopes are steep and rocky. A vegetation-free talus pile dominates the left upland. Sparse vegetation has taken hold on the decomposing granite knob on the right upland. Bank contributions of fine sediment are negligible with the exception of an eroding streambank in a till/outwash deposit at the head of the section (Hotspots 1 to 4, Table 4-10). Upland contributions may be more significant due to the steep upland slope and lack of a floodplain buffer.

4.6.4.1 Summary

Being depositional, the delta reach is very likely a low contributor of fine sediment due to the typically low banks and dense vegetation. The highest quantities of fluvially generated sediment in the watershed likely come from the numerous high escarpments along the lower end of the incised till reach which show up as a series of spikes between river kms 1 to 3 (Figure 4-38 C). The upper half of the till reach is rated as a moderate producer of fine sediment due to the reduced height of the escarpments and greater frequency of coarse material and vegetation protecting the banks Figure 4-35). The aggrading reach is collecting coarse particles (gravel and larger), while passing particles of sand and finer sizes. The fine particles are delivered by channel widening and fluvial scour generated by large woody debris which is reflected in the rise in side-slope erosion from km 4.2 to 6.2 (Figure 4-38 C). Overall, the aggrading reach appears to be a moderate producer of fine material from streambanks. Fine sediment production appears to drop to a low level heading upstream into the canyon reach. Banks are either extremely bouldery or composed of bedrock with essentially no areas of fine material exposed. However steep upland slopes are connected to the channel and may be a relatively high contributor of fine material. General Creek, as a whole, tends to become more stable moving upstream (Figure 4-38 B) due to the higher proportion of cobbles and boulders making up the bank material and the lower bank heights.

Geomorphic interpretations made during the stream walk and evaluated during RGAs are further summarized spatially with maps depicting the:

(1) combined-, channel-, and side-slope erosion indexes (Figure 4-36), and

(2) the occurrence of bank failures combined with fine-grained content of the streambanks (Figure 4-37).

In addition, results are shown graphically, displaying these data relative to distance above the stream mouth (Figure 4-38).

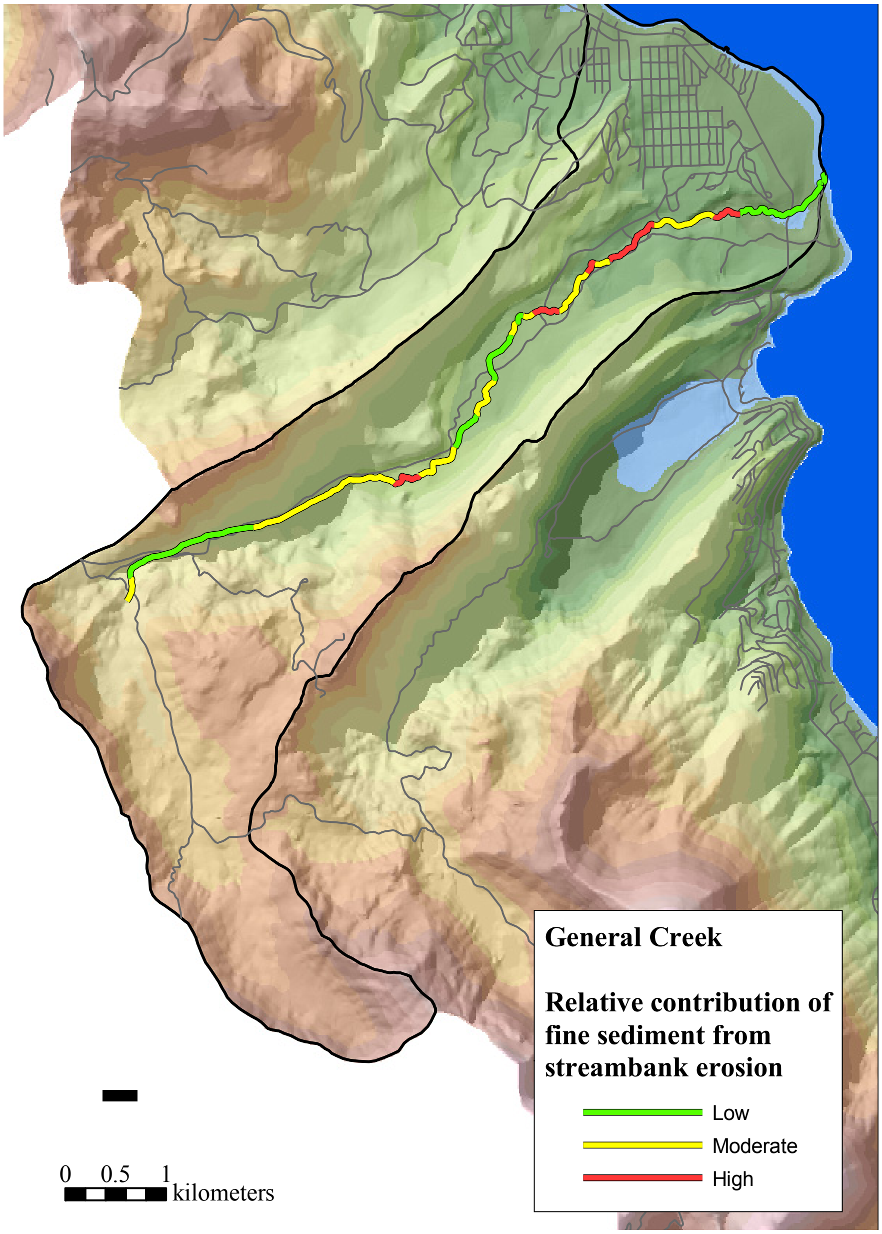


Figure 4-35. Map of the relative contribution of fine sediment from streambank erosion for General Creek.

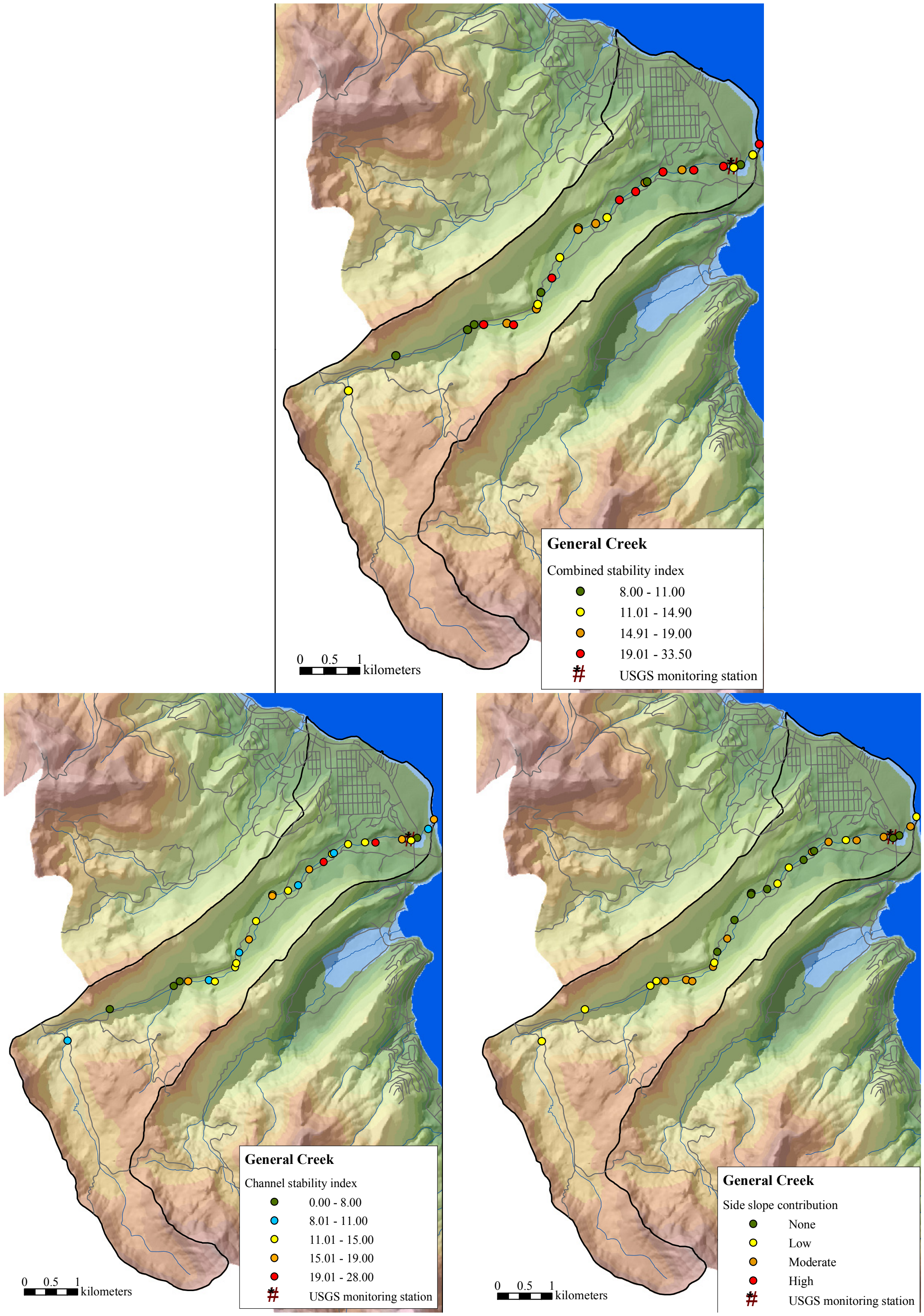


Figure 4-36. Results of rapid geomorphic assessments of General Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

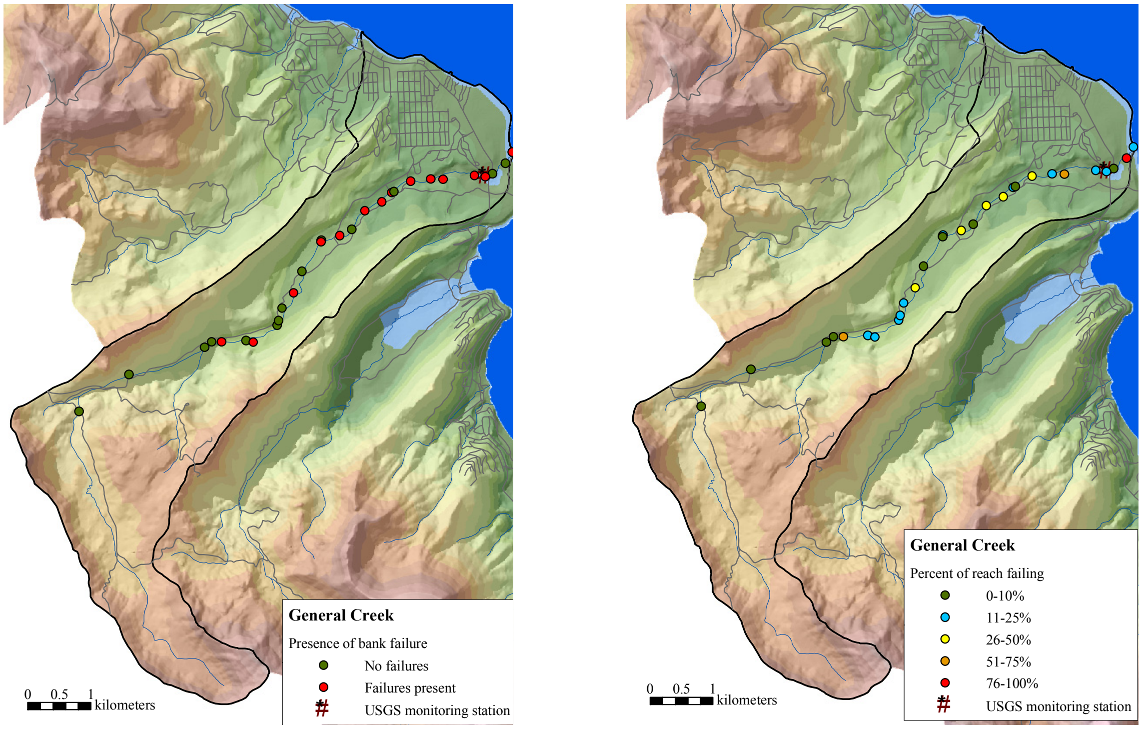


Figure 4-37. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along General Creek.

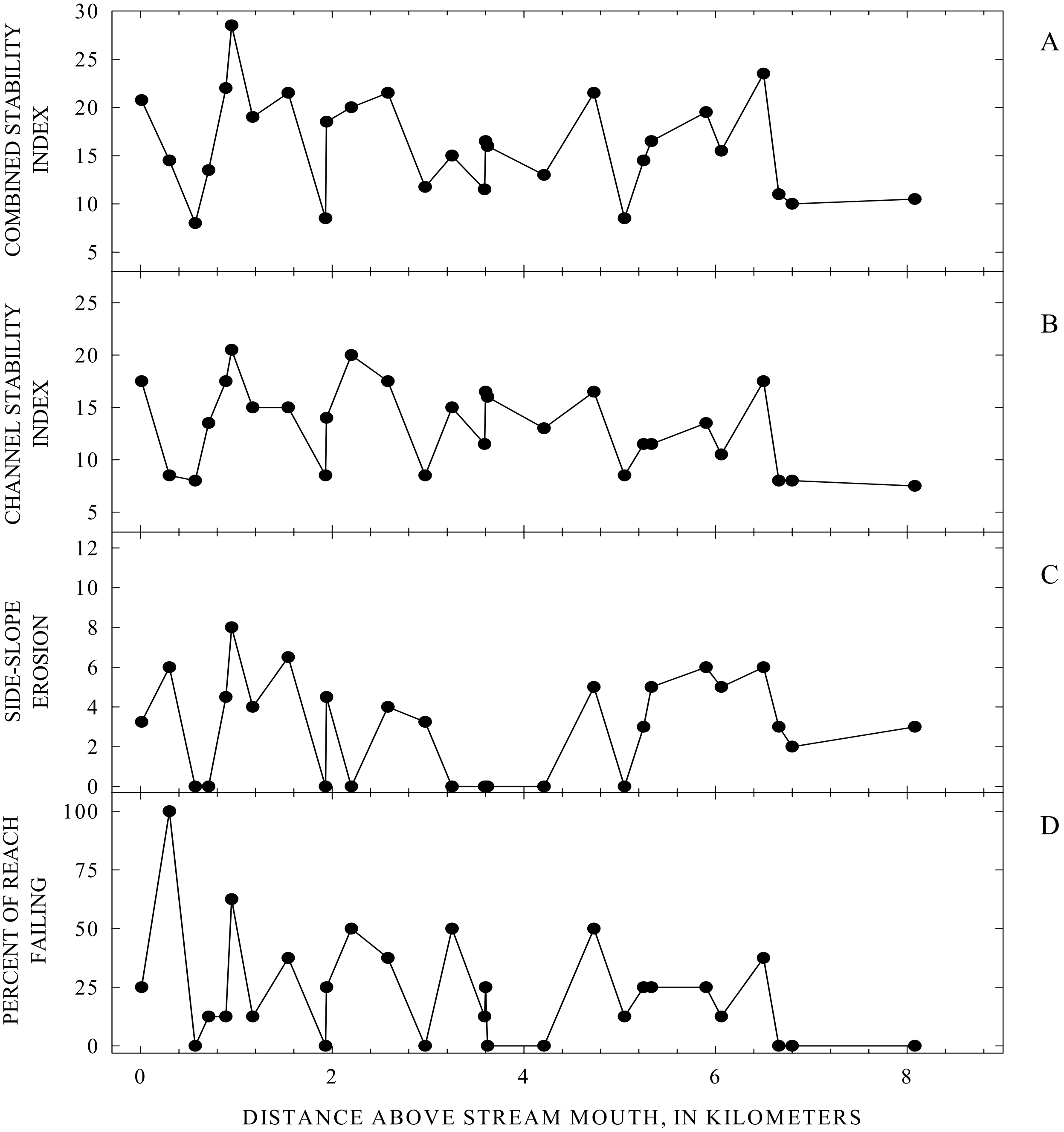


Figure 4-38. Results of RGAs conducted along General Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

4.6.5 Incline Creek

The assessed portion of Incline Creek consists of two major reaches spanning the lowest 5.7 km of the watershed: an upper weathered granite valley and a lower riparian-buffered urban channel (Figure 4-41).

The assessment of the upper, weathered granite valley began at the confluence of the two major forks and ended 2.7 km downstream where the stream entered a 0.6 km-long culvert passing beneath the Diamond Peak ski area. The channel is characterized by a steep gradient, boulder step pools, and cobble/boulder runs. The channel has narrow to non-existent floodplains. However, the floodplains are densely vegetated in alder and willow that tightly hold the low banks (less than 1 meter high) together (Figure 4-39). Colluvial boulders frequent the channel, and granite bedrock banks encroach on the channel occasionally. The granite bedrock typically has a well-weathered surface. Bank-erosion potential of this section is considered low. Only two streambank locations have been noted where the rock had weathered into soil and was able to directly contribute fine sediment to the stream (Hotspots 11 and 12, Table 4-11).

Figure 4-39. Typical channel along the upper reaches of Incline Creek. Dense alders and grass protect the low banks from eroding.

Table 4-11. Summary of reconnaissance-level evaluation of areas of streambank instability and delivery of fine-grained sediments along Incline Creek. UTM zone for Nevada is 10; 11 for California.

Erosion hotspot	Hotspot location (UTM)		Source of fine sediment	Relative erosion magnitude
	Easting	Northing		
1	766104	4351381	undercut banks	low
Lakeshore Road bridge. USGS stream gage 10336700				

2	766142	4351303	bank scour at foot of boulder steps	low
3	766154	4351289	undercut banks	low
4	766176	4351263	undercut banks, bed slightly incised	low
Hwy 28 bridge. USGS stream gage 103366995				
5	766200	4351272	1 m high fill bank scoured at high flows	low
6	766236	4351236	veg removed from L bank and 1 m high banks eroding	moderate
7	766237	4351186	1 m high undercut and slumping banks	moderate
8	766221	4351143	0.5 m high eroding banks	moderate
9	766217	4351138	veg removed from L bank	moderate
10	766155	4351071	undercut L bank	low
11	766148	4350962	disintegrating granite bank	low
USGS stream gage 103366993				
12	766212	4350879	disintegrating granite bank	low

The stream exits the culvert under the ski area and begins to pass through the 2.4 km long riparian-buffered urban reach (Figure 4-41) which ends at Lake Tahoe. Along this section the gradient is reduced and stream form becomes cobble runs and gravel pool-riffles. The urban quality of the reach is expressed through numerous culverted road crossings, and riparian vegetation varying with land use. Banks in several locations experience minor undercutting as the channel gets larger and deeper progressing downstream. The erosion potential is slightly higher along reaches where the riparian vegetation has been removed (Figure 4-40). The overall bank erosion potential for the reach is considered to be low.

Figure 4-40. Lack of vegetation increases potential for erosion on the left bank along the urbanized reach of Incline Creek.

The lower urbanized reach has a greater number of streambank exposures and there are two apparent reasons. Firstly, the channel becomes progressively larger downstream until the banks are higher in places than the depth of plant roots. Secondly, removal or alterations to vegetation in the riparian zone have created short reaches where the banks have been left with inadequate root support. However these areas are infrequent making the overall fine sediment availability rating of the channel low.

4.6.5.1 Summary

Grain-size analyses indicates that the bed is typically less than 1% silt and clay and, therefore, does not have a large amount of fine material available for erosion. Bank face material ranges from 0 to 13% in silt/clay content through out the entire 5.7 km assessed. However the the banks of the upper colluvial valley reach have few exposures due to typical bank heights less than 1 meter, colluvial boulders protecting the banks, and dense vegetation near the water's edge and therefore what fine sediment is in the streambanks is protected from erosion. However, narrow to non-existent floodplains do not offer a substantial riparian buffer to fine sediment eroding from the uplands (Figure 4-44 C). The lower urbanized reach has a greater number of streambank exposures. These areas, however, are infrequent making the fine-sediment availability rating of the channel low (Figure 4-41). Overall, failing reaches along the channel are few (Figure4-44 D making the fine-sediment availability rating "low" for the majority of the channel (Figure 4-41).

Geomorphic interpretations made during the stream walk and evaluated during RGAs are further summarized spatially with maps depicting the:

(1) combined-, channel-, and side-slope erosion indexes (Figure 4-42), and

(2) the occurrence of bank failures combined with fine-grained content of the streambanks (Figure 4-43).

In addition, results are shown graphically, displaying these data relative to distance above the stream mouth (Figure 4-44).

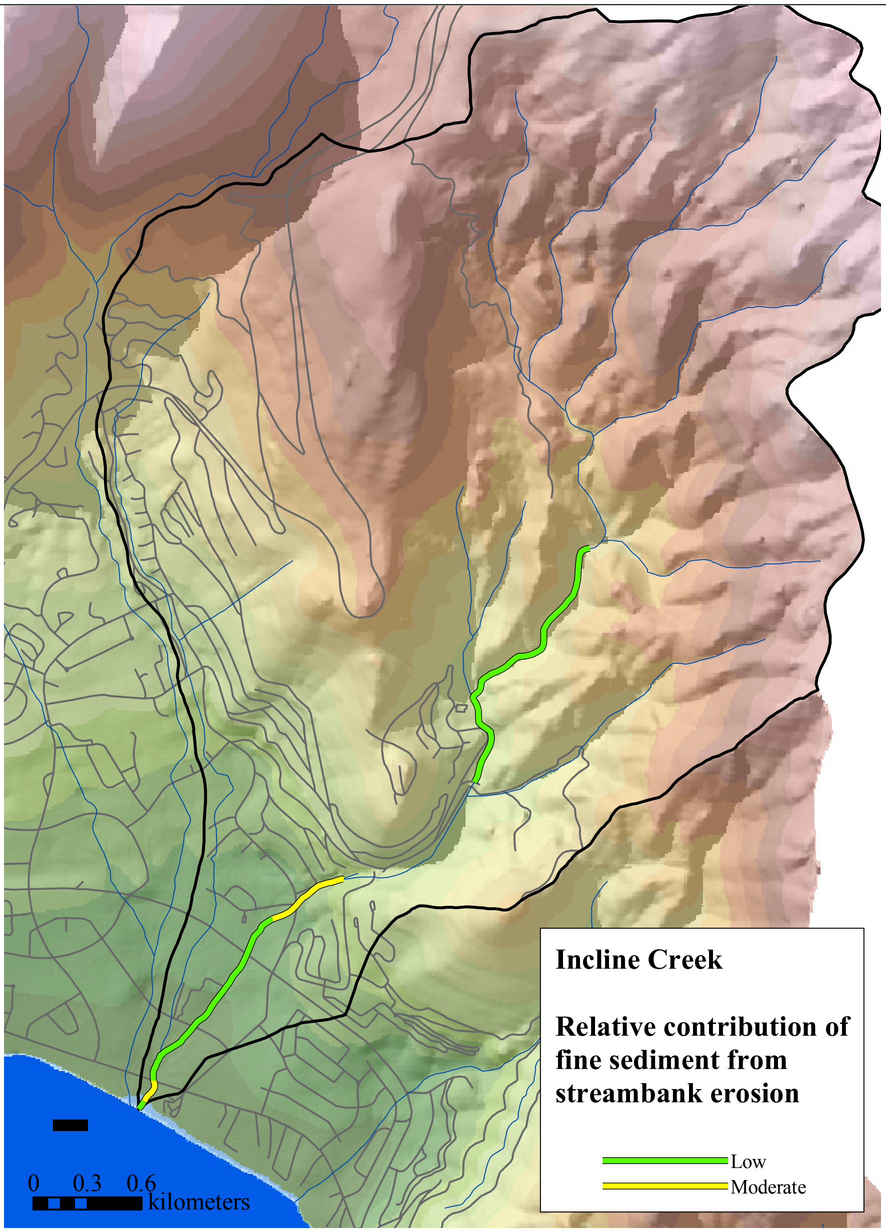


Figure 4-41. Map of the relative contribution of fine sediment from streambank erosion for Incline Creek.

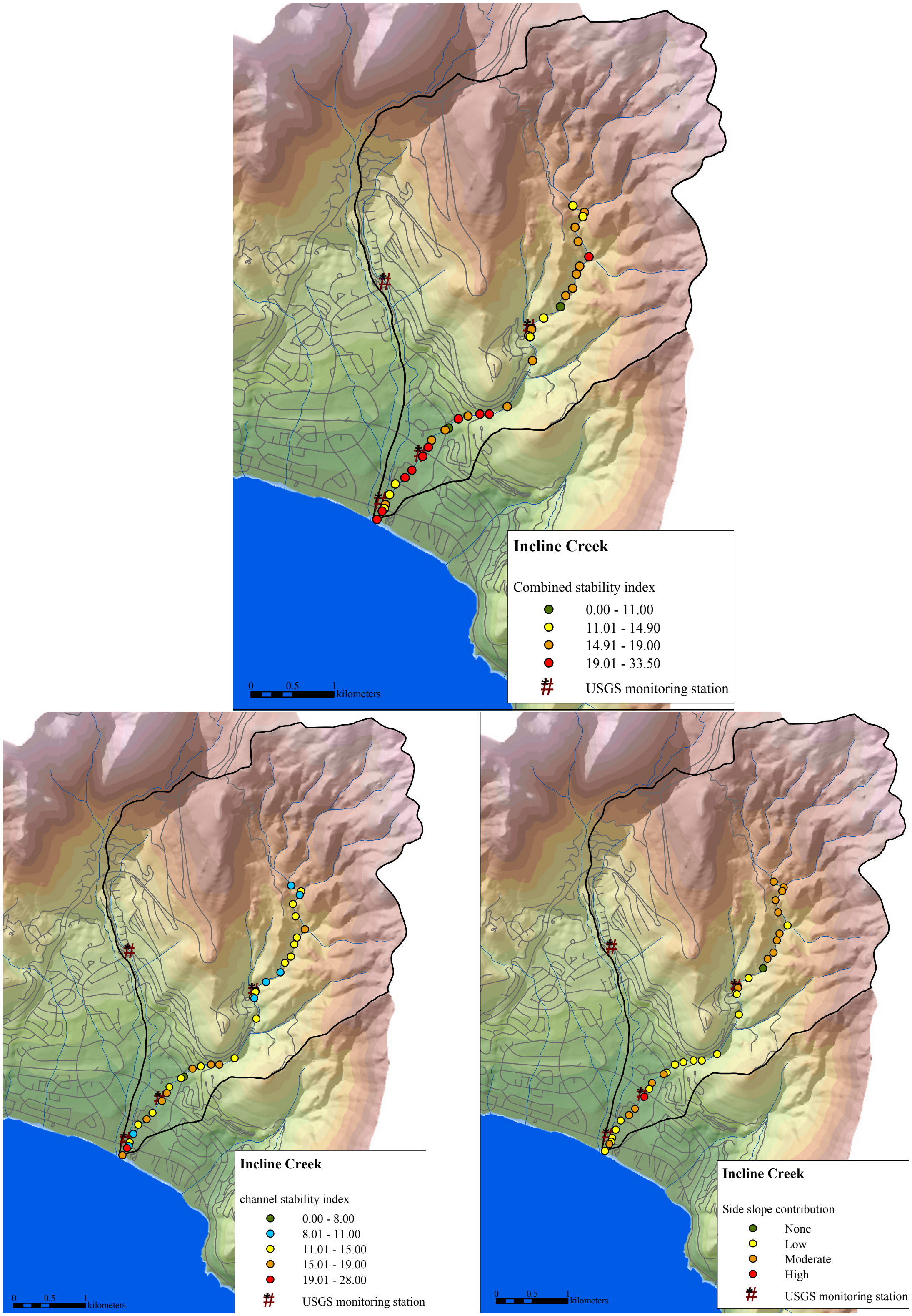


Figure 4-42. Results of rapid geomorphic assessments of Incline Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

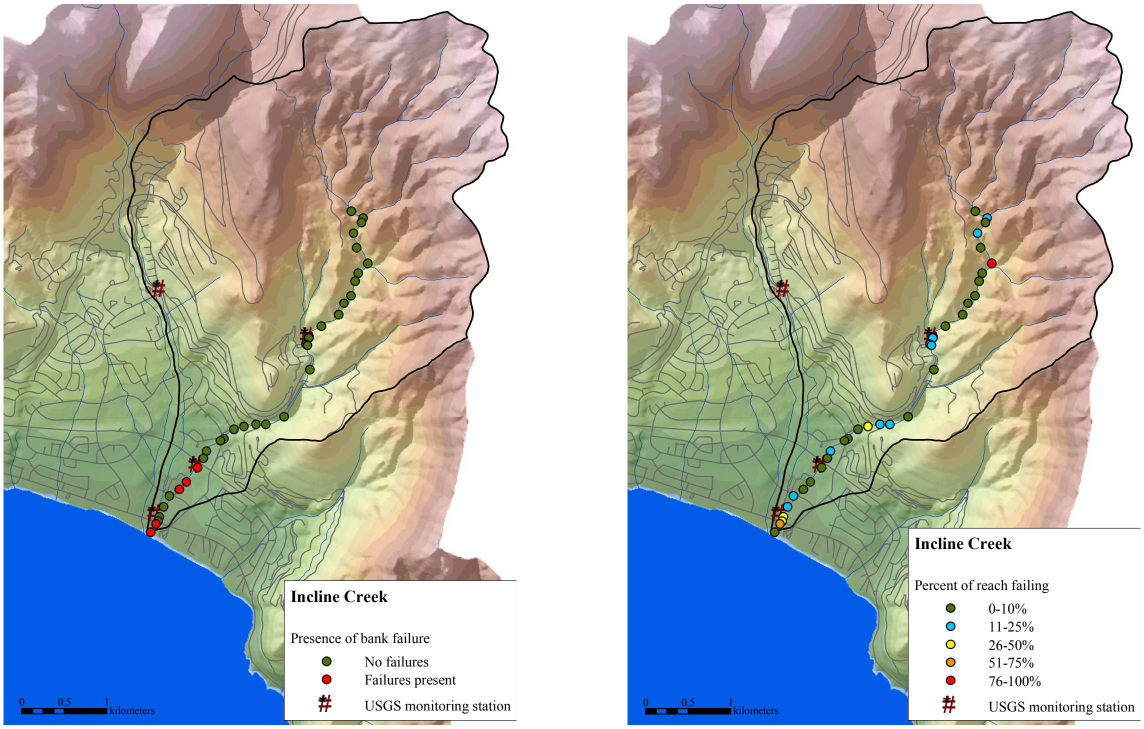


Figure 4-43. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along Incline Creek.

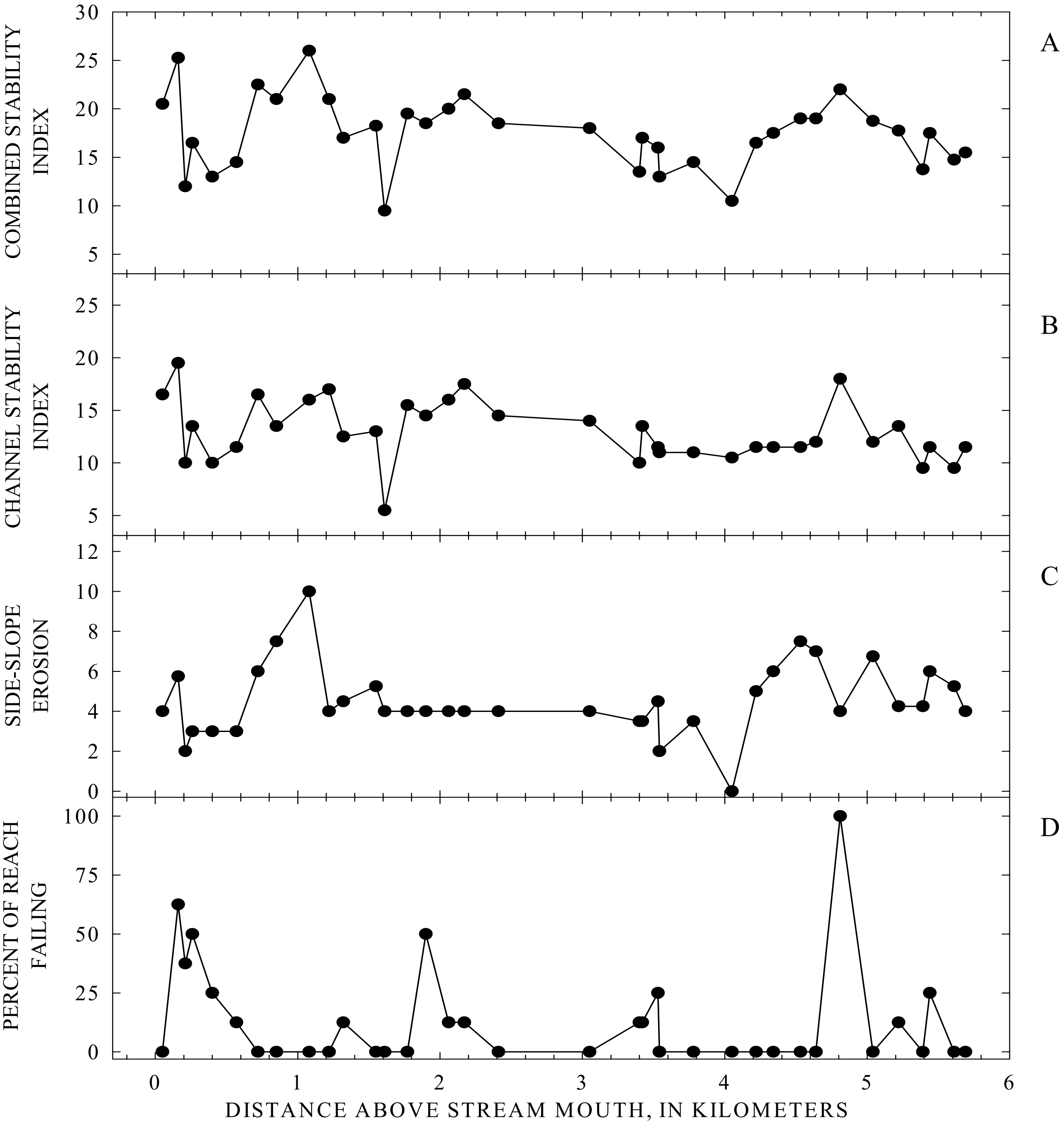


Figure 4-44. Results of RGAs conducted along Incline Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

4.6.6 Logan House Creek

The assessed portion of Logan House Creek covers 4.0 km and consists of three major reaches: an upper meadow reach, a colluvial valley, and a neighborhood reach (Figure 4-45).

The upper meadow reach encompasses the first 1.5 km below the upper Forest Service road crossing. The channel crosses a gently cupped valley densely covered with aspen, willows and grass. Progressing downstream, the vegetation transitions into a pine forest with dense cover of alder, aspen, and grass in the riparian zone. Bank heights are less than 0.5 m, and vegetation on the bank edge is rooted all the way to the bank toes and prevents virtually any stream bank erosion from taking place.

The channel is characterized over the next 1.8 km as flowing through a colluvial valley. Valley slopes encroach on the channel and colluvial boulders frequently control the channel form through step-pools. Floodplains are very narrow, one or two m typically, but they are densely covered with alder and dogwood. Bank heights are less than 0.5 m. Although there are many fallen pine trees, most were so large that they spanned the channel high above the bank tops. If a large tree happened to fall parallel and into the channel, it could generate fine sediment through local bank scour. Overall, the bank erosion in this reach was negligible.

Over the lowest 0.7 km above the mouth, Logan House Creek flows through a residential neighborhood. Bank-erosion potential is negligible. Only two minor erosion points have been noted. One is a 1 m-high bank of fine material lacking root support. The other is a yard where all vegetation and duff has been removed all the way to the water's edge (Hotspots 1 and 2, Table 4-12).

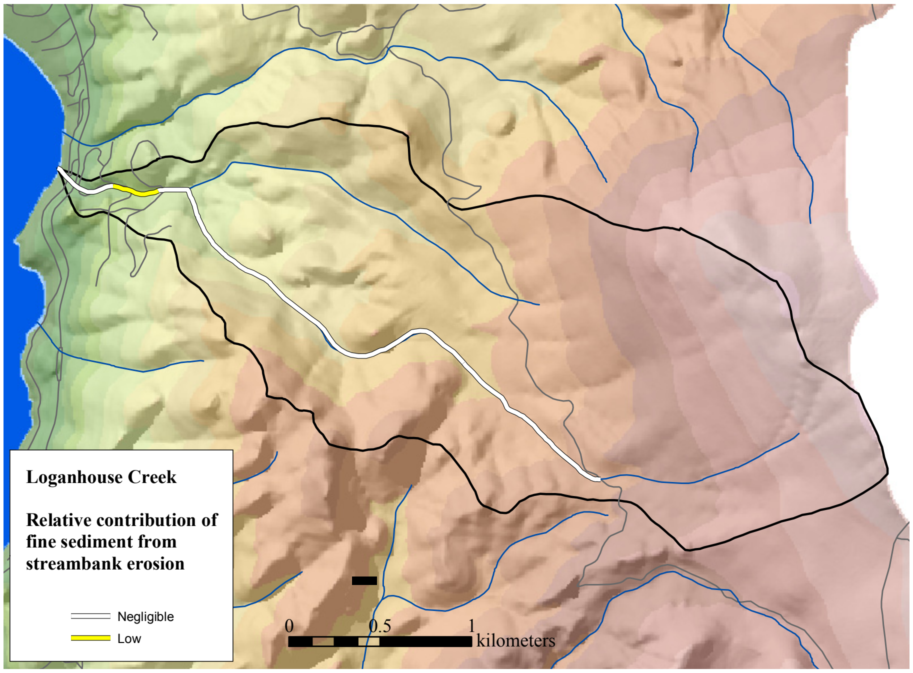


Figure 4-45. Map of the relative contribution of fine sediment from streambank erosion for Logan House Creek.

4.6.6.1 Summary

Logan House Creek is a stable stream producing negligible amounts of sediment from channel sources (Figure 4-48). Grain-size analyses indicate that silt and clay sized particles make up about 1% of the bed. Bank material was not analyzed due to the minimal amount of bank surface exposed to flow and the high density of plant roots binding the bank material. Overall, the bank heights less than 0.5 m and dense grass growth to the water's edge leave little exposed steambank area. The narrow channel typically has a well-vegetated floodplain, albeit narrow in the lower, steeper reach, that serves to buffer the stream from the downslope flow of upland materials (Figure 4-48 C).

Table 4-12. Summary of reconnaissance-level evaluation of areas of streambank instability and delivery of fine-grained sediments along Logan House Creek.

Erosion hotspot	Hotspot location (UTM)		Source of fine sediment	Relative erosion magnitude
	Easting	Northing		
1	764987	4328436	1 m high eroding bank	low
2	765049	4328420	bare banks above road	low
USGS stream gage 10336740				

Geomorphic interpretations made during the stream walk and evaluated during RGAs are further summarized spatially with maps depicting the:

(1) combined-, channel-, and side-slope erosion indexes (Figure 4-46), and

(2) the occurrence of bank failures combined with fine-grained content of the streambanks (Figure 4-47).

In addition, results are shown graphically, displaying these data relative to distance above the stream mouth (Figure 4-48).

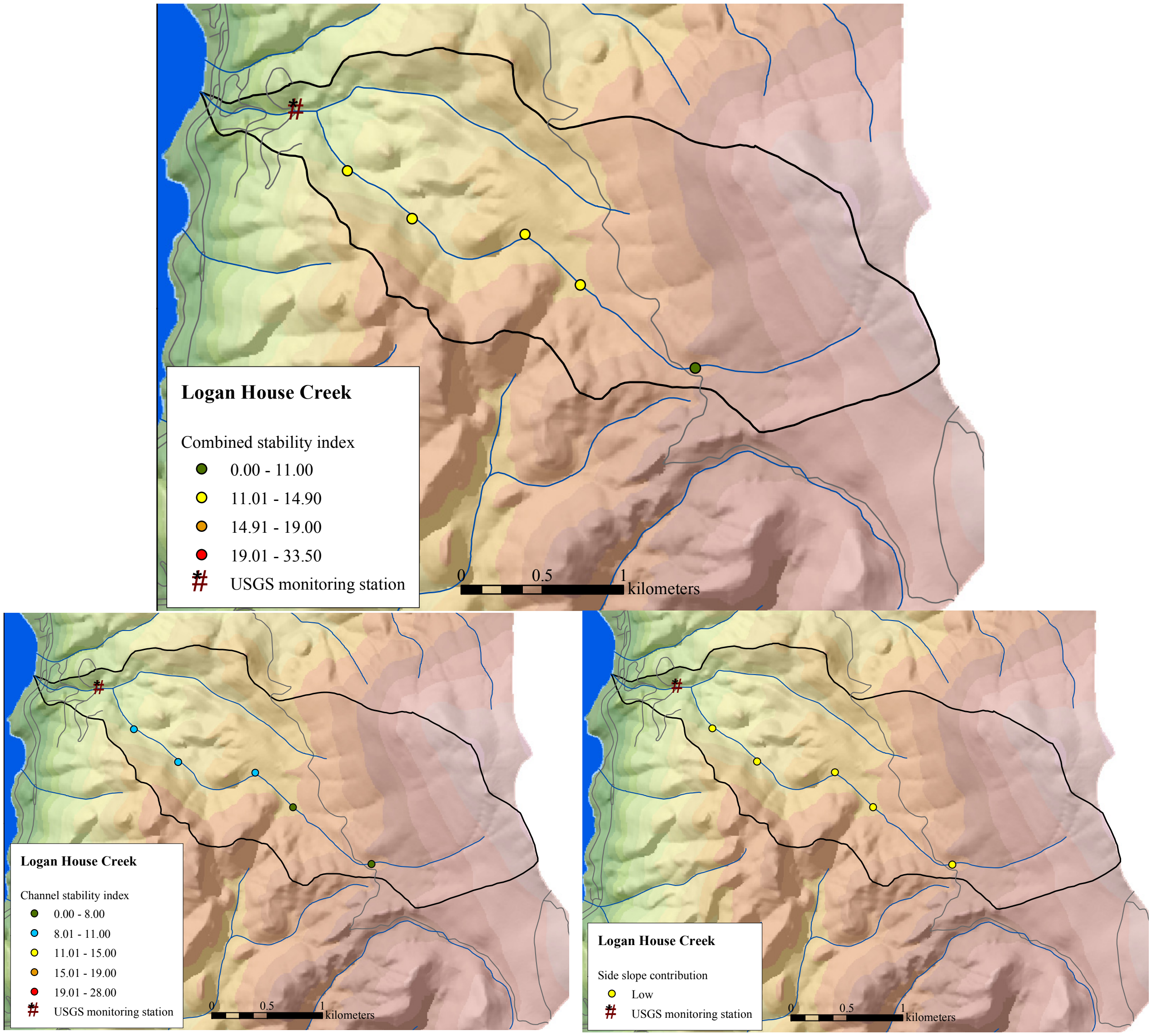


Figure 4-46. Results of rapid geomorphic assessments of Logan House Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

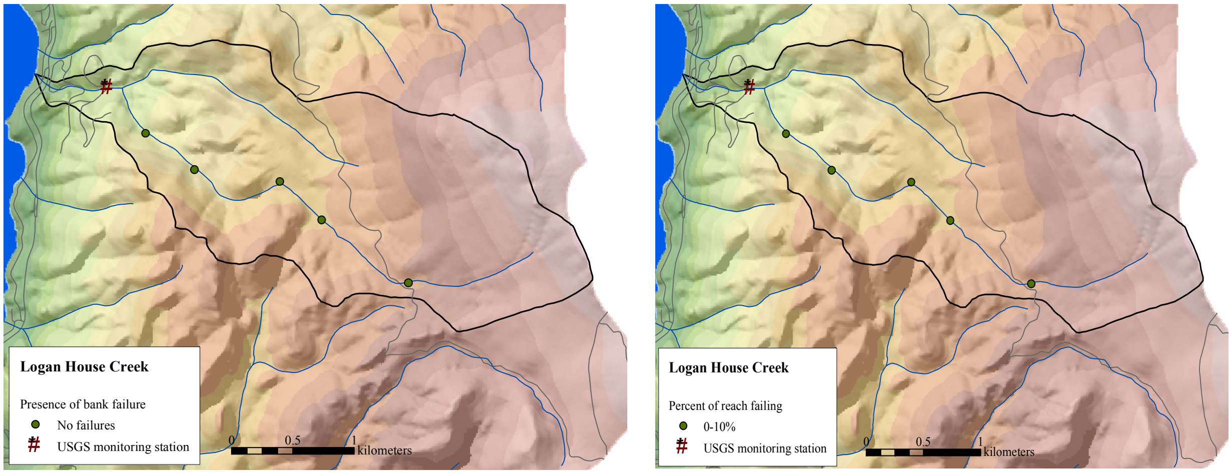


Figure 4-47. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along Logan House Creek.

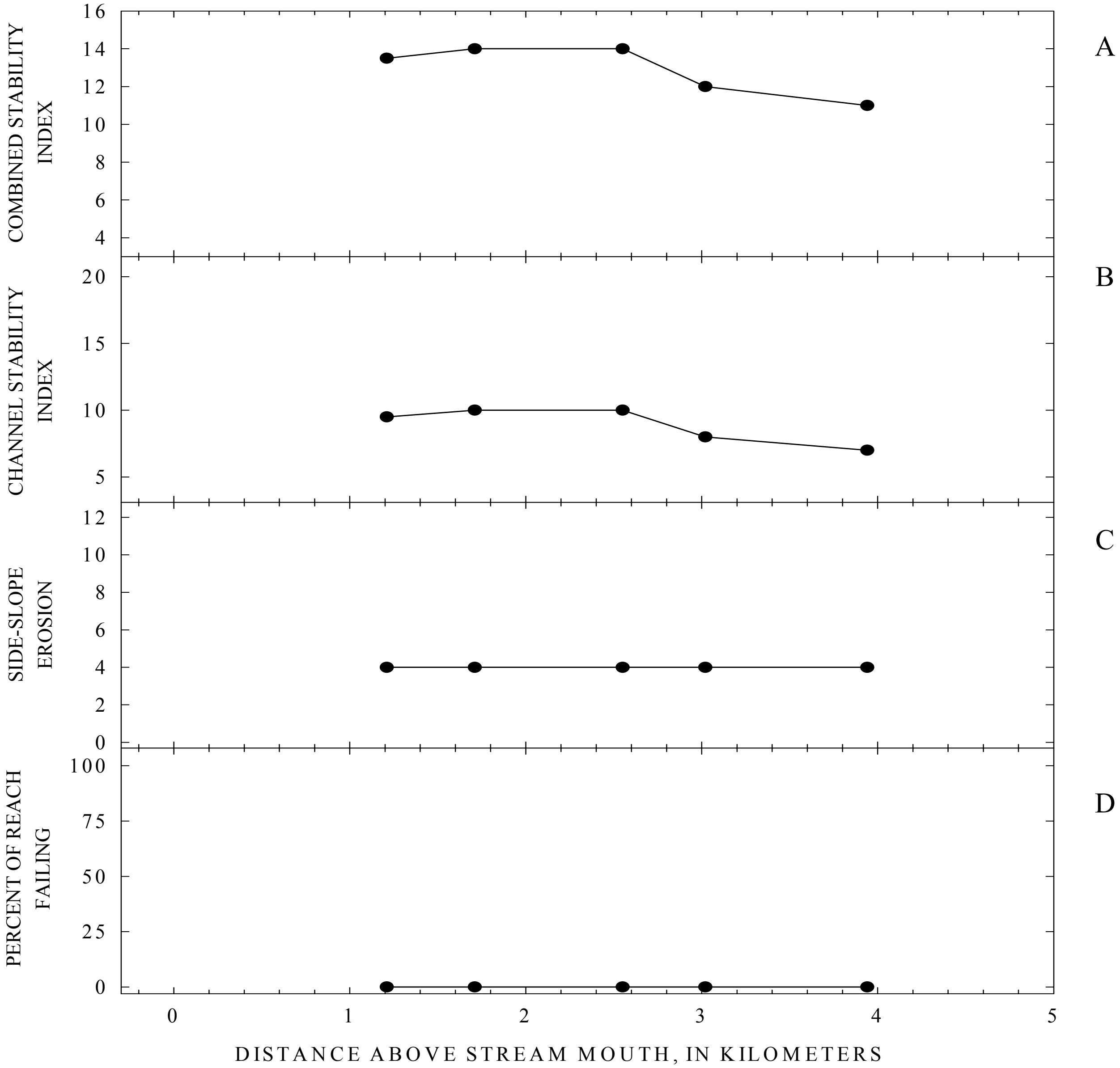


Figure 4-48. Results of RGAs conducted along Logan House Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

4.6.7 Edgewood Creek

Edgewood Creek was not evaluated by stream walks but assessed by conducting RGAs at ten locations historically surveyed by Hill *et al*. (1990), plus two additional locations just above and below Highway 50 near Stateline, Nevada. Locations assessed are on the main channel as well as on tributaries. The watershed can be divided into two reaches: the alluvial plain and the highland. The division is based on the change of channel gradient from about 0.03 m/m along the alluvial plain to about 0.05 m/m along the highland.

In the alluvial plain reach, the lowest 3 km of channel, the outwash plain between the mouth and Highway 50 has been developed as a golf course. The channel has been relocated to suit the golf course layout, and several ponds pool the stream. The banks are stabilized through mesh encased gravel logs buried along the bank-toes. Grass, established in the gravel logs and adjacent soil, provides a protective root mass that prevents scour behind the gravel logs (Hotspot 1, Table 4-13). Above Highway 50 the channel is stable. The bank heights are less than 0.5 meters and the banks have a dense willow coverage (Hotspot 2, Table 4-13). A dam on the channel creates a small reservoir 300 meters above Highway 50. The third assessed location (Hotspot 3, Table 4-13) had greater visible bank erosion than the downstream sites (Figure 4-49 D). However low bank heights and coarse bank material, limit the size of the bank exposed to fluvial erosion and the amount of fine material available for transport. Therefore the overall fine sediment erosion rating for this reach is low.

The highland reach was assessed at one location along the main stem of the north fork (Hotspot 7, Table 4-13), at four locations on tributaries to the north fork (Hotspots 6, 10-12, Table 4-13), and at three locations (Hotspots 5, 8, 9, Table 4-13) along the main stem of the south fork (Figure 4-51). The percent of reach failing is typically low at all assessed locations with a greater number of higher ratings occurring on the northern fork. However, bank heights of less than 0.7 m, and few other noted erosion spots indicate that overall channel contributions of fine sediment are low along the north fork. Channel conditions along the south fork appear more stable (Figure 4-50 channel stability index) to those of the north fork. Bank heights are less than one meter, and there are few obvious areas of erosion. The overall potential for fine-sediment supplied by channel erosion appears low for the South Fork.

Table 4-13. Summary of reconnaissance-level evaluation of areas of streambank instability and delivery of fine-grained sediments along Edgewood Creek.

Erosion hotspot	Hotspot location (UTM)		Source of fine sediment	Relative erosion magnitude
	Easting	Northing		
USGS stream gage 10336765				
1	764449	4317360	None	low
Hwy 50 bridge. USGS stream gage 10336760				
2	765408	4317292	LWD induced scour	low

3	766549	4317041	0.7 m high failing banks	low
USGS stream gage 103367585				
4	767358	4317353	0.5 m high eroding banks	low
5	768221	4317707		low
6	768513	4318230	Erosion on both banks	moderate
Kingsbury Grade bridge. USGS stream gage 10336756				
7	769064	4318842	Fines eroding from both banks	low
8	769227	4317449		low
USGS stream gage 10336750				
9	769444	4317516		low
10	769594	4319113	Both banks eroding	moderate
11	769594	4319113	Left bank mass wasting	moderate
12	769594	4319113		low

4.6.7.1 Summary

Edgewood Creek, based on limited data, overall appears to have a low quantity of fine material readily available for erosion through fluvial action. The channel is stable along its lowest 5 km (Figure 4-49 A) and, although the channel becomes less stable near the headwaters, the fact that the channel is physically small limits the amount of sediment that can be liberated during a high flow event (Figures 4-49 A-D). Overall fine-sediment availability from both the alluvial plain and highland is deemed low. These observations are in general agreement with the analysis of historical cross sections shown in Table 4-2.

Geomorphic evaluations conducted during RGAs are further summarized spatially with maps depicting the:

(1) combined-, channel-, and side-slope erosion indexes (Figure 4-50), and

(2) the occurrence of bank failures combined with fine-grained content of the streambanks (Figure 4-51).

In addition, results are shown graphically, displaying these data relative to distance above the stream mouth (Figure 4-49).

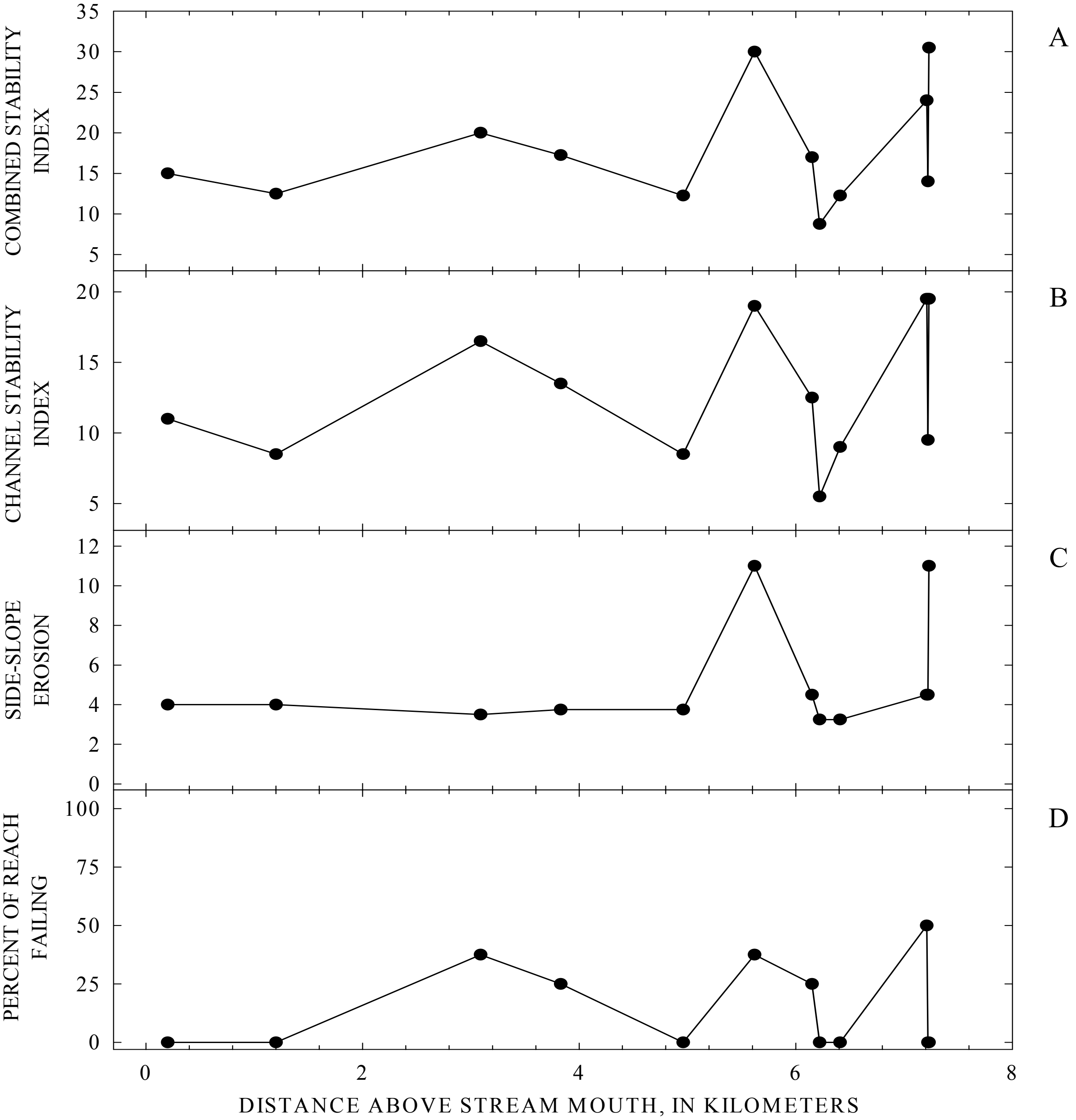


Figure 4-49. Results of RGAs conducted along Edgewood Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

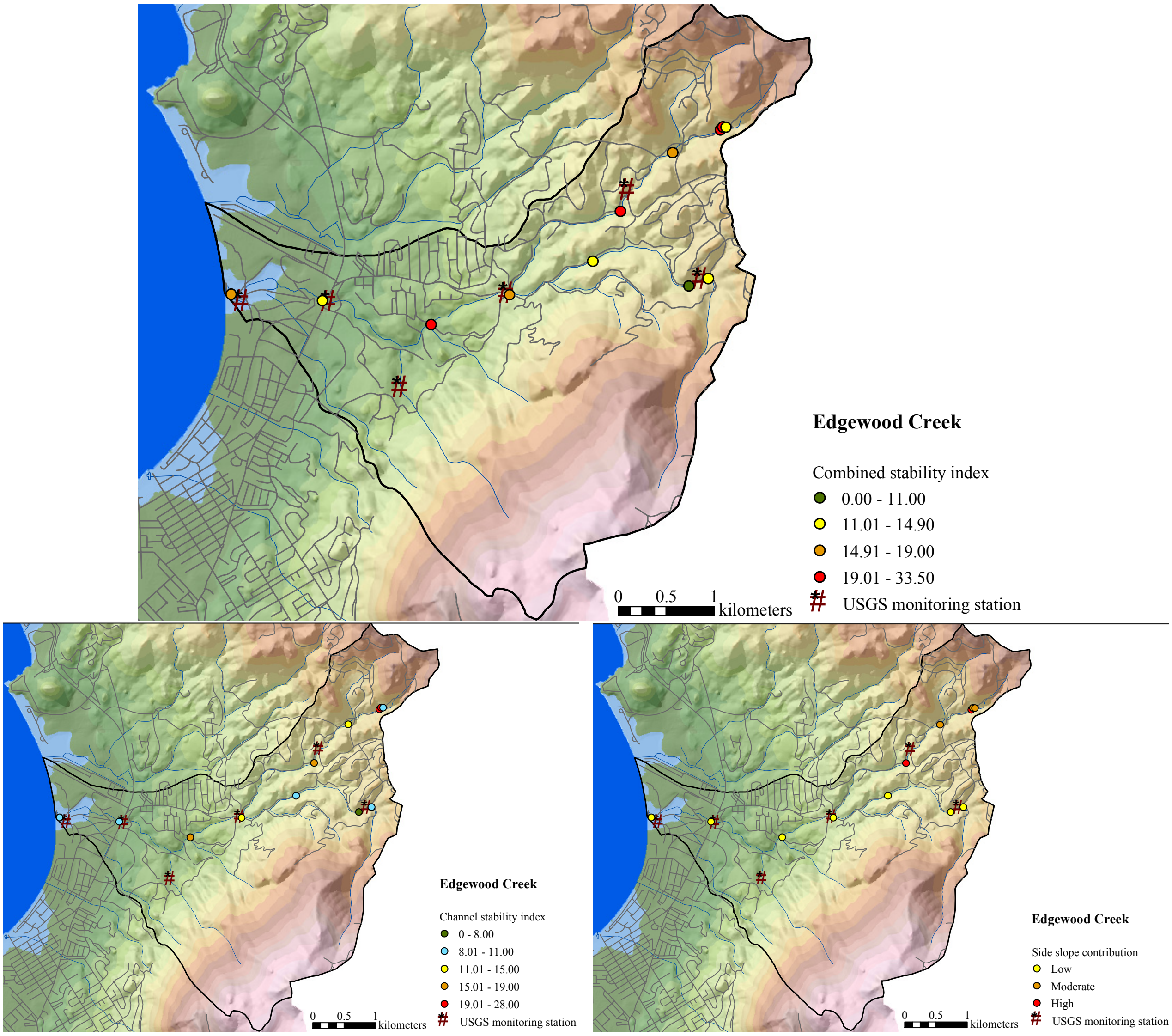


Figure 4-50. Results of rapid geomorphic assessments of Edgewood Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

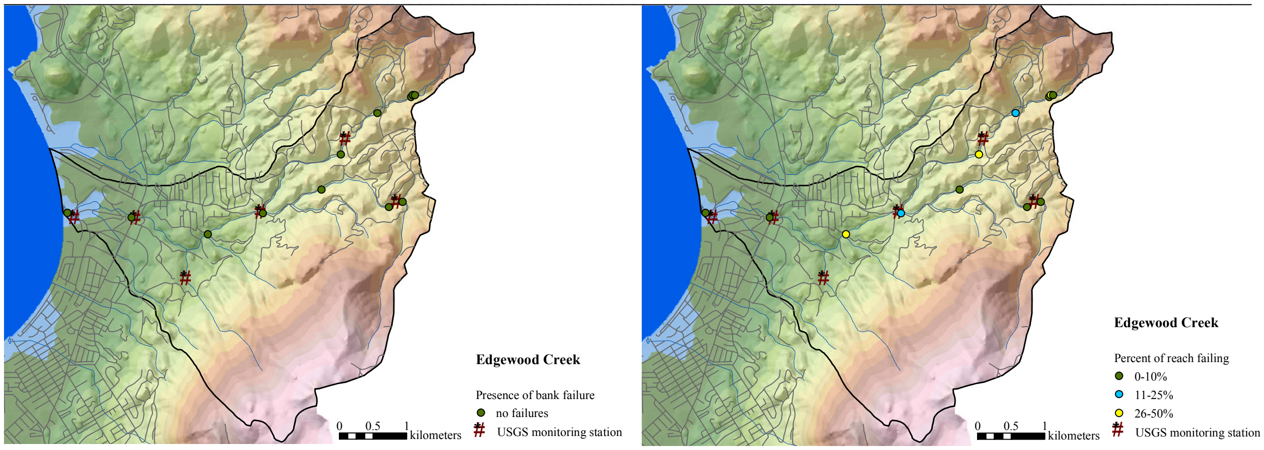


Figure 4-51. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along Edgewood Creek.

4.7 Basin-Wide Evaluations of Channel Conditions

To provide greater spatial resolution around the Lake Tahoe, watersheds particularly in those locations where no stream gage data exists, RGAs and sampling of streambeds and banks were conducted. Including the evaluations that were carried out in the seven intensely studied watersheds, 304 sites were visited between September and November, 2002 (Figure 4-3). The combined stability index for all sites is shown in Figure 4-52 providing a basin-wide management tool to identify potentially high-erosion stream reaches. As with the larger-scale maps of individual watersheds, those sites marked by red, have index values of 19 or above, indicating a marked degree of instability and enhanced sediment production. Sites shown in green and yellow conversely are relatively stable. Maps showing the relative contributions of channel and side-slope characteristics making up the combined stability index are shown in Figure 4-53 as a means of assessing the dominant processes effecting a given reach or stream. It deserves repeating that the side-slope index is not a measure of upland sediment production throughout a given watershed, but instead represents potential sediment contributions to channels from adjacent slopes and terraces.

With streambanks providing a potentially significant proportion of the suspended sediment in streams in the Lake Tahoe watershed, critical areas can be identified in Figure 4-54A and Figure 4-54B by locating those sites that have a combination of a high percentage of banks failing and relatively high silt-clay contents in their banks. Reaches of the Upper Truckee River stand out in this regard as do sections of the wetter western streams. For overall channel-stability conditions across the Lake Tahoe Basin, evaluations of stage of channel evolution provides information on the ongoing vertical and lateral processes for assessed stream reaches. Stages I and VI are indicative of stable channels, while III, IV, and V indicative of varying degrees of instability. Bank failures and channel widening peak during stage IV and are shown in red. Note the generally stable conditions for streams draining the eastern quadrant of the watershed as well as tributaries in the southwest, and even the middle and upper reaches of Incline Creek in the north. Unstable conditions are typical along the Upper Truckee River (except for the boulder reaches) as well as along the western streams, including General Creek. The majority of the unstable streams in the basin are stage V, characterized by widening and deposition on the bed.

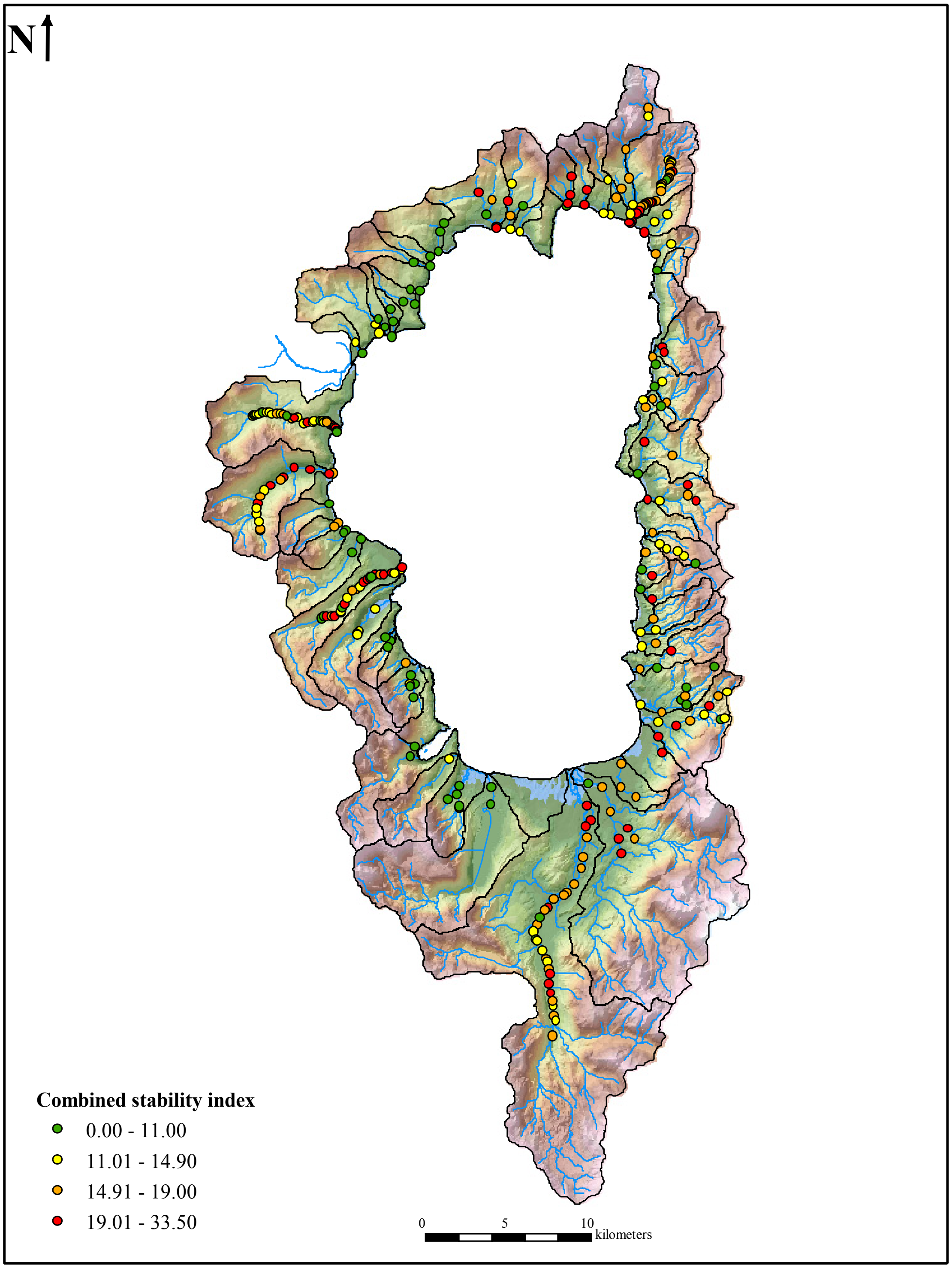


Figure 4-52. Spatial distribution of combined stability index for 304 sites.

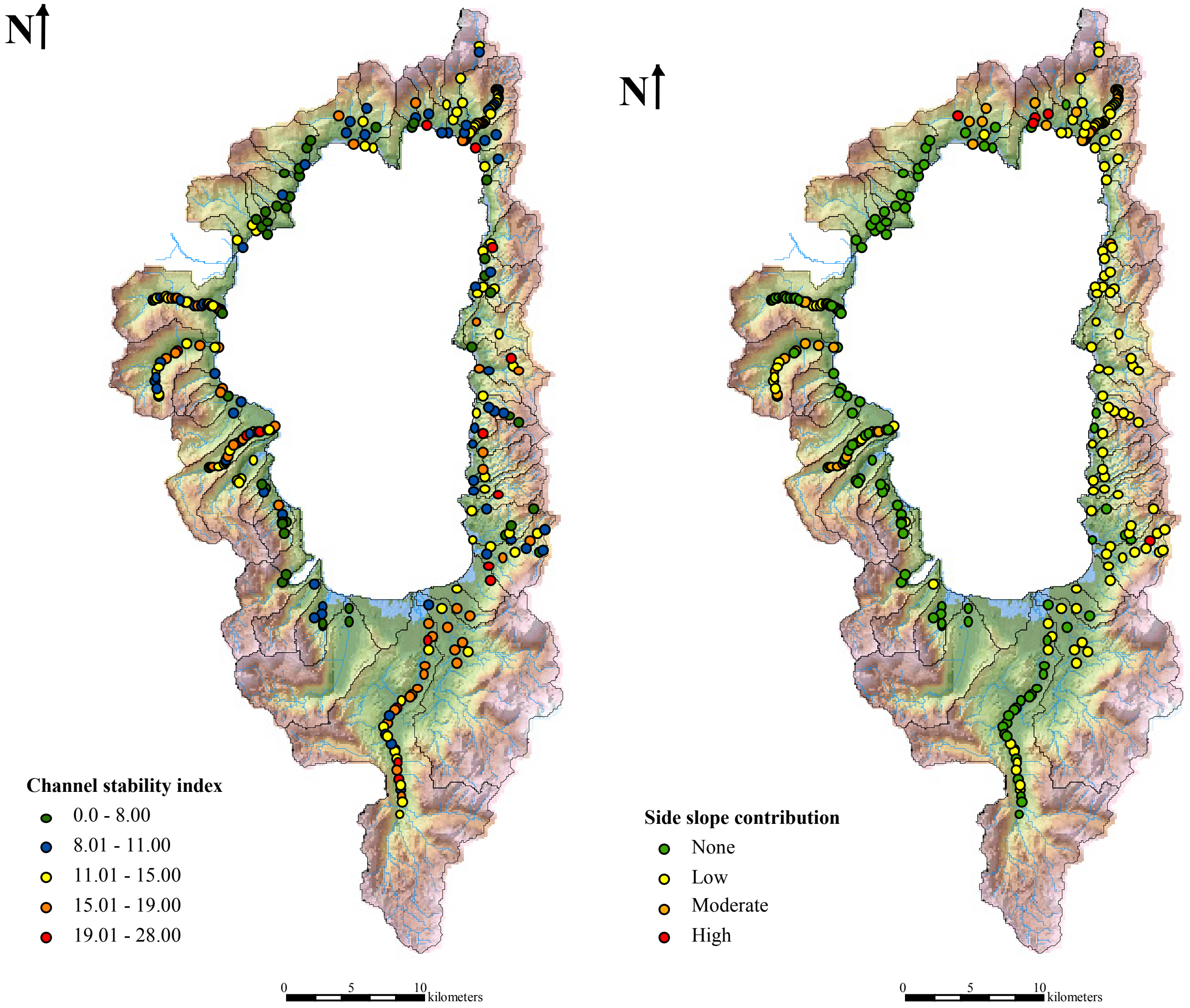


Figure 4-53. Channel-stability (left) and side-slope erosion indexes (right) used to distinguish relative contributions of sediment.

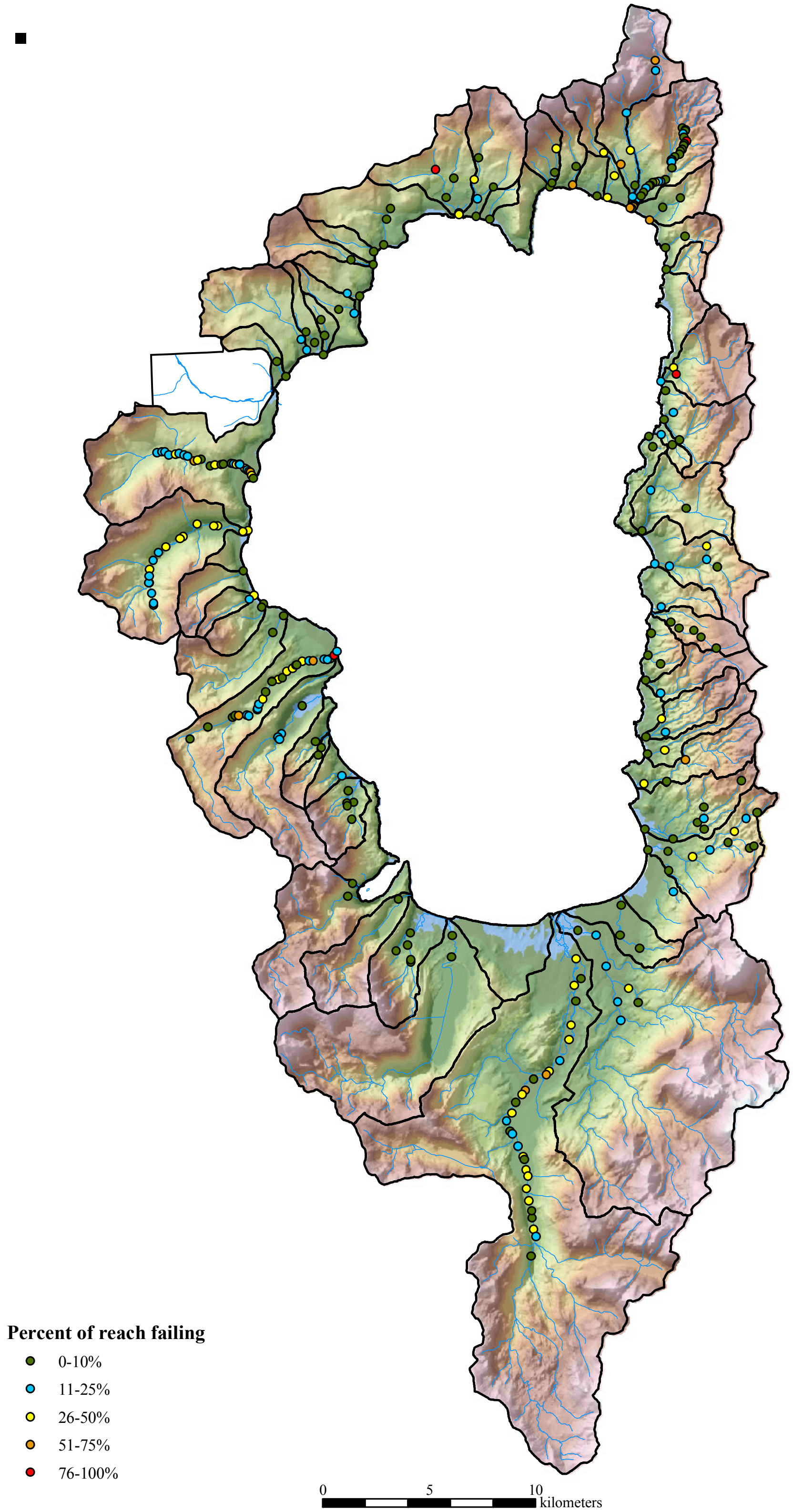


Figure 4-54A. Percent of left and right banks that are failing to be used collectively with Figure 4-54B as a measure of fine-sediment contributions from eroding streambanks.

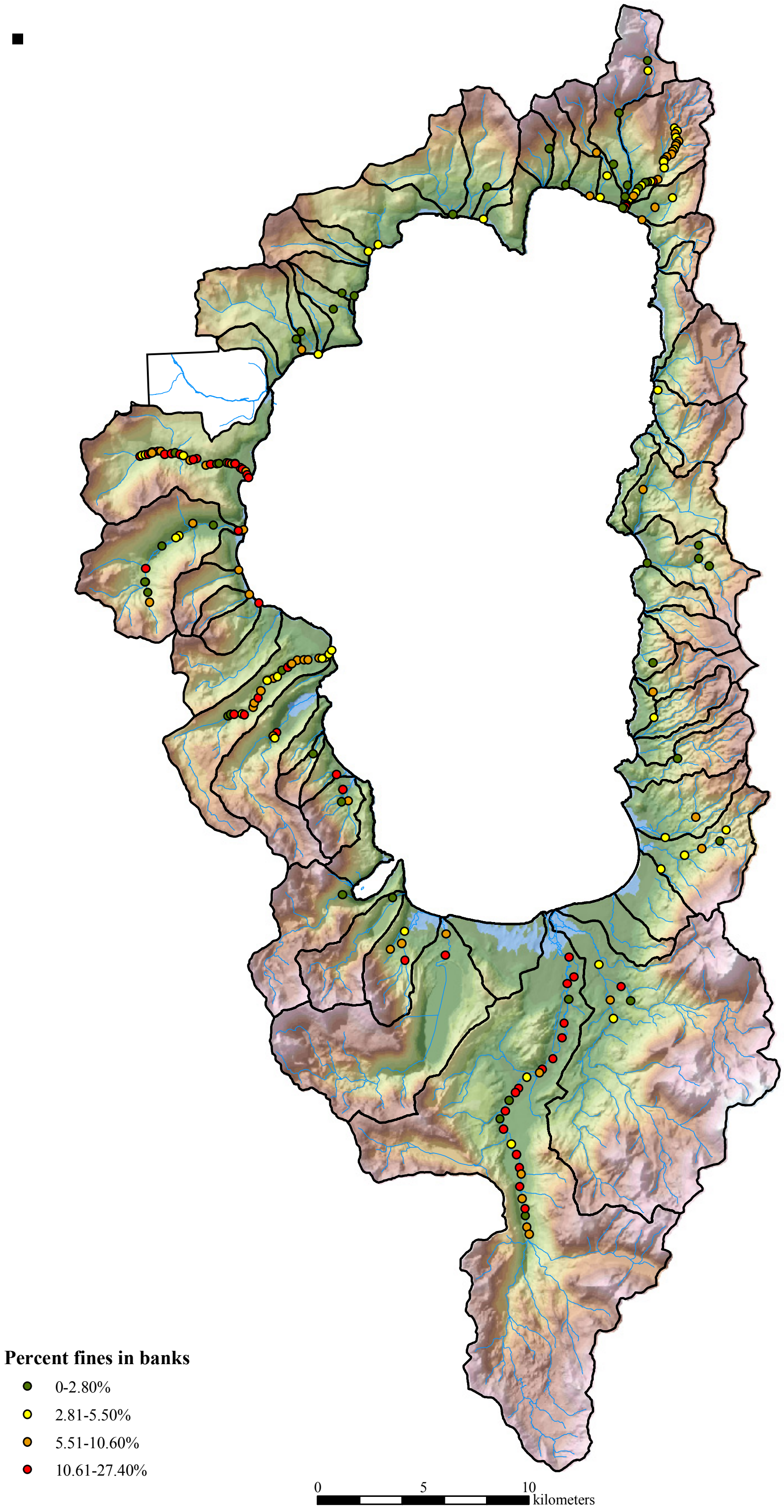


Figure 4-54B. The relative fine-grained (silt plus clay) content in the streambanks to be used collectively with Figure 4-54A as a measure of fine-sediment contributions from eroding streambanks.

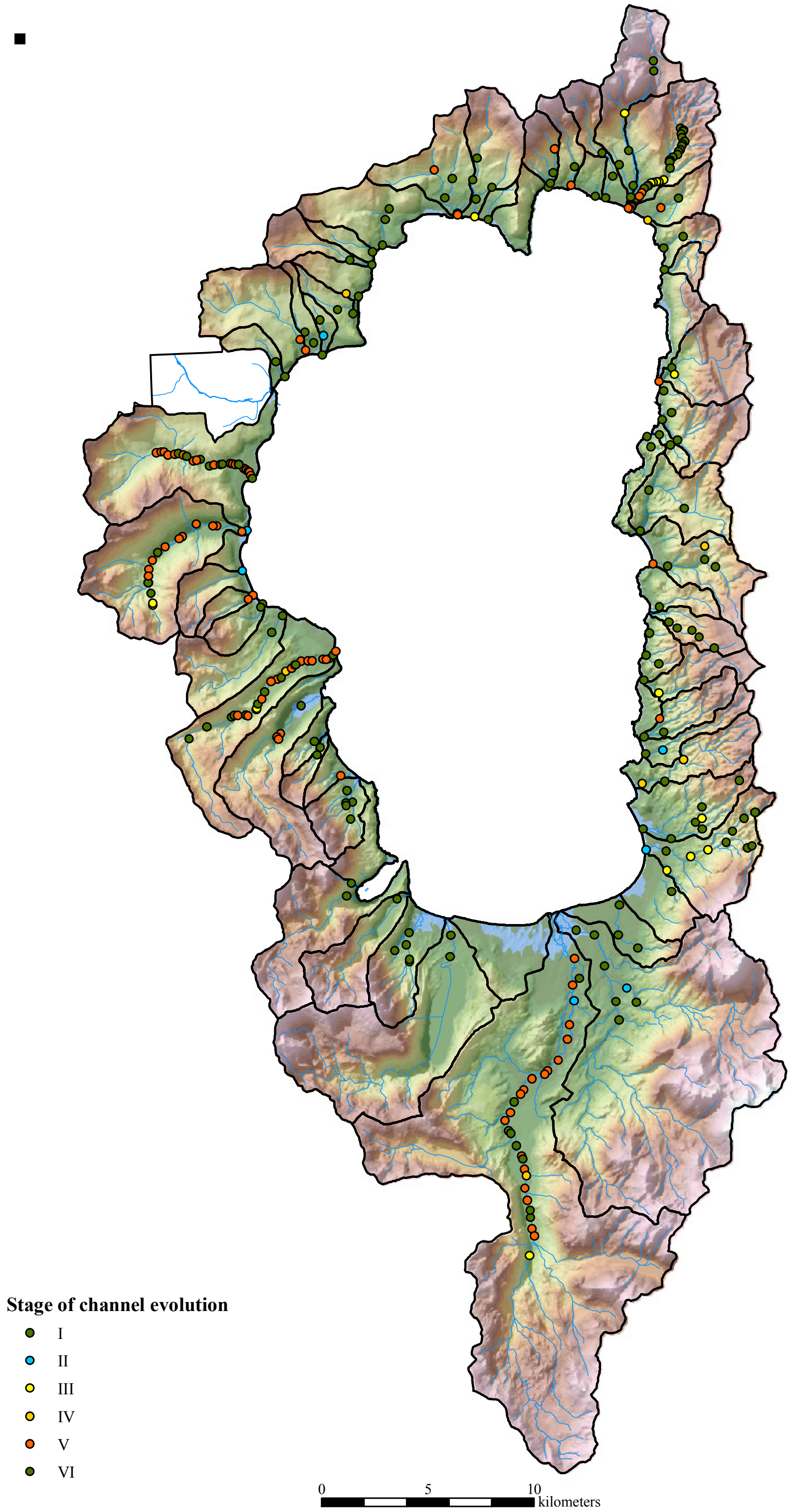


Figure 4-55. Spatial distribution of stages of channel evolution. Stages I and VI are indicative of stability; stages IV and V are indicative of degradation and widening, and aggradation and widening, respectively.

5 NUMERICAL MODELING OF GENERAL AND WARD CREEKS AND THE UPPER TRUCKEE RIVER

5.1 Introduction

Numerical simulations of upland and channel processes using AnnAGNPS and CONCEPTS, respectively were carried out on three representative watersheds comprising General and Ward Creeks, and the Upper Truckee River to:

1. Determine the relative contributions of sediment from upland and channel sources;
2. Simulate the effects of the January 1997 runoff event on future sediment loads;
3. Evaluate 50-year trends in suspended-sediment delivery to Lake Tahoe from the three watersheds.

Results of the numerical simulations in these three watersheds will provide the only comparison of upland versus channel sediment sources in this study. Findings based on this modeling will not be extrapolated to the remainder of the Lake Tahoe watershed because of the great variability in basin and climactic characteristics.

5.2 Input Database for the AGNPS Model

The development of input parameters used for AnnAGNPS to describe the Lake Tahoe watersheds conditions involved assembling many sources of available information, such as elevation maps, soil data, land use and operation management data, and especially weather information. All of the required model parameters can be selected from the available data, which is available publicly or obtained from the measured data collection phase needed for CONCEPTS. The compilation of the data into the form needed by AnnAGNPS was performed using the AGNPS Arcview Interface and the AnnAGNPS Input Editor.

5.2.1 GIS Database

The use of a geographic information system (GIS) is critical in gathering the needed data to perform simulations for watersheds of the size contained in the Lake Tahoe basin. The GIS data provides the vital link between the characteristics of the watershed and the parameters needed by the model. Fortunately, for the Lake Tahoe basin there is a data warehouse that serves as a central location for much of the GIS data available for any watershed in the basin. The Lake Tahoe Data Clearinghouse Internet web site is produced by the United States Geological Survey (USGS) and is located at http://tahoe.usgs.gov/.

For the application of the entire suite of AGNPS, the basic GIS data needed are: the digital elevation models (DEMs) to describe the topography; the land use GIS layer to describe the vegetative cover; and, a soils GIS layer, which all together can provide the spatial variation of the important characteristics of the watershed. Additional GIS data is useful in assessing the creation of model parameters and the impact various features may have on the watershed system. This can include digitized quad sheets, aerial photographs, location of streams, roads, erosion control structures on fields and in the channels, lakes, and other features impacting the watershed. For information that is not available from digital sources, information may be digitized from other maps, or transferred from field work using global positioning system (GPS) techniques.

The projection used for the AGNPS data development by all of the GIS data layers was the UTM NAD27 zone 10 projection. This provided consistency among all of the layers when data was analyzed or paper maps were produced. Other GIS layers can easily be reprojected from another projection to the UTM projection.

Topographic Analysis

Every watershed has unique topography that is difficult to characterize without having maps that describe the elevation throughout the watershed. Topographic information is crucial in determining the watershed and subwatershed boundaries, channel locations, channel slopes, routing of flow from fields to channels to the watershed outlet, field slopes, travel time of flows, the RUSLE LS-factor, aspect and elevation of fields. The use of DEMs provides a convenient source of topographic information, but often is derived from basic topographic contours, such as USGS 7.5 minute quad maps. Thus, the resolution can range from 120m x 120m raster grids with 5m elevations, to 30m x 30m with 1m elevations, to 10m x 10m with 0.1m elevations, depending on the source of the DEMs. The 10m x 10m raster grid can provide a better definition of the watershed topography, but generates a much larger file size needed to store the data. Other considerations in using the 10m x 10m raster grid are that this will require more computer resources to execute the AGNPS topographic tools, such as more memory, more hard disk space, and additional computational time. Also, the 10m x 10m DEM raster grid is available from MARIS with the elevation provided in feet and requires the conversion to meters before using TOPAGNPS, while the 30m x 30m DEM already has the elevation in meters. The current modeling effort used 10m x 10m raster grid.

Digital Elevation Model (DEM)

The USGS Western Geographic Science Center created DEMs with 10m x 10m resolution from 18 7.5-minute quadrangle hypsographic maps that have 40 ft contours covering the entire Lake Tahoe Basin (Figure 5-1). From this DEM, each of the DEMs covering the watersheds of General Creek, Ward Creek, and Upper Truckee River were clipped and used individually for to develop AnnAGNPS data sets to minimize the computational time needed for the topographic analysis of each watershed. The Upper Truckee River watershed DEM was clipped closely to the expected boundary to minimize the amount of the Trout Creek watershed that would be captured during the topographic analysis procedure. The confluence of Trout Creek and the Upper Truckee River occurs near Lake Tahoe and only the Upper Truckee River watershed was simulated.

Modification of Digital Elevation Models (DEMs)

The modification of DEMs may be required when local features within a watershed are not captured during the development of the DEM. This could be because of recent human activities that change the elevation within areas of the watershed. This includes land-leveling of fields, channel straightening, road construction, or development of ditches to route water around fields or residential areas. The watershed characteristics generated by AGNPS components then may not correspond to actual stream locations or watershed boundaries. To account for these topographic variances, the DEM can be modified to adopt the required features. More likely areas that may require modification of a DEM are measures that have produced straightened or altered channels.

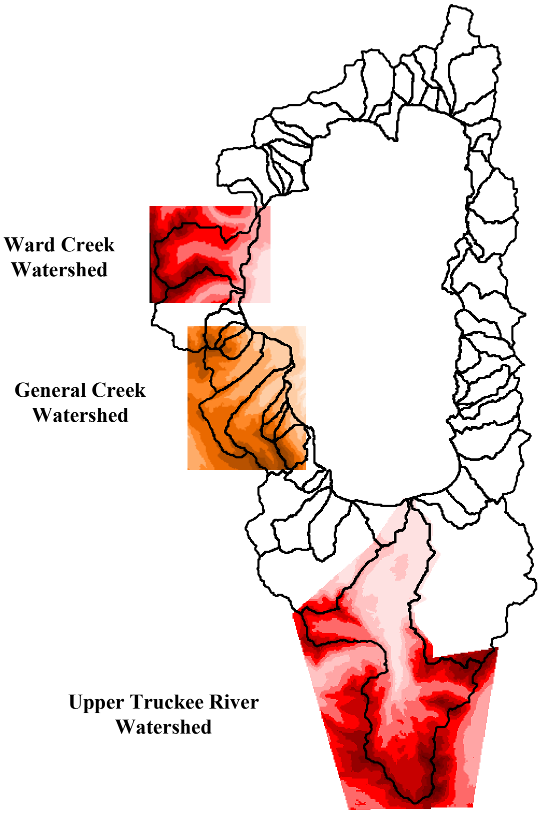


Figure 5-1. The Lake Tahoe watersheds with the digital elevation model (DEM) obtained from USGS at the 10 m by 10 m resolution for the Ward Creek, General Creek, and Upper Truckee River watersheds.

Digitized Soil Maps

The soils GIS layer obtained from the United States Department of Agriculture (USDA) - Natural Resources Conservation Service (NRCS) is the Soil Survey Geographic (SSURGO) data base layer based on the NRCS County Soil surveys that is available for the entire Lake Tahoe Basin. From the SSURGO GIS layer, every digitized soil is assigned a mapping-unit symbol, which corresponds to a database of soil characteristics needed for use with AnnAGNPS. This is also obtained from the NRCS. Soils in the Lake Tahoe Basin are too numerous to list or easily show in a figure, but an example of the spatial variability of the digitized soils contained within General Creek watershed is shown in Figure 5-2.

Digitized Land use Maps

An accurate description of the land use is critical in defining the impact land-management practices may have on soil erosion. The determination of the historical land use for large watersheds such as the Lake Tahoe Basin can be difficult without the use of satellite imagery. Although, local information based on documented aerial photography can be used, this often requires considerable time in analyzing and digitizing the data. Various sources were used to derive the best description of the land use in Lake Tahoe watersheds by the amount and location of the various types of vegetation.

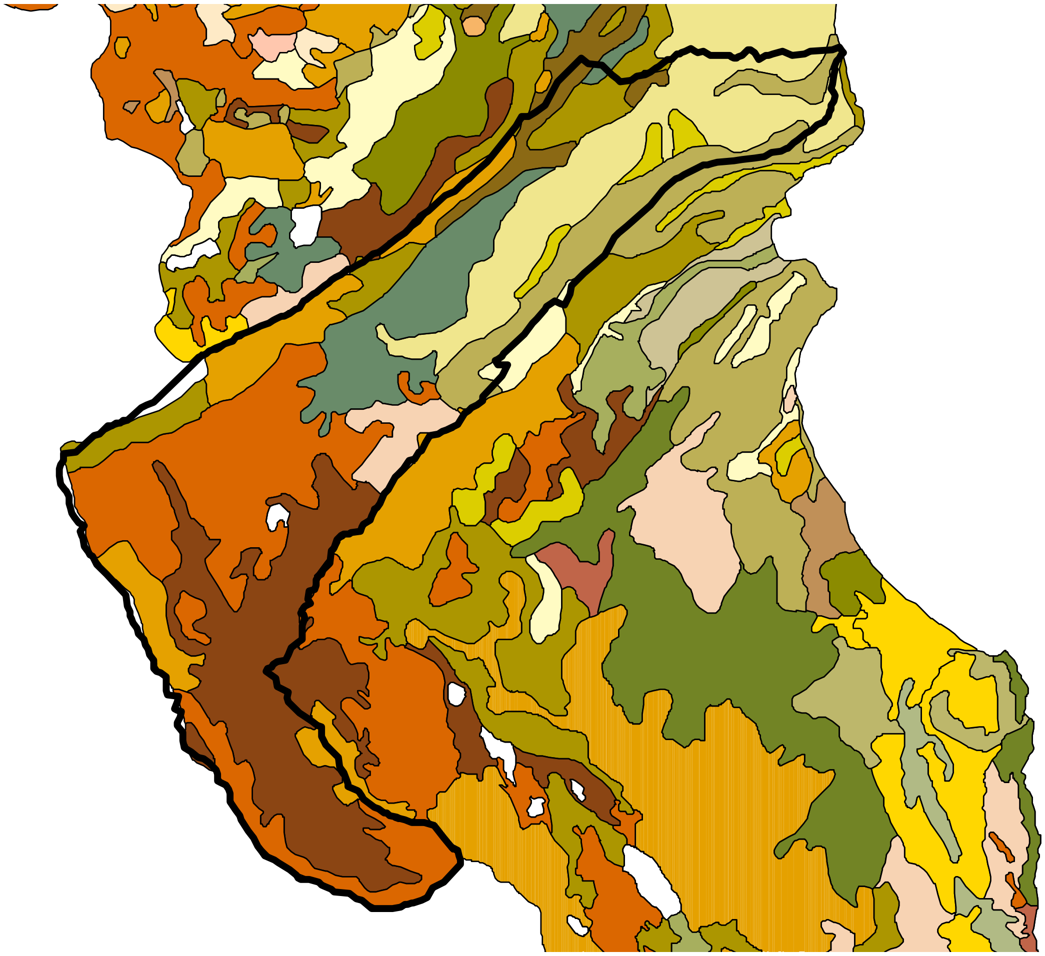


Figure 5-2. The Soil Survey Geographic (SSURGO) GIS layer for General Creek watershed obtained from the USDA-NRCS.

There were two types of land use information available for Lake Tahoe. One was the National Land Cover Data (NLCD) and the other was from the University of California at Davis, Tahoe Research Group (TRG). Generally, the NLCD data provided good definition of the non-urban areas, while the TRG data provided good definition of the urban areas. For this study a combination of both land use GIS layers were used to determine the appropriate land use to apply to each AnnAGNPS cell. NLCD data were ultimately used for the entire watershed, with the exception of urban areas, which were defined by TRG data. The NLCD was developed by the

Multi-Resolution Land Characteristics (MRLC) Consortium that was sponsored originally in 1992 by various federal agencies. The data can be obtained at the Internet Web address: http://www.epa.gov/mrlc/nlcd.html.

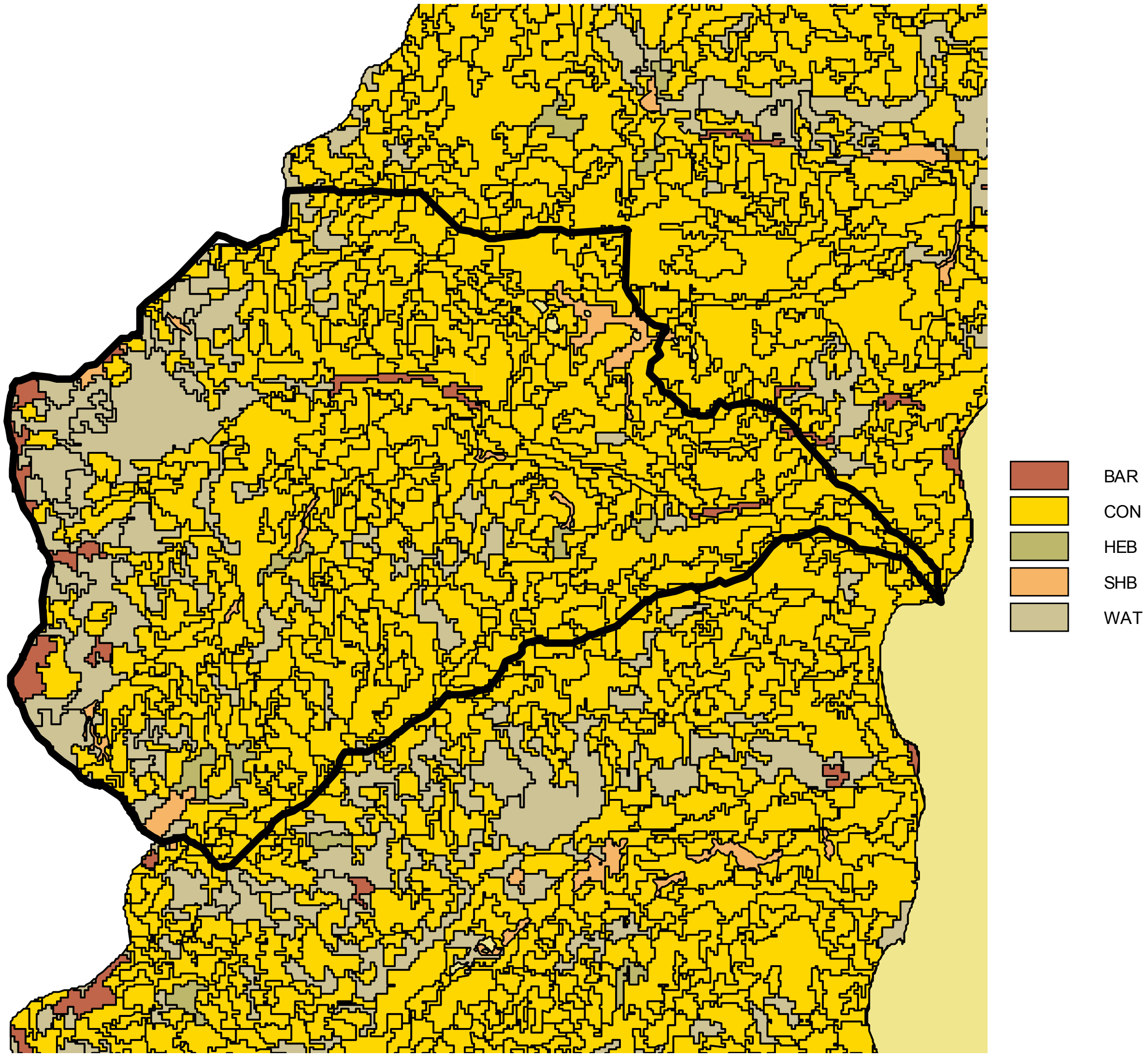


Figure 5-3. The National Land Cover Data (NLCD) based on images from 1990-1993 within the Ward Creek Watershed boundary.

Land-cover was mapped using general land cover classes. For example, forest is classified as either, deciduous, evergreen or mixed. Land-cover classification was based on MRLC's Landsat 5 Thematic Mapper (TM) satellite data archive and a host of ancillary sources. For the Lake Tahoe basin images from 1990 to 1993 were used to develop the GIS layer, such as for Ward Creek watershed (Figure 5-3). This is also distributed at the USGS Lake Tahoe Data Clearinghouse web site. The TRG GIS land use layer for Ward (Figure 5-4) shows considerably more urban area than the NLCD coverage (Figure 5-3).

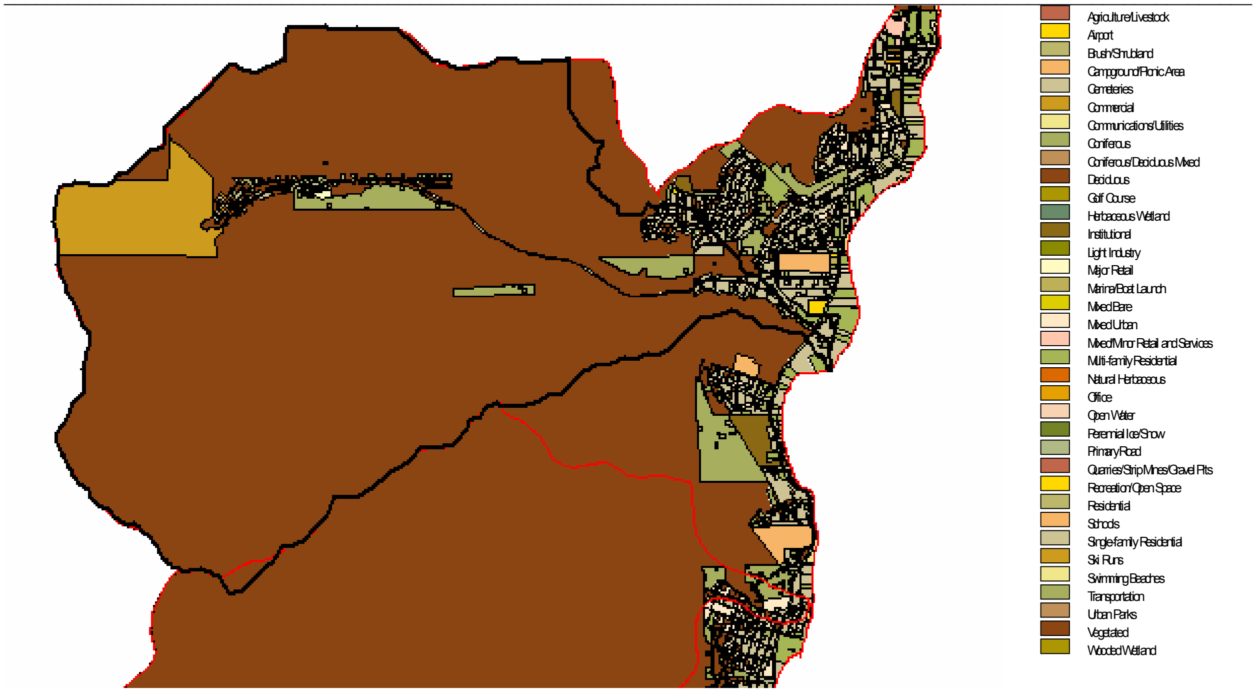


Figure 5-4. The University of California at Davis, Tahoe Research Group (TRG) land use GIS layer for Ward Creek watershed where the dark brown color represents non-urban areas and the other colors are urban areas.

Additional GIS Layers

<u>Digital Raster Graphics (DRG)</u>. Digital Raster Graphics (DRG) are digital copies of 7.5 minute - 1:24,000 topographic maps published by the USGS. The USGS produces their DRG product by scanning paper copies of the map at 500dpi and then re-sampling them to 250 dpi. USGS topographic maps covering Lake Tahoe were likely published over a number of years. The DRGs are output as geotiff image files. The DRGs are very useful in evaluating the location of the watershed boundary and channels generated by TOPAGNPS.

<u>Digital Ortho Quarter Quads (DOQQs)</u>. Digital Ortho Quarter Quads (DOQQs) were produced from 23 millimeter by 23 millimeter (9 x 9 inch) film images scaled at 1:40,000 and mosaicked to produce an image in UTM projection for the entire Lake Tahoe Basin. They have ground resolution of one meter and are available for 1992 and 1998. These images can then be used to investigate various features in the watershed such as the location of terraces, gullies, or ponds.

<u>Perennial and Intermittent Streams</u>. The location of perennial and intermittent streams is important in determining if the generated stream network by TOPAGNPS is of a sufficient accuracy to use with AnnAGNPS. The location of streams can also provide information as to whether the watershed boundary has been determined accurately. This can be seen if a stream crosses a watershed boundary, resulting in a problem with the DEM. One technique to improve the accuracy of the location of the watershed boundary and generated streams is to adjust the DEM based on the location of the digitized streams. Whenever a digitized stream would fall

onto a DEM raster then the elevation of the DEM raster can be adjusted by a set amount, such as subtracting three meters from the DEM raster value. This would help to ensure that the slope of the streams would be maintained when the TOPAGNPS module generates the stream network. For the Lake Tahoe Basin, the digitized perennial and intermittent streams were obtained from the USGS Lake Tahoe Data Clearinghouse WEB site.

5.2.2 AGNPS Arcview Interface Application

The AGNPS Arcview interface can simplify many of the steps used in developing the input parameters required by AnnAGNPS. The User's Guide for the AGNPS interface details the application of the program. A summary of what was done for the Lake Tahoe watersheds to develop the AnnAGNPS input dataset using the interface is provided in this chapter.

5.2.3 Watershed Segmentation

General Creek Watershed

Drainage Boundary. A determination of the drainage boundary for General Creek watershed is critical before proceeding to other issues, such as using the land use and soils GIS layers to determine the attribute identifier from each layer. Having an accurate watershed boundary focuses the area of concern so all of the important watershed characteristics can be examined. Using the AGNPS Arcview interface, which accesses the TOPAGNPS files, and the DEM, the watershed boundary file was produced. Additional files for use with AGNPS were also produced, but the use of those will be discussed in later sections. The first step in this process is to determine the watershed outlet.

For the General Creek watershed, the outlet coincides with the mouth of General Creek as it flows into Lake Tahoe. The exact location of the outlet in terms of the position within the DEM was determined using the perennial streams and the DRG. This also allows the DEM to be reduced in size by clipping the drainage area that includes only General Creek watershed (Figure 5-1) using the AGNPS Arcview Interface. This reduces the computational time needed when using TOPAGNPS and displaying the final determinations with Arcview. The DEM was clipped based on the location of the confluence of General Creek and Lake Tahoe, and the drainage area that would flow into the farthest upstream channel locations. Elevations were then converted to meters. The watershed outlet location used by TOPAGNPS was determined by viewing the DRG and DOQQ layers with digitized streamflow locations for the entire General Creek watershed DEM, and using the "Step 2 Select watershed Outlet" menu item of the Interface with the "Interactively Select Outlet" option. Once the outlet was determined, AGNPS Arcview Interface Steps 3-6 were performed to generate the topographic parameters used by AnnAGNPS. The watershed boundary along with the generated stream network, and other associated files were also produced for use in analyzing the data for any noticeable problems.

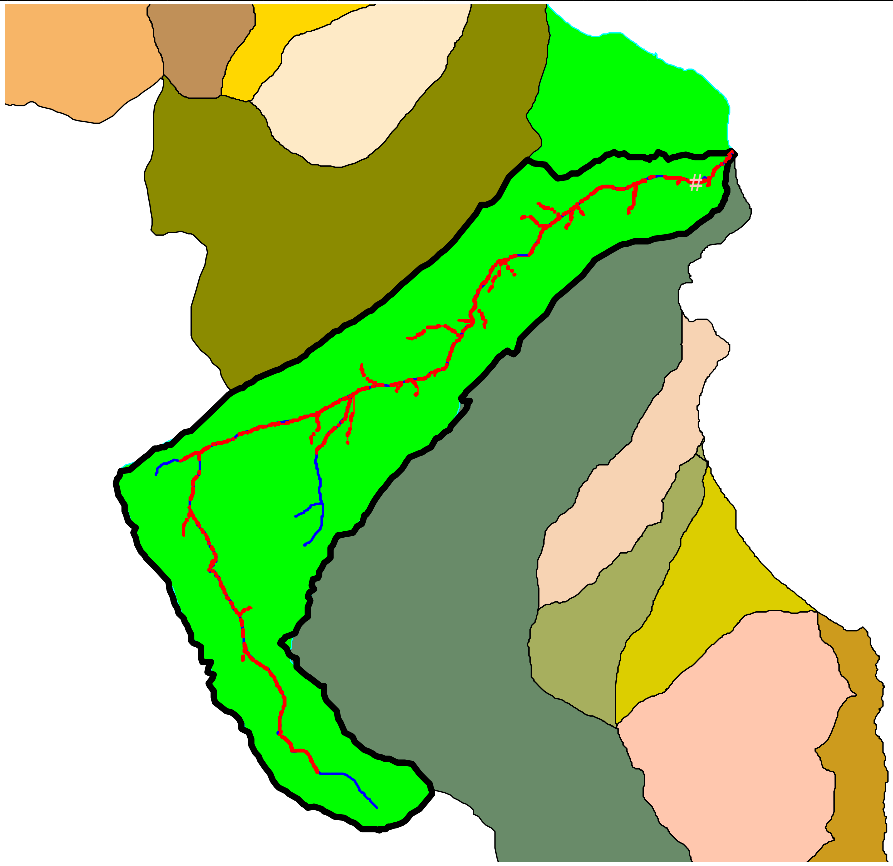


Figure 5-5. The General Creek generated watershed boundary (black line), digitized boundary (light green area), generated stream network (red line), and digitized stream network (blue line).

From previous experience, the location of the stream network generated by TOPAGNPS may not define very well the location of the major confluences as observed from the digitized streams. Thus, a modification of the clipped DEM was made to lower the elevation by one meter wherever a stream raster occurred based on the location of the digitized perennial and intermittent stream locations. This would provide information within the DEM concerning the location of concentrated flows and the generated stream network that would likely produce a stream network similar to the digitized stream network (Figure 5-5).

<u>Subdrainage Areas: AnnAGNPS Cells</u>. The determination of the subdrainage areas of the General Creek watershed into AnnAGNPS cells was performed based on the spatial variation of land use and the location of the digitized stream network. The watershed was subdivided into a significant number of cells to reflect appropriate land use. The process started with an assumption of the critical source area (CSA) and minimum source channel length (MSCL) required with the use of TOPAGNPS. An initial 100 hectare CSA and 300 m MSCL values were selected to produce AnnAGNPS cells that are of significant size that individual AnnAGNPS cells can be identified for further subdivision. The process of starting with the generation of AnnAGNPS cells with large drainage areas and working to subdivide only those areas of major

concern to the user's satisfaction provides the simplest approach to capturing the main features of the watershed.

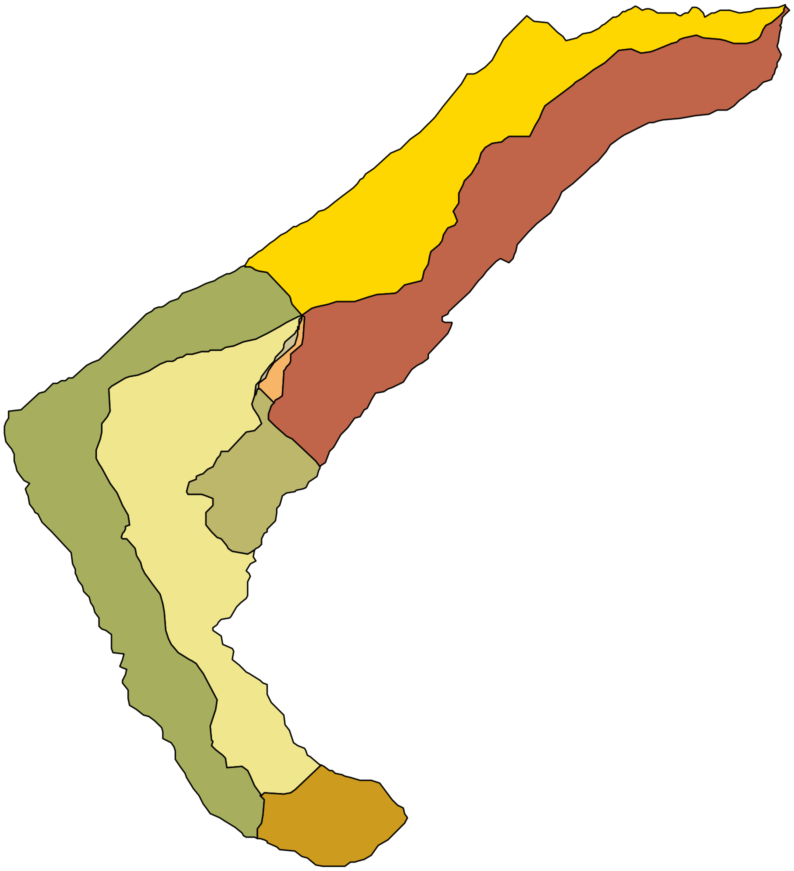


Figure 5-6. The first trial of the generation of AnnAGNPS cells for General Creek watershed.

The initial subdivision produced 8 AnnAGNPS cells distributed throughout the watershed (Figure 5-6). Since land use areas did not appear to be adequately characterized, various AnnAGNPS cells were selected for further subdivision using one of four various TOPAGNPS regions defined within the generation of the network region generation file (ntgcod.inp) (Figure 5-7). The final subdivision of General Creek watershed with TOPAGNPS produced 126 AnnAGNPS cells based on four TOPAGNPS regions using CSA and MSCL values provided in Table 5-1, with an associated stream network of 52 reaches to produce the final subwatershed layer (Figure 5-8).

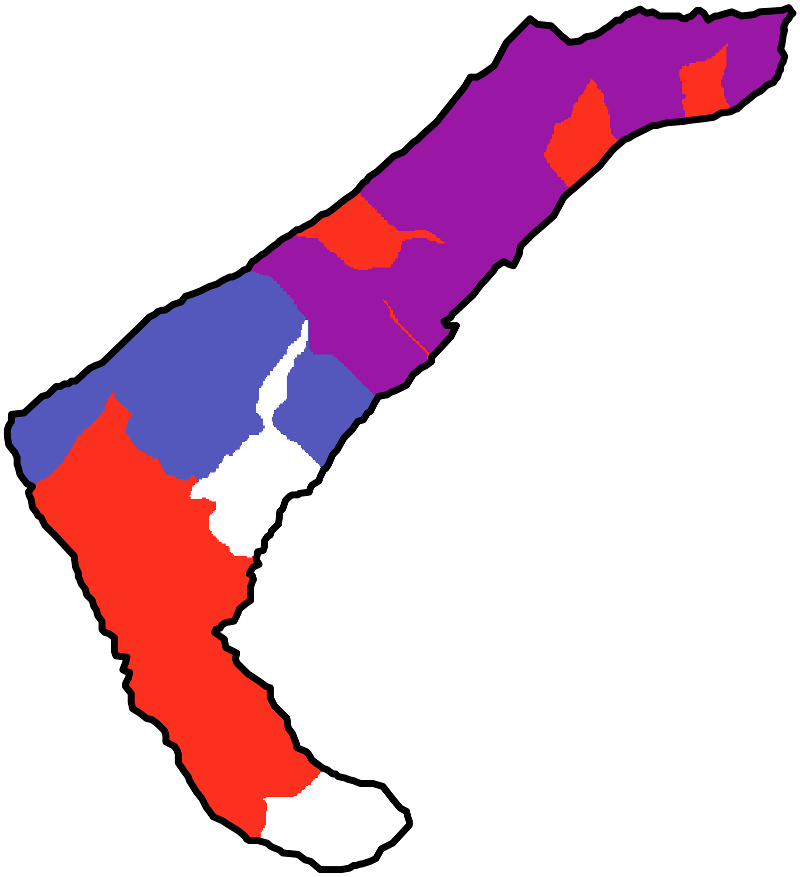


Figure 5-7. The delineation of TOPAGNPS regions for use with various CSA and MSCL values within TOPAGNPS to develop a more detailed subdivision of the watershed for use as AnnAGNPS cells. Region 1 is indicated with white, Region 2 with blue, and Region 3 with red, and Region 4 is purple.

Table 5-1. The TOPAGNPS critical source area (CSA) and minimum source channel length (MSCL) parameters used for each of the four regions defined for the final subdivision of the watershed into AnnAGNPS cells.

TOPAGNPS CSA and MSCL Region	CSA Parameter (hectares)	MSCL Parameter (meters)
1	100	300
2	50	150
3	25	75
4	10	30

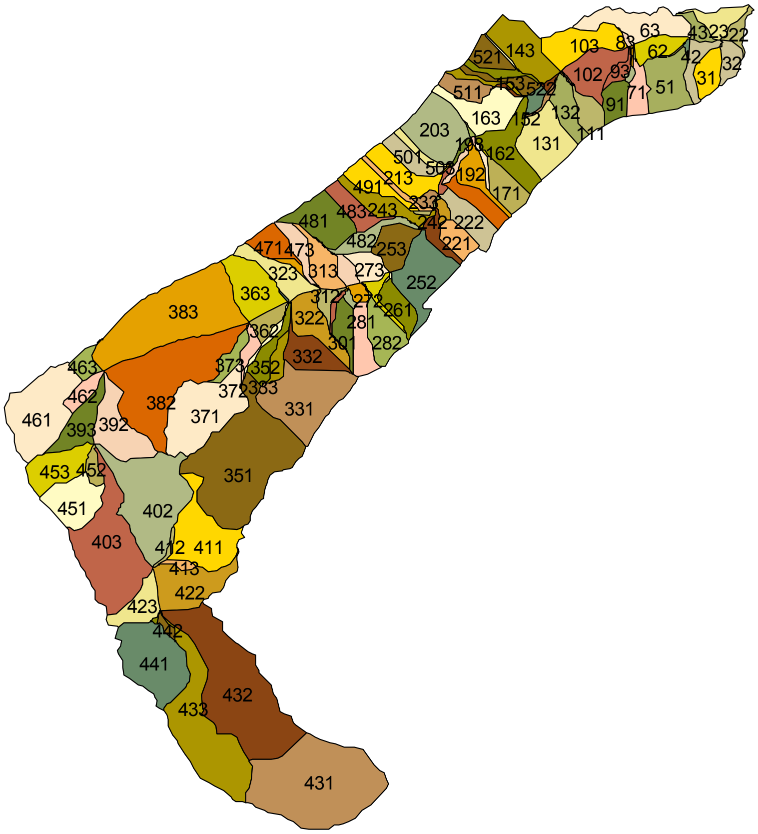


Figure 5-8. The final generation of AnnAGNPS cells used for the General Creek watershed simulations.

<u>Stream Network</u>.

Generated and Digitized Drainage Network. In order to ensure that the process of using TOPAGNPS produced an adequate stream network to link with the CONCEPTS model, the stream network was compared to the digitized location of the perennial and intermittent streams (Figure 5-9). Major confluences of tributaries and the main channel were examined along with the physical location of the channels as observed using the DOQQs. The generated stream network reflected the digitized stream network in most cases. This procedure was also performed in the Upper Truckee and Ward Creek watersheds.

Location of Tributary Confluences Within the Main Channel. The confluences of tributaries generated by TOPAGNPS that flow into the main channel of General Creek were determined from visual inspection of the generated stream network (Figure 5-10). Each tributary outlet reach number identifier assigned from TOPAGNPS was designated as a point that AnnAGNPS would produce information needed by CONCEPTS for each runoff event that occurred between January 1, 1976 and December 31, 2002. The tributary confluence was then assigned as inflow to the main channel as simulated by CONCEPTS with the tributary information from AnnAGNPS produced in a single file. This procedure was also performed in the Upper Truckee and Ward Creek watersheds.

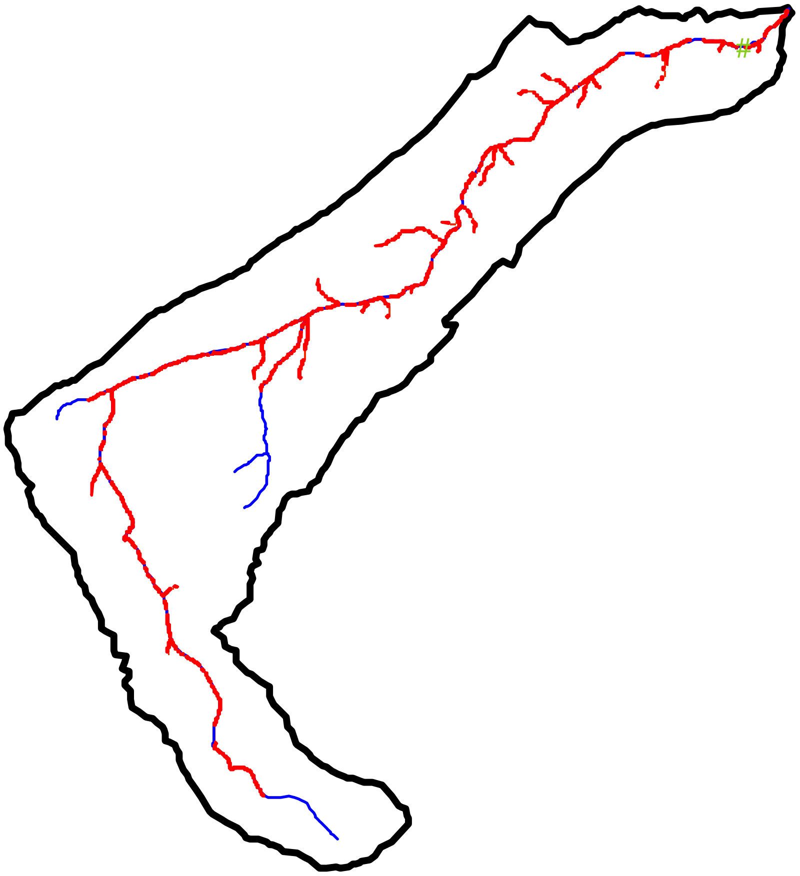


Figure 5-9. The generated stream network (red) in comparison with the digitized streams (blue) with the General Creek watershed boundary (black), plus the location of the gage represented by the green dot at the top of the figure.

Upper Truckee River Watershed

<u>Drainage Boundary</u>. A determination of the drainage boundary for Upper Truckee River watershed follows similar procedures as used for General Creek watershed (Figure 5-11). For Upper Truckee River watershed the outlet coincides with the mouth of Upper Truckee River as it flows into Lake Tahoe. A modification of the clipped DEM was made based on the location of the digitized perennial and intermittent stream locations.

<u>Subdrainage Areas: AnnAGNPS Cells</u>. The determination of the subdrainage areas of the Upper Truckee River watershed into AnnAGNPS cells was performed based on the spatial variation of land use and the location of the digitized stream network. The watershed was subdivided into a significant number of cells in order to reflect land use. The initial subdivision produced 73 AnnAGNPS cells distributed throughout the watershed (Figure 5-12). Further TOPAGNPS delineation provided the subdivision shown in Figure 5-13. The final subdivision of Upper Truckee River watershed with TOPAGNPS produced 264 AnnAGNPS cells and an associated stream network of 107 reaches (Figure 5-14; Table 5-2).

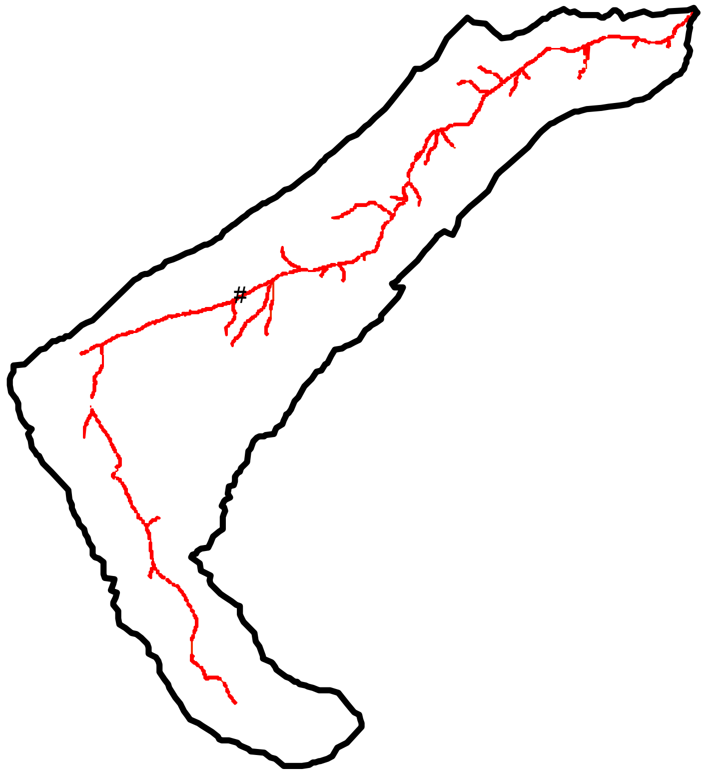


Figure 5-10. The TOPAGNPS generated stream network for General Creek with the main channel simulated by CONCEPTS starting at the black dot and continuing to the outlet.

Figure 5-11. The Upper Truckee River generated watershed boundary (black line) and digitized boundary (shaded area).

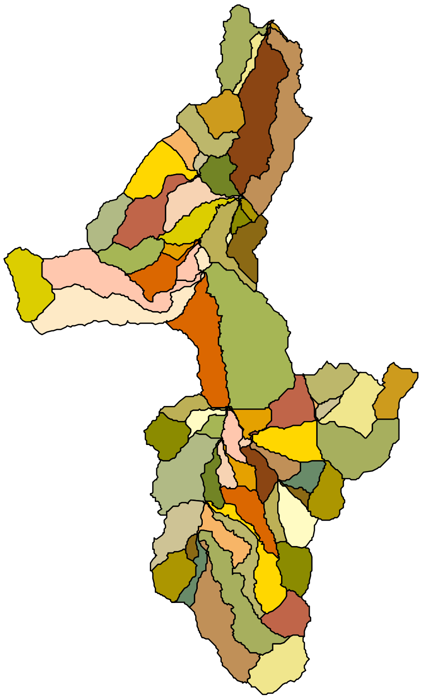


Figure 5-12. The first trial of the generation of AnnAGNPS cells for Upper Truckee River watershed.

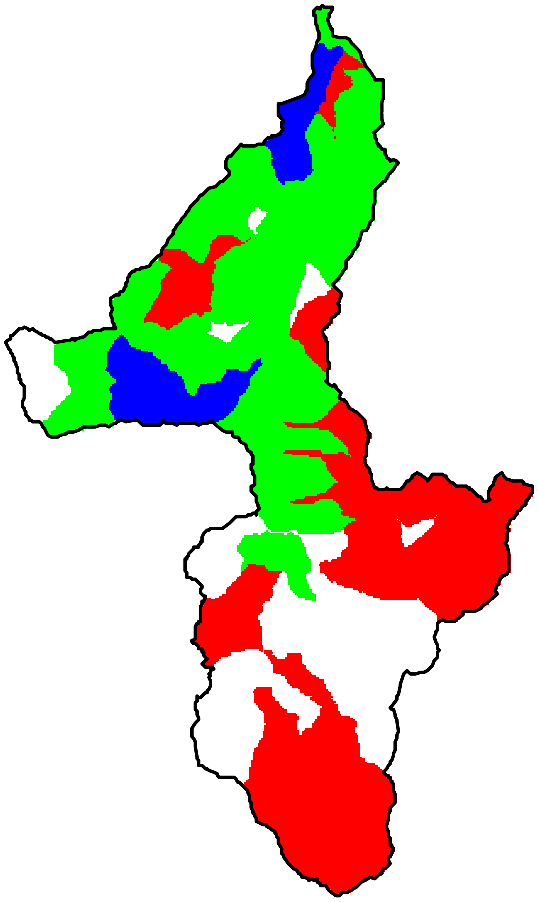


Figure 5-13. The delineation of TOPAGNPS regions for use with various CSA and MSCL values within TOPAGNPS to develop a more detailed subdivision of the Upper Truckee River watershed for use as AnnAGNPS cells. Region 1 is indicated with white, Region 2 with red, and Region 3 with green, and Region 4 is blue.

Table 5-2. The TOPAGNPS critical source area (CSA) and minimum source channel length (MSCL) parameters used for each of the four regions defined for the final subdivision of the Upper Truckee River watershed into AnnAGNPS cells.

TOPAGNPS CSA and MSCL Region	CSA Parameter (hectares)	MSCL Parameter (meters)
1	200	500
2	100	250
3	50	100
4	25	50

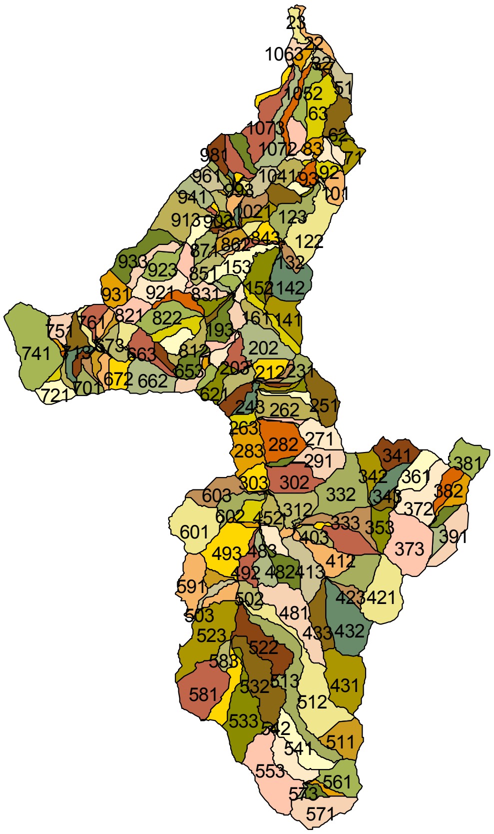


Figure 5-14. The final generation of AnnAGNPS cells used for the Upper Truckee River watershed simulations.

Ward Creek Watershed

Drainage Boundary. A determination of the drainage boundary for Ward Creek watershed follows similar procedures as used for General Creek watershed (Figure 5-15). For Ward Creek watershed the outlet coincides with the mouth of Ward Creek as it flows into Lake Tahoe.

Subdrainage Areas: AnnAGNPS Cells. The determination of the subdrainage areas of the Ward Creek watershed into AnnAGNPS cells was performed based on the spatial variation of land use and the location of the digitized stream network. The initial subdivision produced 33 AnnAGNPS cells distributed throughout the watershed (Figure 5-16). Various AnnAGNPS cells were selected for further subdivision using one of three various TOPAGNPS regions defined within the generation of the network region generation file (Figure 5-17). The final subdivision of the Ward Creek watershed with TOPAGNPS produced 139 AnnAGNPS cells based on three TOPAGNPS regions using CSA and MSCL values provided in Table 5-3, with an associated stream network of 58 reaches to produce the final subwatershed layer (Figure 5-18).

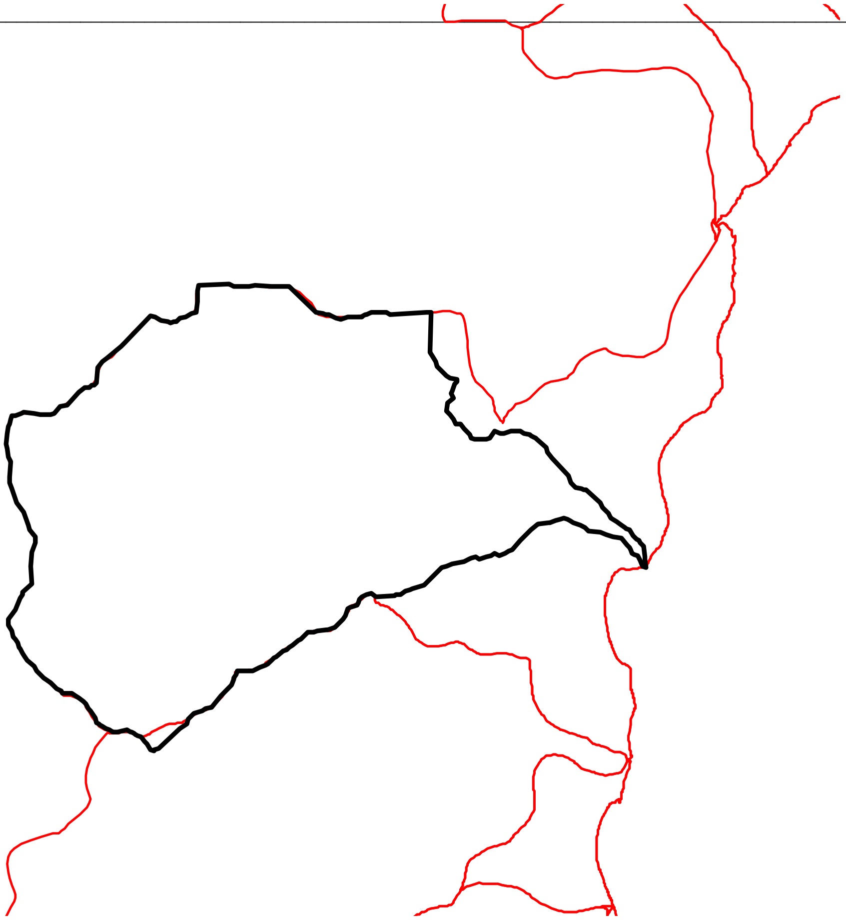


Figure 5-15. The Ward Creek generated watershed boundary (black line) and digitized boundary (red line).

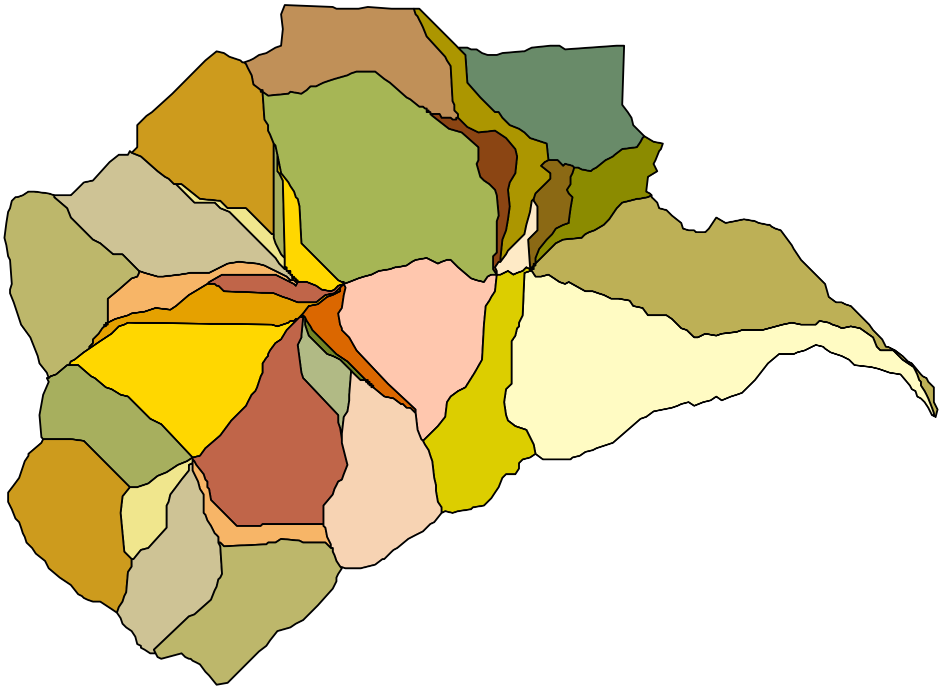


Figure 5-16. The first trial of the generation of AnnAGNPS cells for Ward Creek watershed.

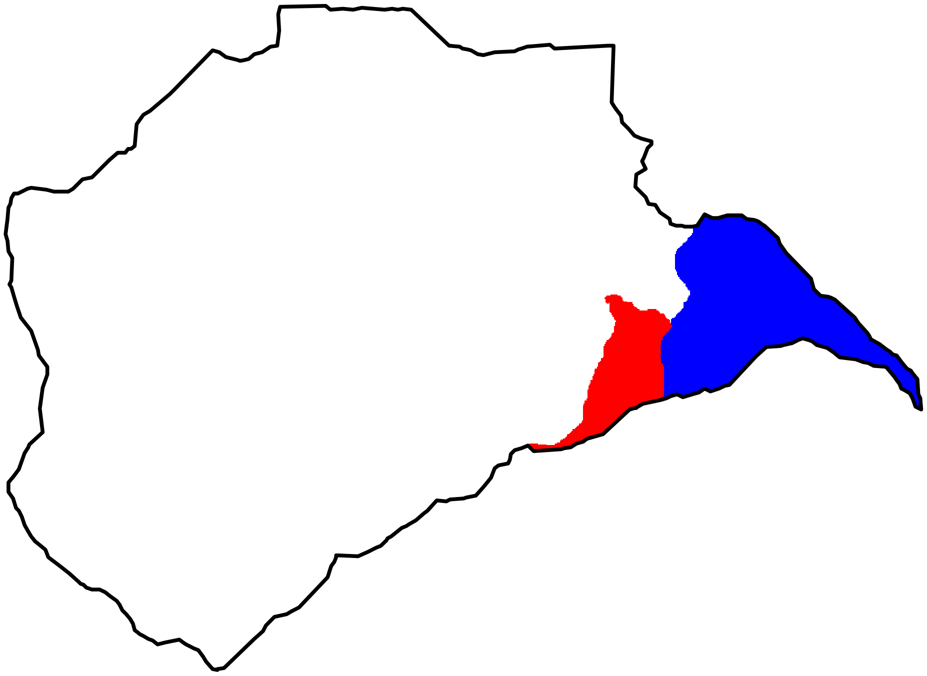


Figure 5-17. The delineation of TOPAGNPS regions for use with various CSA and MSCL values within TOPAGNPS to develop a more detailed subdivision of the Ward Creek watershed for use as AnnAGNPS cells. Region 1 is indicated with white, Region 2 with red, and Region 3 with blue.

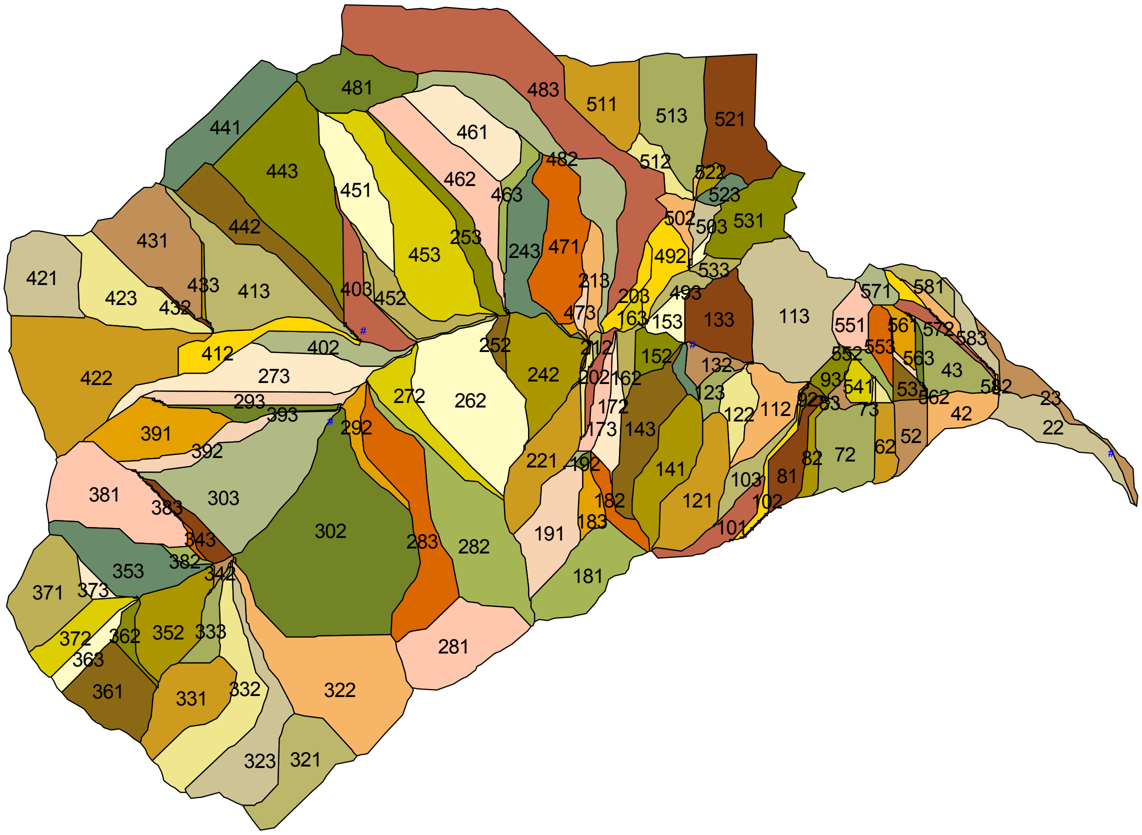


Figure 5-18. The final generation of AnnAGNPS cells used for the Ward Creek watershed simulations.

Table 5-3. The TOPAGNPS critical source area (CSA) and minimum source channel length (MSCL) parameters used for each of the three regions defined for the final subdivision of the Ward Creek watershed into AnnAGNPS cells.

TOPAGNPS CSA and MSCL Region	CSA Parameter (hectares)	MSCL Parameter (meters)
1	25	75
2	10	40
3	5	20

5.2.4 Weather Data

Development of the Climate Database

All weather data was obtained from the nearest NRCS SNOTEL site and was assigned to each of the modeled watersheds (Figure 5-19). Each station was used to determine the individual event information describing measured precipitation and temperature for the years 1976-2002

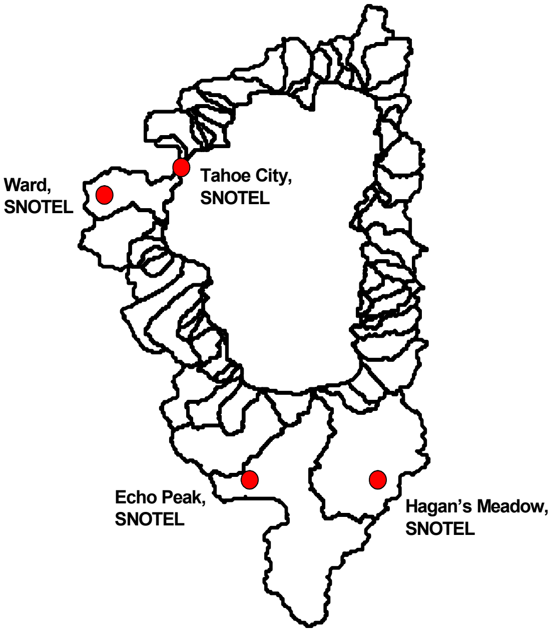


Figure 5-19. Climate stations from the NRCS SNOTEL sites used in the AnnAGNPS simulations.

from the Tahoe City climate station needed for the AnnAGNPS simulation. Climate data, based on numerical simulations conducted by a concurrent research project, were not available for this study.

For the Ward climate station, information from 1980-2002 was available and for Echo Peak and Hagan's Meadow climate stations, only information from 1981-2001 was used. Additional weather data was generated using the GEM climate generator for parameters describing sky cover, dew point, and wind speed, and then actual precipitation and temperature data for those dates replaced the generated values. The annual precipitation measured from each of the climate stations is shown in Figure 5-20. Annual precipitation is generally higher for those climate stations at higher elevations and on the western side of the Lake Tahoe Basin. The climate record for the 50-year simulation was developed for each climate station by repeating the same period of record to create a continuous 50-year climate record. For example, at the Tahoe City climate station, the 1976-2002 record was used for the first 27 years and then 1976-1998 record was used for years after 2002, although the runoff events of January 1 and 2, 1997 were not repeated. A similar approach was used for all of the other climate stations.

The available climate data provides daily precipitation at the climate stations, but the application of AnnAGNPS is for storm events. Thus, events that occurred over more than one day are difficult to separate from the climate database. This then effects the runoff and erosion simulations produced by AnnAGNPS and subsequently, CONCEPTS. The available climate stations for each watershed were the only stations available that provide a concurrent record with the other measured watershed characteristics, such as flow and channel cross-sections. More spatial variability of climate information within these watersheds would provide better simulation results in comparing with measured results. A coordinated climate database throughout the watershed with a central database clearinghouse would provide better information that is needed by the models, both spatially and temporally.

Assignment of a Climate Station to an AnnAGNPS Cell

Each climate station represents a point in the Lake Tahoe Basin. Precipitation can be highly variable based on the predominate movement of storms and the elevation at any point. Since there was limited precipitation data in the watersheds, an attempt was made to distribute precipitation in the Upper Truckee and Ward watersheds. Since General Creek watershed did not have a precipitation gage at higher elevations, only the Tahoe City climate station was used.

For the Upper Truckee River watershed, the Echo Peak and Hagan's Meadow climate stations were used and assigned to an AnnAGNPS cell, based on the GIS layer containing the isopluvial lines (Sierra Hydrotech, 1986). For the Ward Creek watershed, the Tahoe City and Ward climate stations were used.

Two additional climate stations were developed for the Upper Truckee River watershed based on the location of the Echo Peak and Hagan's Meadow climate stations within the iso-pluvial line GIS layer. Since the Echo Peak climate station represented a value of 1260 mm on the hypsography and Hagan's Meadow represented a value of 690 mm, two additional climate stations were developed that were a function of each based on the changing hypsography between them. The adjustment in precipitation for the 833 mm to 975 mm file was then a simple increase in Hagan's Meadow precipitation based on the increase in the associated iso-pluvial values, and similarly a decrease in the Echo Peak precipitation for the 975 mm to 1120 mm file. The assignment of the appropriate climate file for each AnnAGNPS cell in the Upper Truckee River watershed is shown in Figure 5-21 and was based on the centroid of the AnnAGNPS cell falling within each isopluvial region defined for each climate file. Water draining from Echo Lake was diverted out of the watershed and thus, was not routed to the Upper Truckee River watershed outlet.

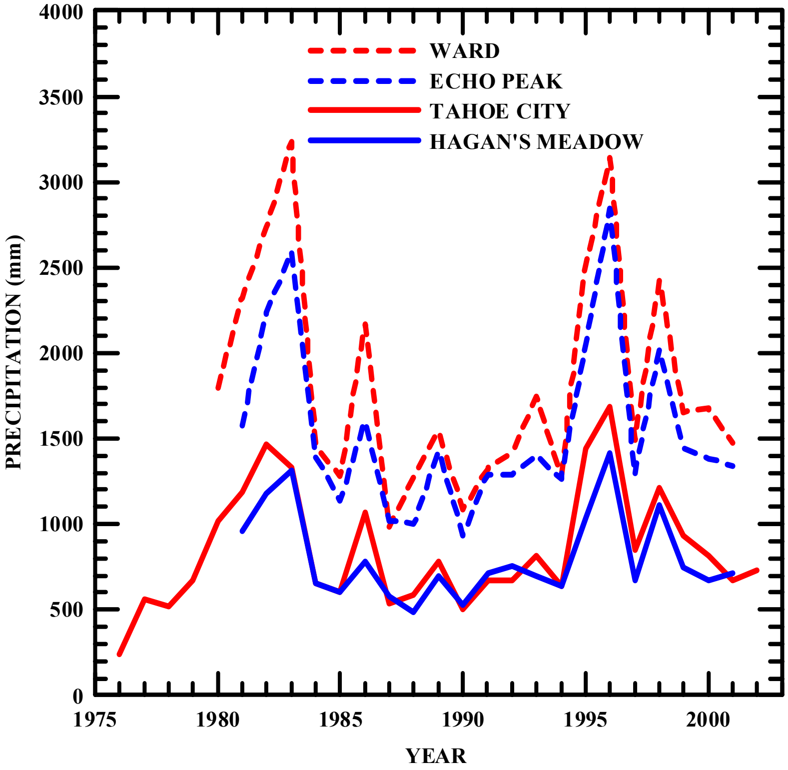


Figure 5-20. Annual precipitation measured at the Ward, Echo Peak, Tahoe City, and Hagan's Meadow climate stations.

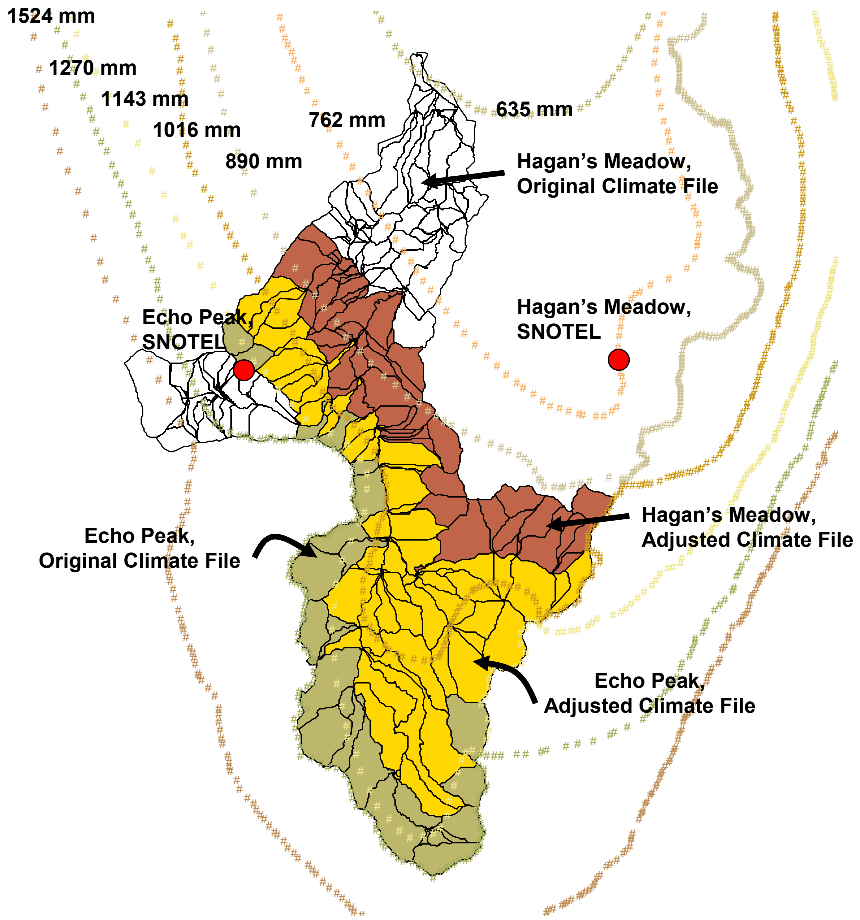


Figure 5-21. Climate files assigned to AnnAGNPS cells based on the isopluvial lines (Sierra Hydrotech, 1986) of Upper Truckee River watershed.

A similar approach was used on Ward Creek watershed for the Ward and Tahoe City climate stations that fell on the 1820 mm and 914 mm values, respectively. The assignment of the appropriate climate file for each AnnAGNPS cell in the Ward Creek watershed is shown in Figure 5-22.

Development of Temperature Lapse Rate

The AnnAGNPS model has the capability to vary temperature by elevation and in a mountainous region this can be critical in defining whether precipitation falls as snow or rain, or runoff occurs as a result of snowmelt. The default lapse rate within AnnAGNPS is the accepted global average decrease of 3.6 degrees Fahrenheit (F) per 1000 feet increase in elevation. For Ward Creek watershed, the Tahoe City and Ward climate stations were used to determine the average lapse rate. Using the corresponding climate period, an average annual lapse rate of 3.9 degrees F was calculated for the Ward Creek Watershed (Figure 5-23).

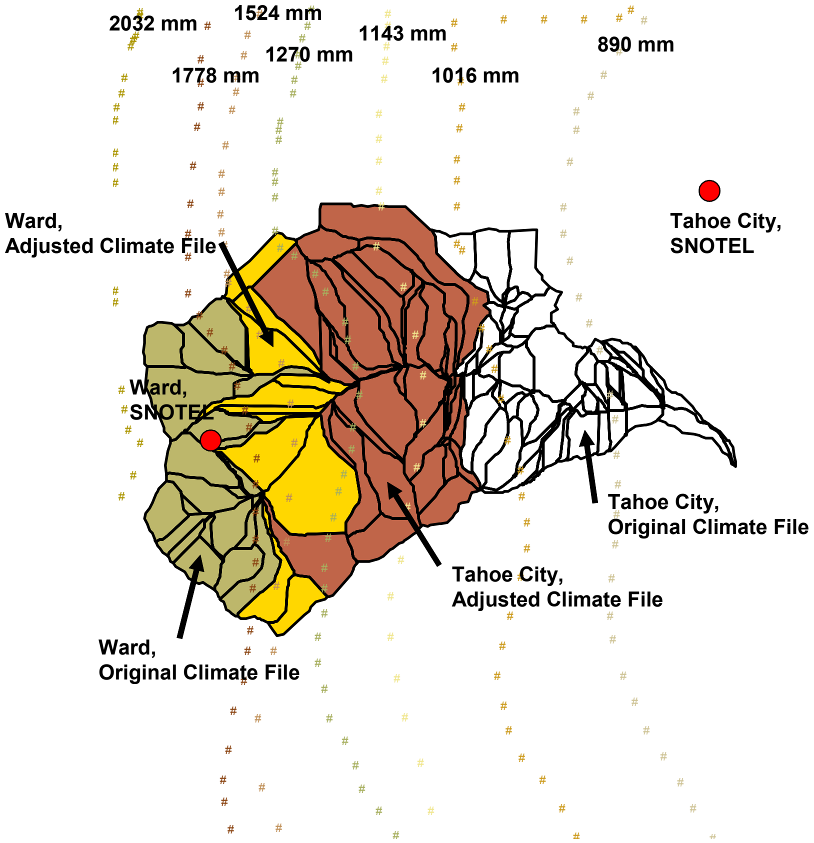


Figure 5-22. Climate files assigned to AnnAGNPS cells based on the iso-pluvial lines of Ward Creek watershed.

For the General Creek and Upper Truckee watersheds, a slightly different approach was used to adjust the timing of snow and rainfall runoff events. Using a 30-year period of mean-daily maximum and minimum temperature data for the Daggett Pass and Glenbrook climate stations, lapse rates were calculated for each day of the year. This was done by taking the average between the average daily maximum and the average daily minimum, and then dividing by the difference in elevation between the stations (930 feet). These data were plotted (Figure 5-24), and the average value during days of below freezing was calculated to be 8.4 degrees F per 1000 feet.

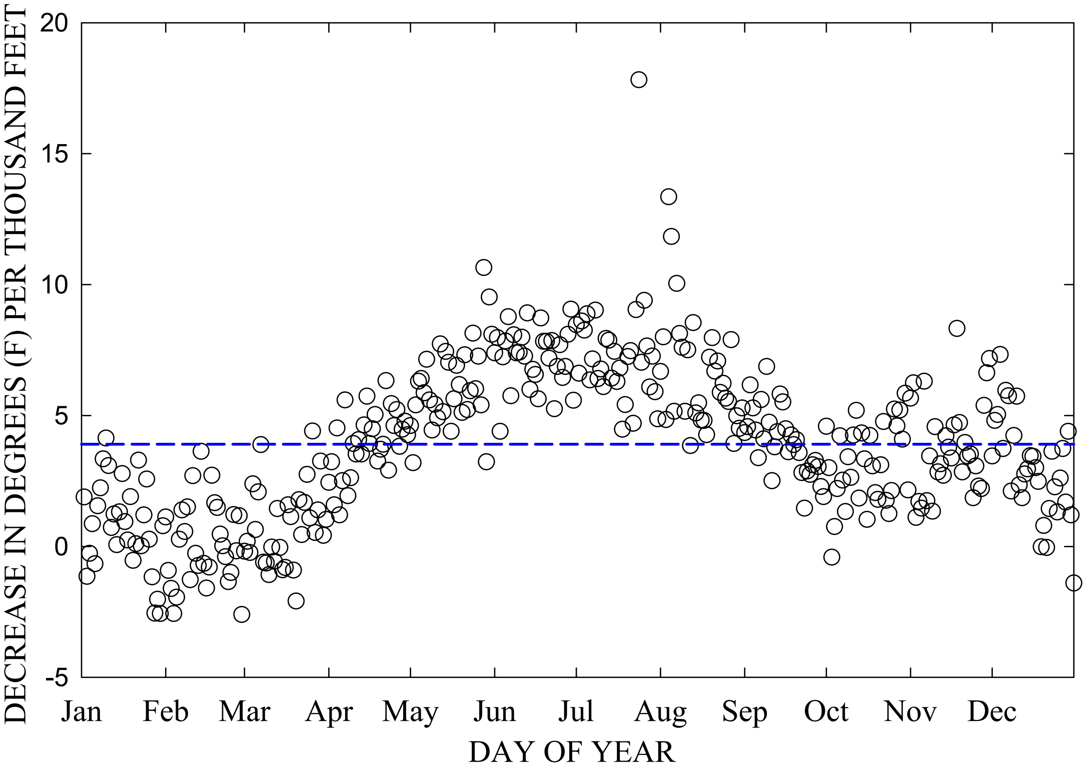


Figure 5-23. Average daily temperature lapse rate between Ward and Tahoe City climate station for Ward Creek watershed.

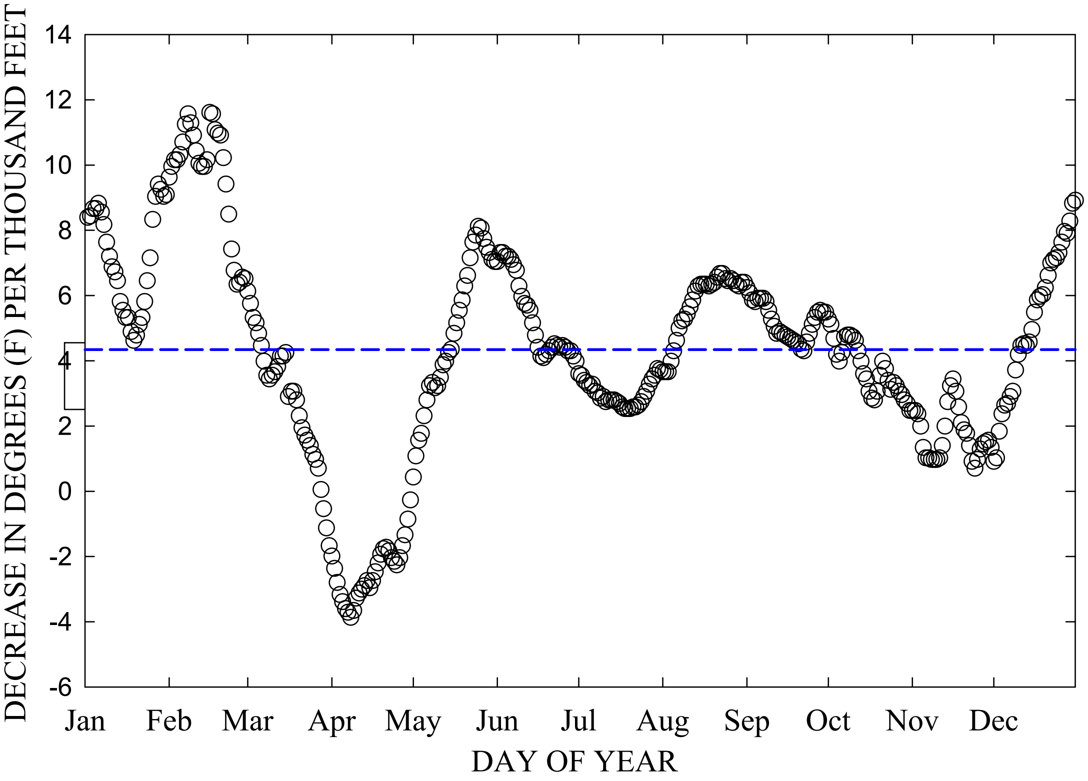


Figure 5-24. Average daily temperature lapse rate between Daggett Pass and Glenbrook climate stations for General Creek and Upper Truckee River watersheds.

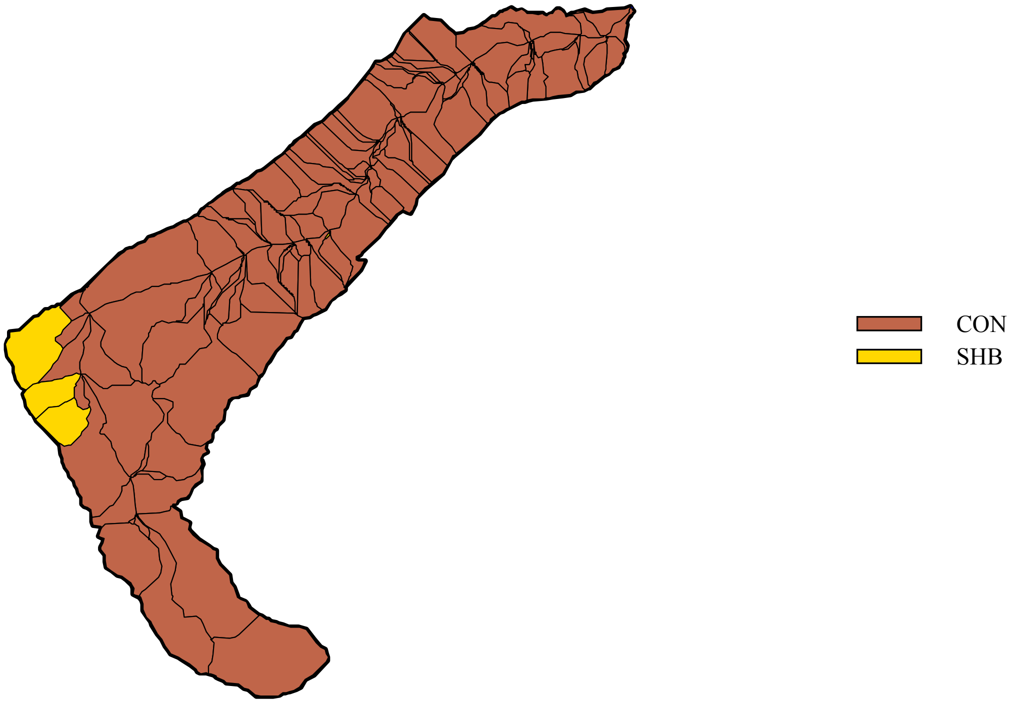


Figure 5-25. Land use assigned to each AnnAGNPS cell for General Creek watershed. See Table 5-4 for definition of symbols.

5.2.5 Land use Data

Information pertaining to the land use of the watershed can be defined for those areas that have a direct impact on runoff and sediment loadings. This information can be defined for best management practices (BMPs) and the assignment of SCS runoff curve numbers associated with specific land uses. The type of land use assigned to each AnnAGNPS cell was determined using the AGNPS Arcview interface procedure. This procedure assigned a land use to each cell based on the predominate land use from the land use GIS layer and the subwatershed GIS layer associated with the General Creek (Figure 5-25), Upper Truckee River (Figure 5-26), and Ward Creek (Figure 5-27) watersheds, respectively.

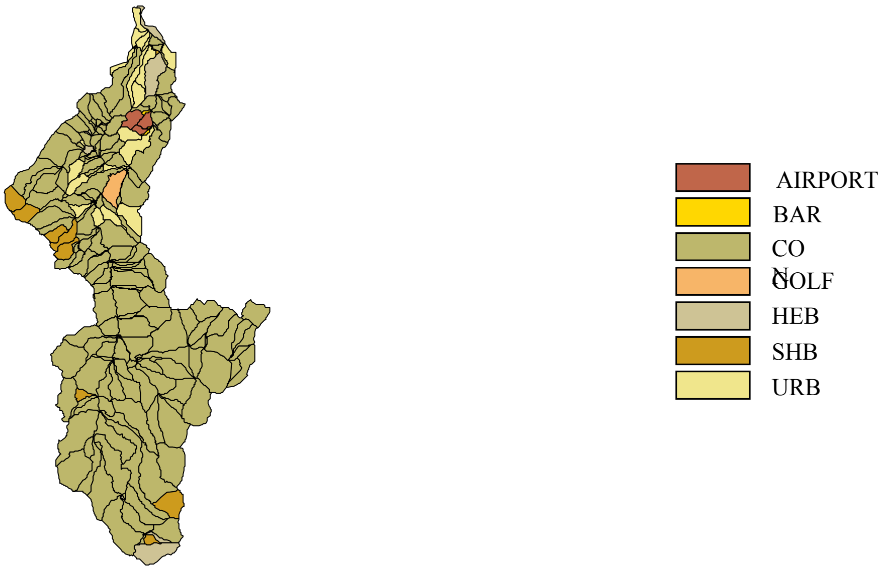


Figure 5-26. Land use assigned to each AnnAGNPS cell for Upper Truckee River watershed. See Table 5-4 for definition of symbols.

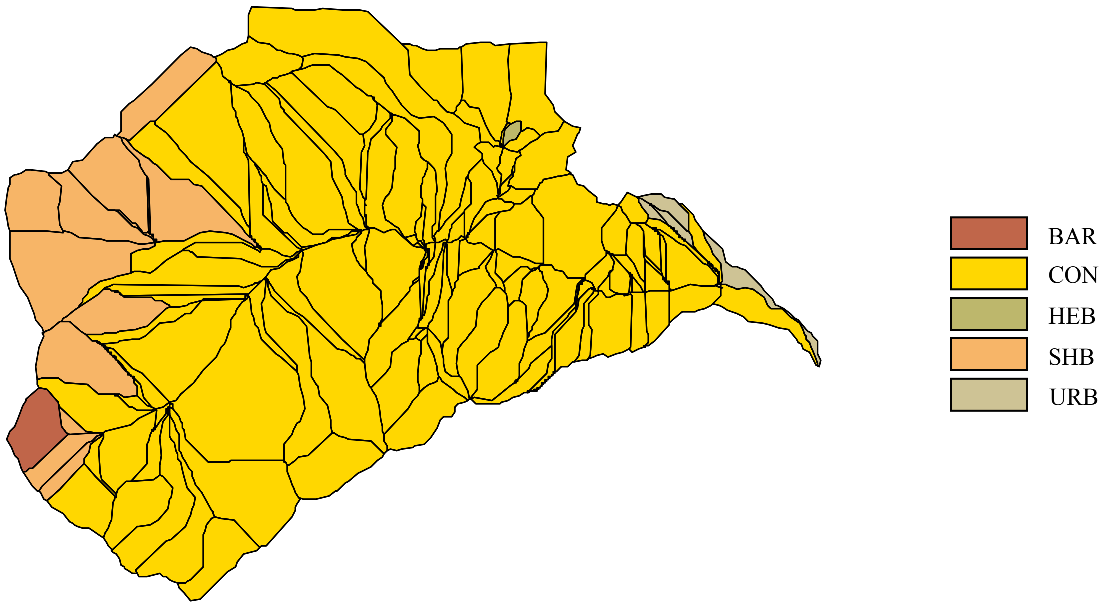


Figure 5-27. Land use assigned to each AnnAGNPS cell for Ward Creek watershed. See Table 5-4 for definition of symbols.

Soil Conservation Service (SCS) Runoff Curve Numbers Associated with Watershed Characteristics

The Soil Conservation Service (SCS) runoff curve number (CN) is a key factor in obtaining an accurate prediction of runoff and sediment yields. Curve numbers were selected based on the National Engineering Handbook, Section 4 (USDA, Soil Conservation Service, 1985). The SCS CN's used in the model simulation are listed in Table 5-4 and are based on typical values used by NRCS for the land cover classes present in the watersheds. Additional curve numbers were selected for airport and golf conditions to represent those scenarios in the simulation. Each cell assumes that the area within the cell is defined homogeneously throughout the cell.

Table 5-4. SCS curve numbers for the Lake Tahoe Basin watershed simulations by land cover class.

Land Cover Class	Curve Number			
	Hydrologic soil group			
	A	B	C	D
BAR, Fallow Bare soil	77	86	91	94
HEB, Grassy fields, Fair	32	43	60	70
SHB, Shrubs Poor	36	50	68	76
CON, Conifer Forest Good	30	55	70	77
AIRPORT, Some paved roads	83	89	92	93
GOLF	89	92	94	95
URB, Urban, Commercial, and Business	89	92	94	95

5.2.6 Soil Properties

Within the Lake Tahoe Basin there are 73 separate soil types identified from the soil GIS layer. The dominant soils are sandy to sandy loam with many areas defined entirely as rock outcrops. Most of the soils information was derived from the NRCS Soils 5 database. Input parameters that had no impact on soil erosion were set using default parameters. These included parameters such as the soil initial organic nitrogen ratio, which was set based on AnnAGNPS guidelines as 500 PPM for the top layer and 50 PPM for the subsequent layers. The soil assigned to each AnnAGNPS cell was based on the predominant soil type within each AnnAGNPS cell.

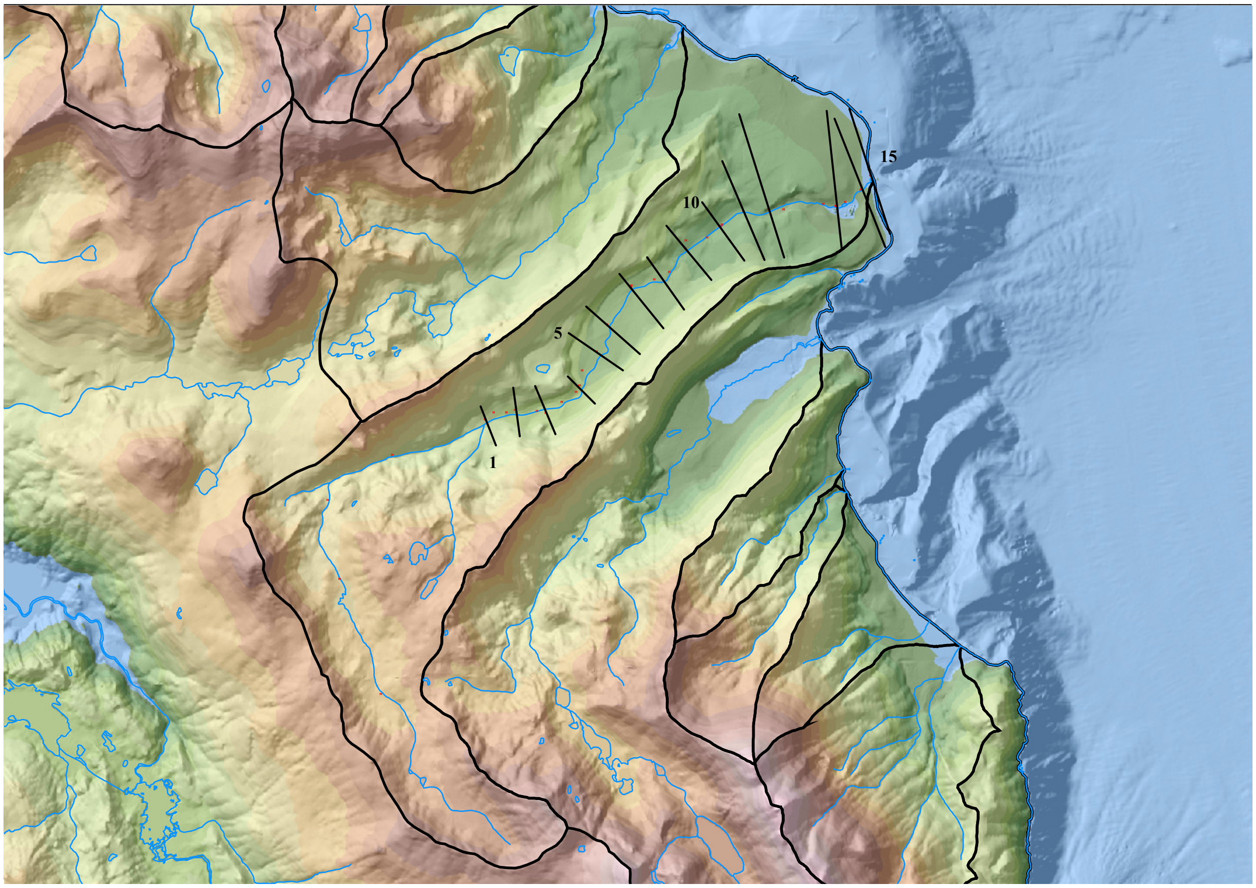


Figure 5-28. Modeling reach and cross section locations along General Creek. Cross section transects are shown in black.

5.3 CONCEPTS Model Setup

5.3.1 Modeling Reach and Parameters

General Creek

Modeling Reach. The modeling reach of General Creek extends from the mouth of the channel (river km 0.01) to river km 6.80 (Figure 5-28). The water and sediment loadings into the modeling reach are provided by the watershed model AnnAGNPS. The modeling reach is composed of 15 cross sections (Figure 5-28). These cross sections are hereafter referred to as cross sections “1” through “15,” where “1” is the most upstream cross section and “15” is the most downstream cross section. The cross sections were surveyed during the data collection campaign in the fall of 2002 (see section 2.2), except for cross section 8. Cross section 8 is cross section “85” surveyed in 1983 by Nolan and Hill (1991). Cross sections 2, 4, 6, and 13 correspond to cross sections “55,” “60,” “70,” and “90” surveyed in 1983 by Nolan and Hill (1991). The latter cross sections will be hereafter referred to as NH55, NH60, NH70, and NH90.

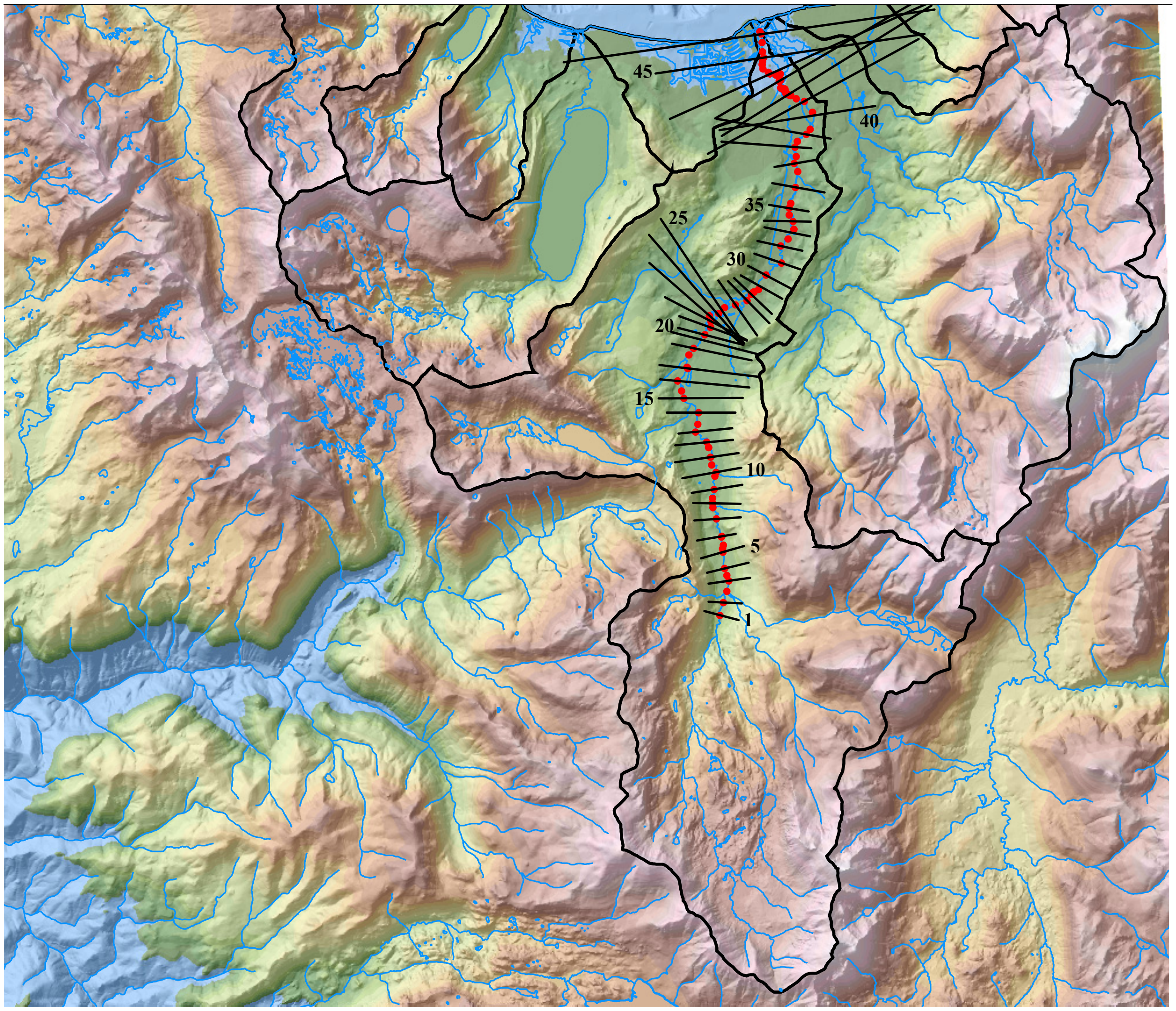


Figure 5-29. Modeling reach and cross section locations along the Upper Truckee River. Cross section transects are shown in black.

Physical Properties. Roughness values were assigned to bed, bank, and floodplain sections of each cross section based on visual inspection of the channel and following guidelines set forth by Aldridge and Garrett (1973) and Jarrett (1985). Bed- and bank-material composition and properties at each cross section were provided by local sediment samples and BST tests (section 2.3). Streambank materials have an average silt/clay composition of 10% (46 samples). In case these data were locally unavailable, data collected at the nearest similar site were used. Table G-1 in the appendix lists the data used at each cross section.

Upper Truckee River

Modeling Reach. The modeling reach along the Upper Truckee River extends from the mouth of the channel (river km 0.38) to river km 24.19 (Figure 5-29). The water and sediment loadings into the modeling reach are provided by the watershed model AnnAGNPS. The modeling reach is composed of 46 cross sections (Figure 5-29). These cross sections are hereafter referred to as cross sections "1" through "46," where "1" is the most upstream cross section and "46" is the most downstream cross section. Cross sections "1" (river km 24.19) through "28" (river km 10.84) were surveyed during the data collection campaign in the fall of 2002 (see section 2.2). Cross sections "19" (river km 13.70) through "26" (river km 11.68) were surveyed by the California State Parks repeatedly between 1992 and 2001. Cross sections "29" (river km 10.56) through "41" (river km 3.37) were surveyed by Mussetter Engineering in 2001. Cross sections "42" (river km 2.77) through "46" (river km 0.38) were surveyed by Entrix Incorporated in 2001.

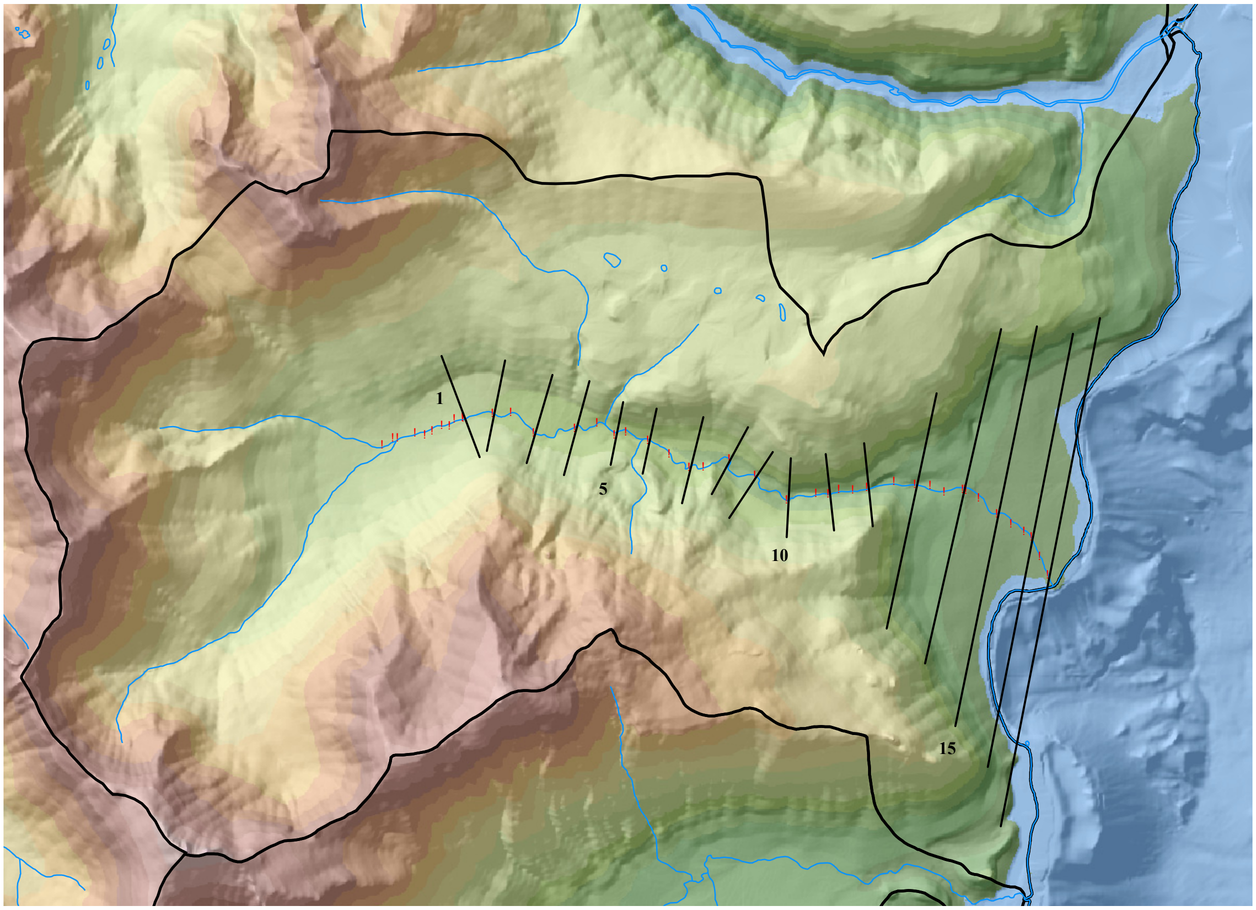


Figure 5-30. Modeling reach and cross section locations along Ward Creek. Cross section transects are shown in black.

Physical Properties. Roughness values were assigned to bed, bank, and floodplain sections of each cross section based on visual inspection of the channel and following guidelines set forth by Aldridge and Garrett (1973) and Jarrett (1985). Bed- and bank-material composition and properties at each cross section were provided by local sediment samples and BST tests (section 2.3). The average silt/clay composition of the streambanks throughout the modeled reach is 14%. In case these data were locally unavailable, data collected at the nearest similar site were used. Table G-2 in the appendix lists the data used at each cross section.

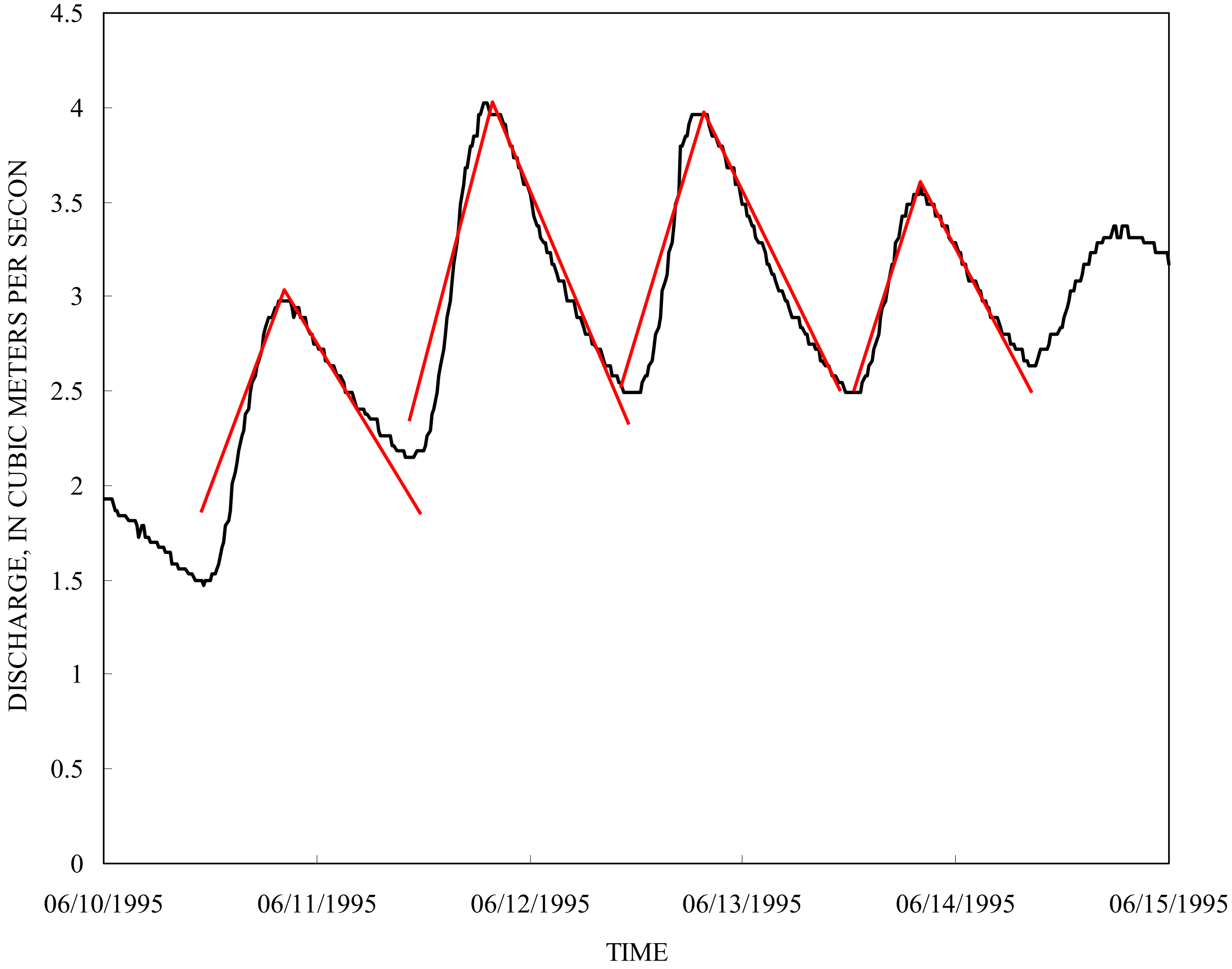


Figure 5-31. Hydrograph shape of typical snowmelt runoff events. NRCS (1996) triangular hydrograph (red line) is superimposed on the measured discharge record. Discharge data is from USGS gaging station 10336674 on Ward Creek.

Ward Creek

Modeling Reach. The modeling reach of Ward Creek extends from the mouth of the channel (river km 0.09) to river km 5.80 (Figure 5-30). The water and sediment loadings into the modeling reach are provided by the watershed model AnnAGNPS. The modeling reach is composed of 17 cross sections (Figure 5-30). These cross sections are hereafter referred to as cross sections "1" through "17," where "1" is the most upstream cross section and "17" is the most downstream cross section. These cross sections were surveyed during the data collection campaign in the fall of 2002 (see section 2.2).

Physical Properties. Roughness values were assigned to bed, bank, and floodplain sections of each cross section based on visual inspection of the channel and following guidelines set forth by Aldridge and Garrett (1973) and Jarrett (1985). Bed- and bank-material composition and properties at each cross section were provided by local sediment samples and BST tests (section 2.3). Ward Creek streambanks, on average, have the highest measured silt/clay content of those streams sampled, 17%. In case these data were locally unavailable, data collected at the nearest similar site were used. Table G-3 in the appendix lists the data used at each cross section.

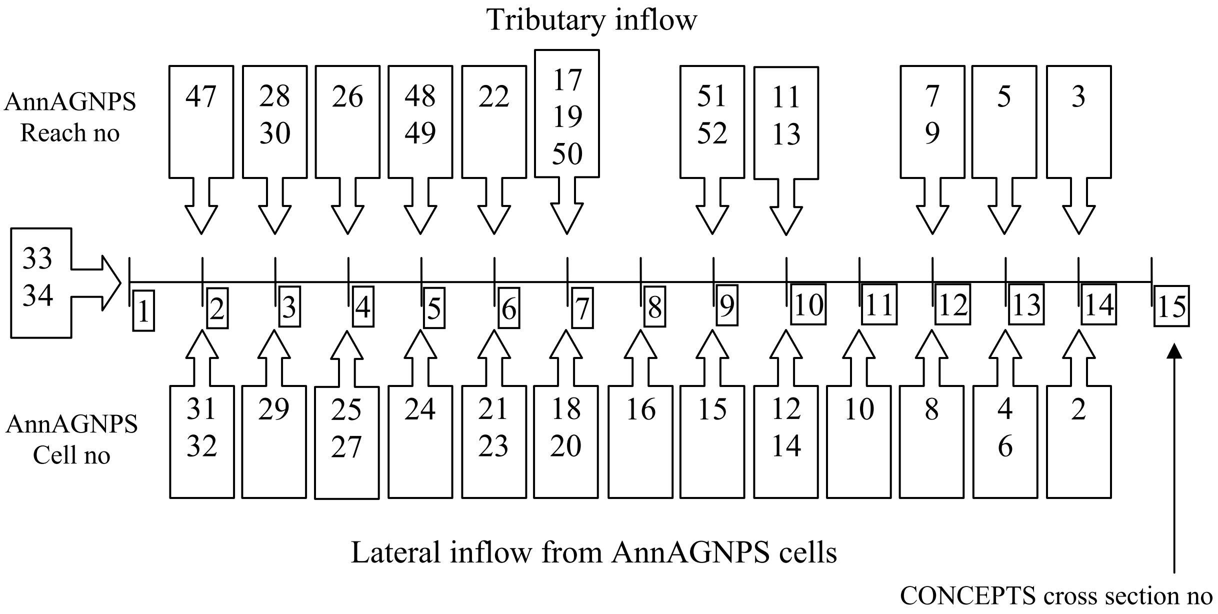


Figure 5-32. Linkage between AnnAGNPS reaches and cells (Figure 5-8) and CONCEPTS cross sections for General Creek. (The last digit of the cell ID (a 2 or a 3) is omitted.)

5.3.2 Tributary and Lateral Inflow

AnnAGNPS provides peak flow discharge (m^3/s), runoff volume (m^3), and clay, silt, and sand mass (T) for each runoff event for reaches and cells draining into the modeling reach. These data are then converted into triangular-shaped hydrographs (NRCS, 1986). The duration of the hydrograph is calculated as twice the runoff volume in m^3 divided by the peak discharge. The time-to-peak occurs at 37.5% of the hydrograph duration. The shape of the hydrograph and the value of time-to-peak agree well with that observed for snowmelt events in the Lake Tahoe basin (Figure 5-31).

The linkage between AnnAGNPS cells and reaches and CONCEPTS cross sections is shown in Figure 5-32 for the modeling reach along General Creek, Figure 5-33 for the Upper Truckee River, and Figure 5-34 for Ward Creek. The AnnAGNPS reach and cell IDs in these figures are those of AnnAGNPS subareas. The subarea ID can be obtained from the reach or cell ID by omitting the last digit of the latter ID (a 1, 2, 3, or 4). The reach and cell IDs for General Creek, Upper Truckee River, and Ward Creek are shown in Figures 5-8, 5-14, and 5-18, respectively.

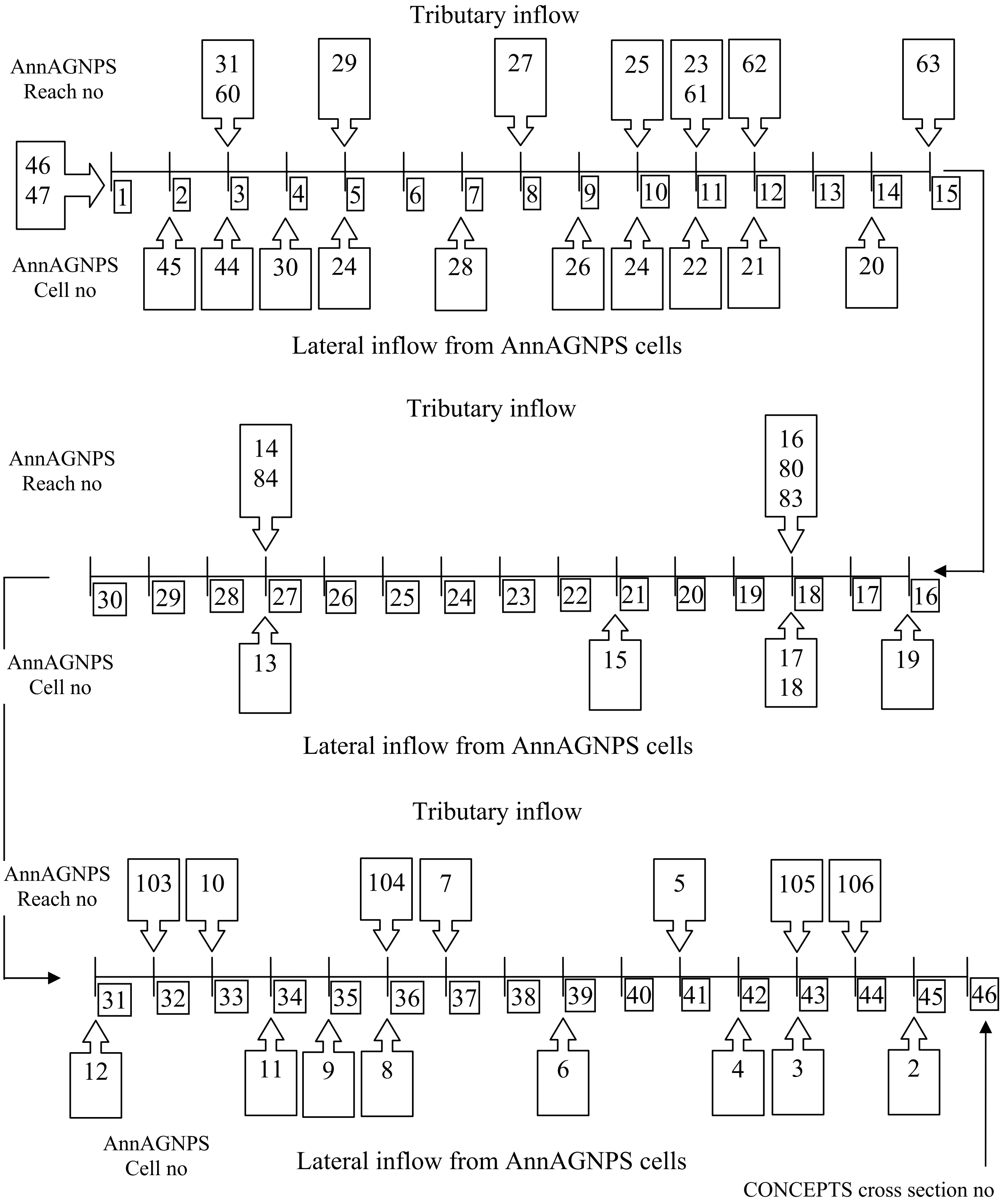


Figure 5-33. Linkage between AnnAGNPS reaches and cells (Figure 5-14) and CONCEPTS cross sections for the Upper Truckee River. (The last digit of the cell ID (a 2 or a 3) is omitted.)

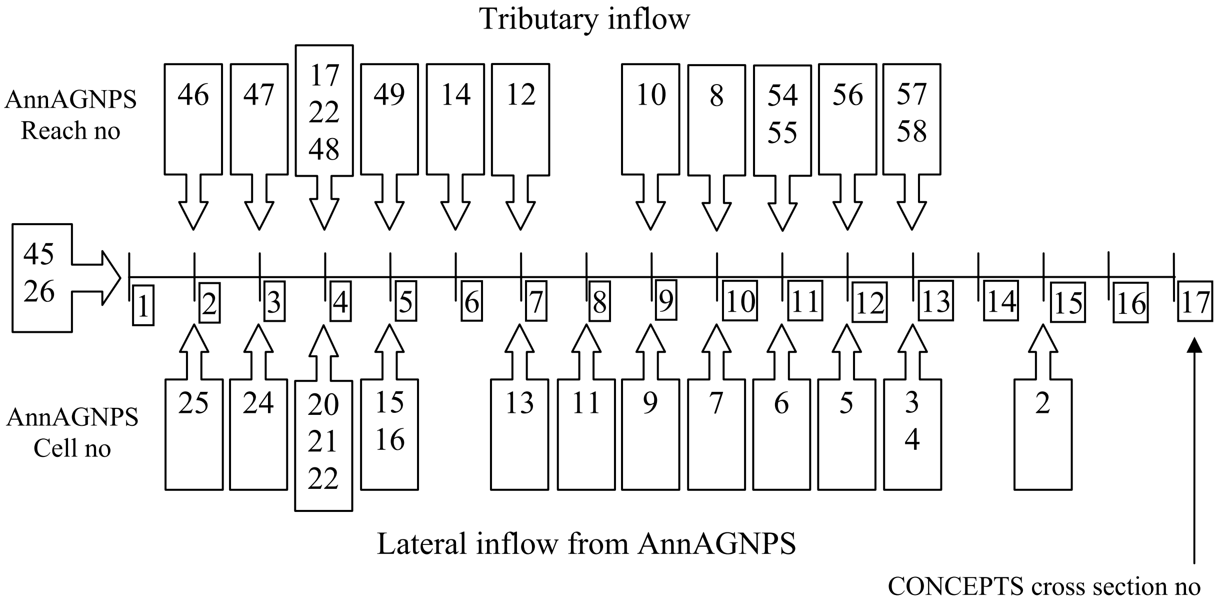


Figure 5-34. Linkage between AnnAGNPS reaches and cells (Figure 5-18) and CONCEPTS cross-sections for Ward Creek. (The last digit of the cell ID (a 2 or a 3) is omitted.)

5.4 Model Validation and 50-Year Simulation

5.4.1 General Creek

AnnAGNPS

Since AnnAGNPS provides the loadings into the main channel for eventual simulation by CONCEPTS, an evaluation of the capability of AnnAGNPS to reproduce the measured values of runoff, sediment, and peak rates helps in developing the input parameters needed by CONCEPTS in reproducing trends in watershed loadings. The location of an USGS gaging station (10336645) near the outlet of the watershed provided data needed for this comparison as well as any calibration that would be required. While AnnAGNPS can produce information at any point in the watershed, this gage was the only point available to compare simulated results with measured data. There were several techniques used to evaluate the performance of AnnAGNPS on the General Creek watershed by comparing annual and monthly runoff and sediment as well as an evaluation of the sources of the runoff and sediment within the watershed.

Annual Runoff. The annual runoff was simulated from 1976 to 2002 at station 10336645, while measured runoff was only available from 1981 to 2000 (Figure 5-35). The percentage of precipitation to runoff was very high, mainly because the snowmelt process occurred too early in the year. The comparison of measured and simulated runoff was good, but in some years the snowpack at higher elevations was not adequately reflected at the Tahoe City climate station resulting in underestimation of total runoff (Figures 5-35 and 5-36). Better climatic information would have improved the simulations of runoff.

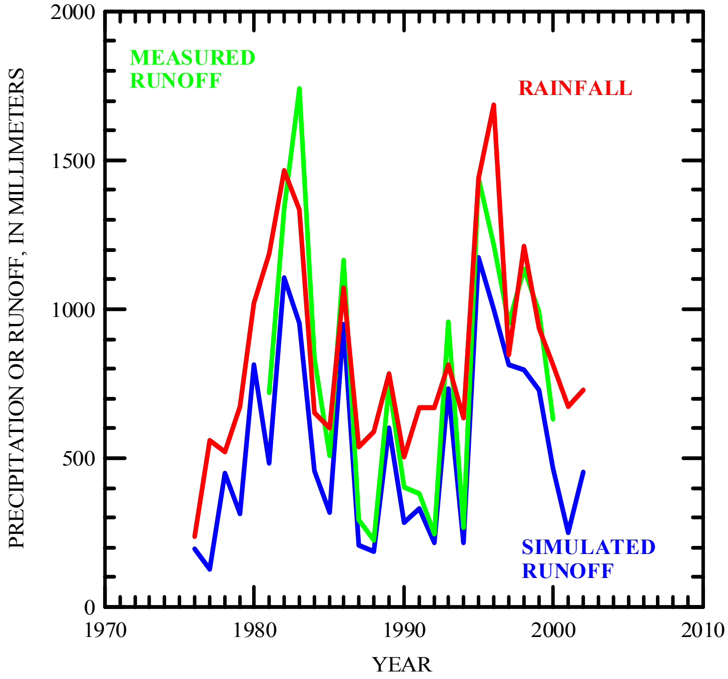


Figure 5-35. AnnAGNPS simulated and measured yearly runoff at the USGS gaging station 10336645 and the yearly precipitation from the Tahoe City climate station used within the simulation of the General Creek watershed.

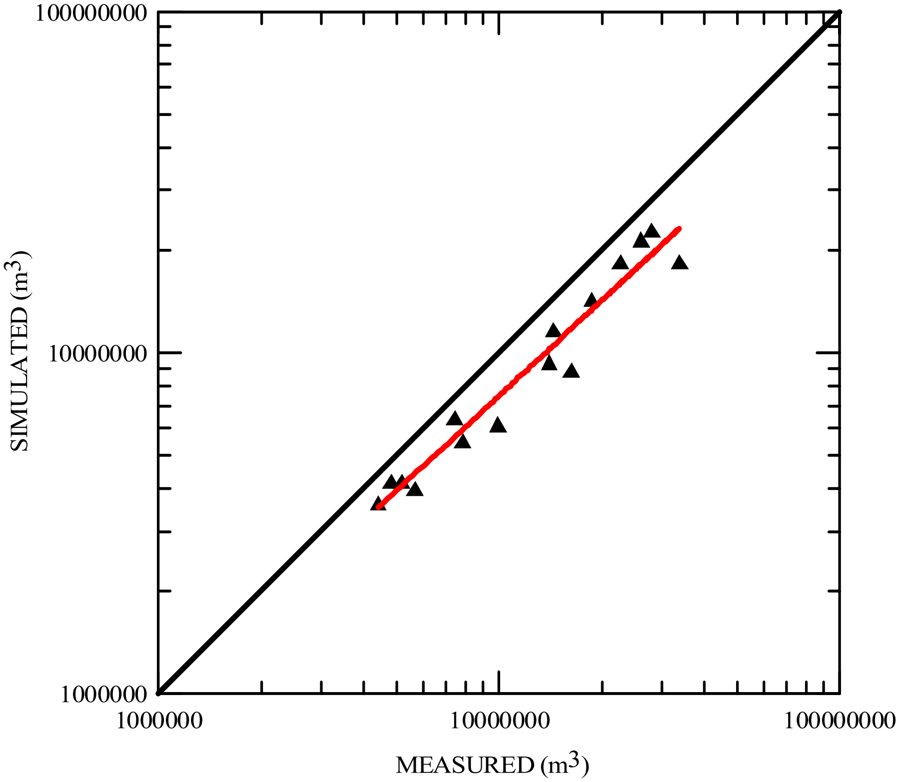


Figure 5-36. AnnAGNPS simulated versus measured yearly runoff from 1981-2000 at station 10336645, General Creek watershed.

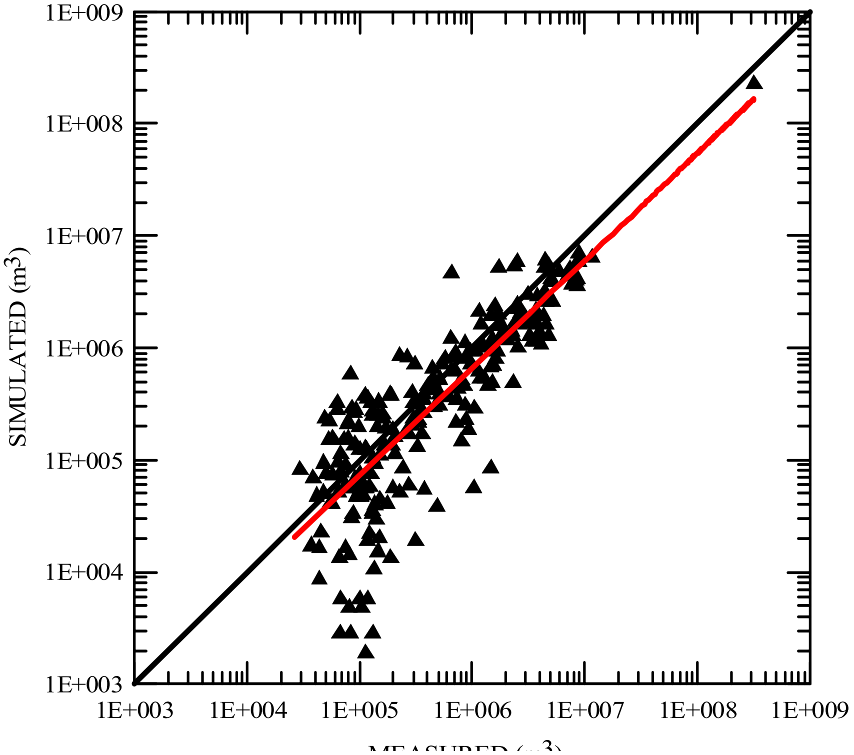


Figure 5-37. AnnAGNPS simulated versus measured monthly runoff during 1981-2000 at the station 10336645, General Creek watershed.

Monthly Runoff. Simulated monthly runoff was compared with measured data for all months from 1981 t -2000 at station 10336645 (Figure 5-37). The trend of simulated monthly runoff matched the measured data very well indicating that the modification made to the lapse rate (Figure 5-24) was appropriate for matching the timing of snowmelt peaks. Since precipitation occurred mainly as snowfall, it is critical that snowmelt be accurately reflected so that channel erosion could be adequately simulated by CONCEPTS.

Annual Fine-Sediment Loads. Simulated, annual fine-sediment loads were compared to calculated annual values at station 10336645 from 1981 to 2001 (Figure 5-38). Simulated fine-sediment transport compared relatively well with data from the gaging station in low- and moderate-flow years. For high flow and sediment- producing years such as 1983 and 1997 where AnnAGNPS results are low relative to the calculated values at the gage, the bulk of the sediment may be coming from channel sources. The application of CONCEPTS will show considerable improvement in the comparison with measured values.

Monthly Fine-Sediment Loads. Monthly, simulated fine-sediment loads were compared with data from station #0336645 for the period 1981 to 2001 (Figure 5-39). General temporal variability of the simulated fine-sediment loads matched the measured reasonably well indicating that upland sources of fine sediment may be an important contributor in the General Creek watershed. Fine-sediment loads simulated by AnnAGNPS from upland sources were less than the calculated values at the gage. This is to be expected because fine sediments emanating from channel sources are neglected here and will be simulated by CONCEPTS.

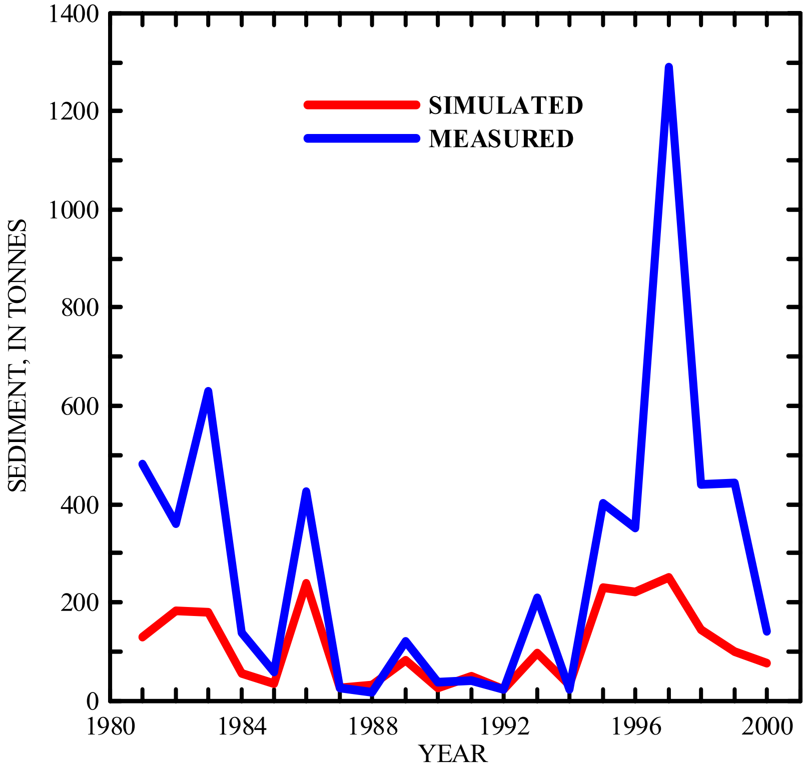


Figure 5-38. AnnAGNPS simulated and measured yearly sediment at station 10336645, General Creek watershed.

Sources. The simulated runoff by AnnAGNPS cells can be used to describe the degree of runoff from the various cells within the watershed (Figure 5-40). A significant amount of runoff occurs in the upper end of the watershed where the land use is rock outcrop. The erosion that occurred within each AnnAGNPS cell can also show the spatial variability throughout the watershed (Figure 5-41). The fine sediment yield that reaches the edge of each AnnAGNPS cell also shows considerable variability throughout the watershed (Figure 5-42) For the most part, monthly fine-sediment loadings do plot around the line of perfect agreement in Figure 5-39, providing evidence that upland sources may provide the majority of the fine sediment to the downstream gage.

Recurrence Interval for the Annual Maximum Instantaneous Peak Discharge. A comparison of measured and simulated peak discharges for water years 1981 – 2001 is shown in Table 5-5. Simulated peaks listed as CONCEPTS represent runoff values input from AnnAGNPS into CONCEPTS and then routed downstream by the channel-evolution model. Generally, the calculated annual peak discharge is 30 to 50 percent larger than those observed. The simulated peak discharge on January 2, 1997 is twice as large as that observed. The 2-year, 5-year, 10-year, and 20-year peak discharges calculated from the observed annual peaks are 6.1, 11.7, 16.5, and 21.9 m^3/s, respectively. The corresponding peak discharges computed by: 1) AnnAGNPS are 8.0, 15.0, 21.8, and 30.5 m^3/s, respectively; and 2) CONCEPTS are 8.4, 15.9, 23.6, and 33.9 m^3/s, respectively.

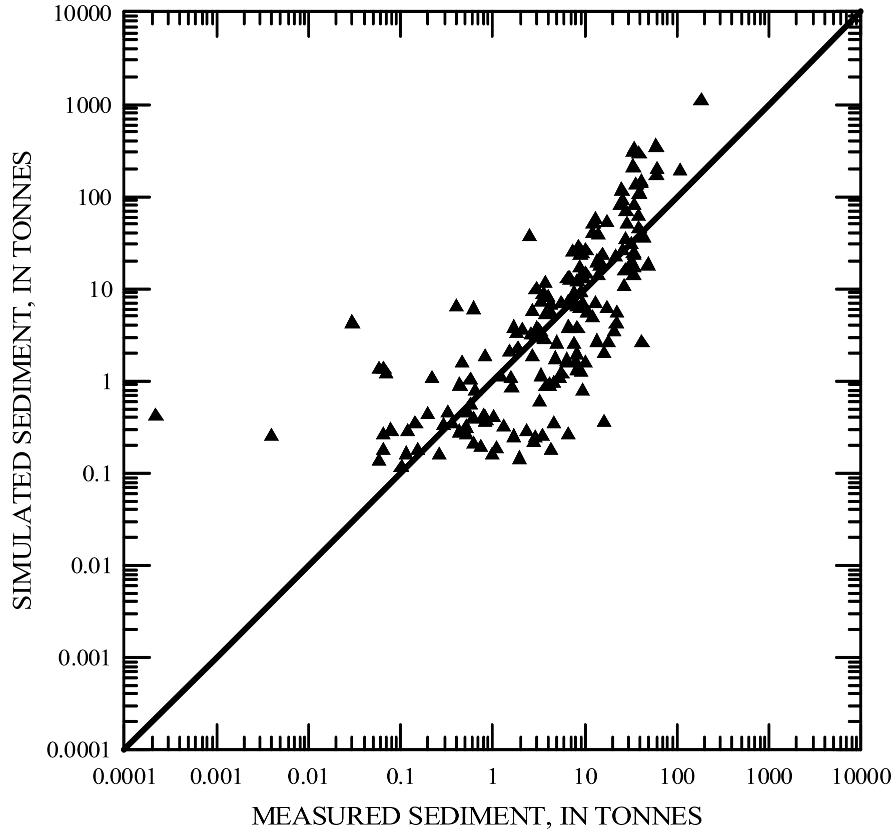


Figure 5-39. AnnAGNPS simulated versus measured monthly fine sediment during 1981-2000 at the USGS gaging station 10336645 at General Creek watershed.

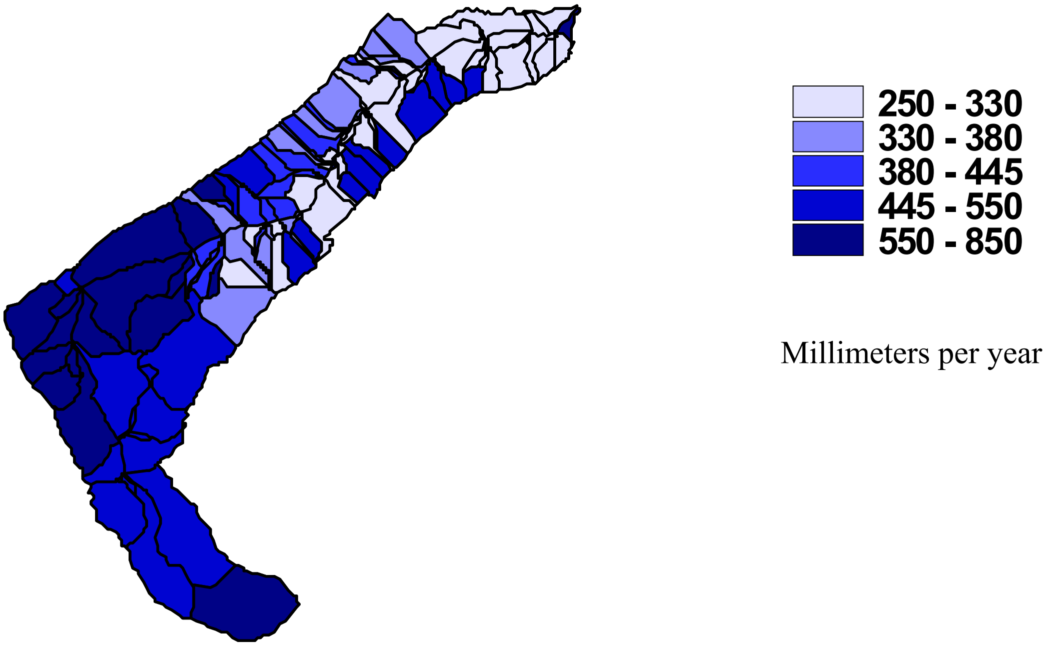


Figure 5-40. Average annual runoff simulated from AnnAGNPS for each cell on General Creek watershed.

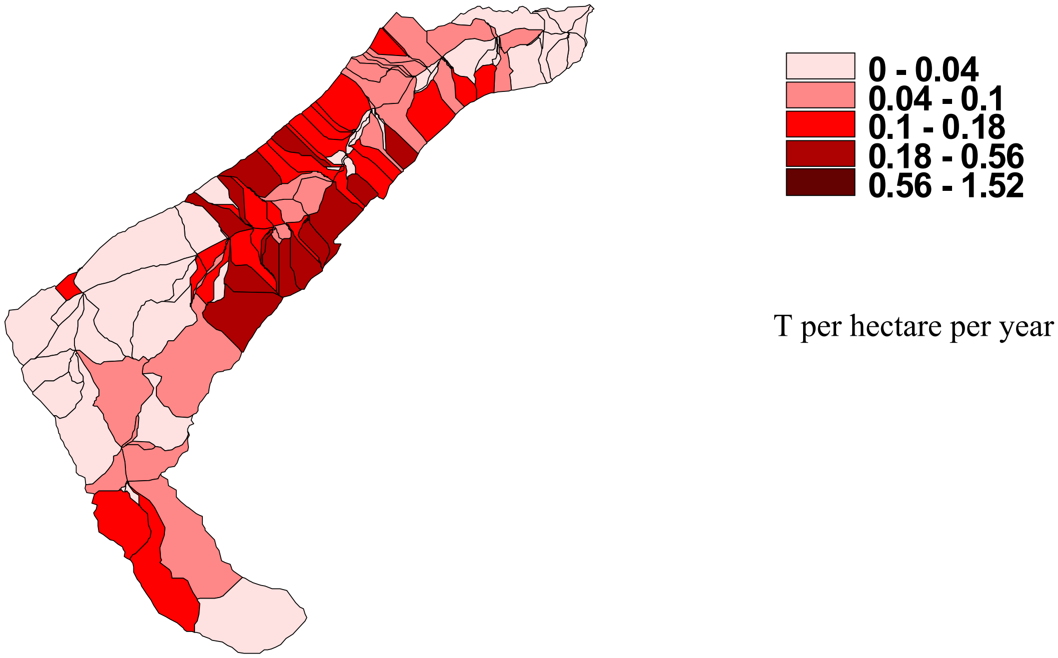


Figure 5-41. Average annual erosion simulated from AnnAGNPS for each cell on General Creek watershed.

Table 5-5. Comparison of measured and simulated annual peak discharge at USGS gaging station 10336645 on General Creek. Values are in cubic meters per second.

Water year	Observed	CONCEPTS	Water year	Observed	CONCEPTS
1981	3.79	5.73	1992	2.80	4.82
1982	21.66	25.45	1993	8.16	10.13
1983	9.49	9.10	1994	2.46	4.55
1984	10.17	8.43	1995	9.37	12.32
1985	3.65	4.66	1996	15.94	14.09
1986	15.12	28.80	1997	22.57	47.90
1987	2.92	5.26	1998	8.58	22.55
1988	1.22	3.46	1999	8.69	9.27
1989	5.69	8.07	2000	5.83	12.31
1990	2.46	4.58	2001	3.23	5.37
1991	4.36	6.55			

CONCEPTS Validation

Calculated suspended-sediment loads at station 10336645 (see section 3.4) and the observed changes at cross sections 2, 4, 6, and 13 between 1983 and 2002 were used to validate CONCEPTS for the period August 1983 through December 2002. Figures 5-43 through 5-46 show the results of the validation. Simulated annual peak discharges are listed in Table 5-5 and discussed above.

Changes in cross section geometry. Figure 5-42 shows that simulated cross-sectional changes between 1983 and 2002 agree very well with those observed. Changes in bed elevation along General Creek are negligible and channel width adjustment is minor. The simulated adjustment occurred in February 1986, whereas in reality it probably occurred during the high runoff events in the first week of January 1997 (see next subsection).

Sediment Load. Figure 5-43 compares measured and simulated monthly loads of fines (clay- and silt-sized particles), sands, and total suspended sediments. The points plot around the line of perfect agreement. The observed scatter is to be expected due to of the variability between measured and simulated monthly runoff (Figure 5-37). The r^2 values for the fines, sands, and total suspended sediments are 0.67, 0.43, and 0.70 respectively.

Generally, annual loads of fines, sands, and total suspended sediment appear to be correlated with variations in annual runoff (Figure 5-44). Years with low runoff correspond to years with low annual sediment loads. Largest measured annual suspended sediment load occurred in 1997 (1300 T), whereas the largest simulated suspended load occurred in 1986 (1250 T). The latter tonnage is related to simulated channel width adjustment in 1986 (see previous subsection). The measured suspended load in 1986 is about 400 T, about 850 T lower than that simulated. This is similar to the difference of about 800 T between measured and simulated suspended sediment load in 1997. Hence, it can be inferred that channel width adjustment must have occurred in 1997, most probably during or after the January 2-3 runoff event, and contributed approximately 800 T of fines and sands to the annual suspended load at the gaging station. Between 1984 and 2001 measured average-annual sediment loads of fines, sands, and total suspended sediment are 61, 178, and 238 T, respectively. The corresponding simulated average annual loads are 64, 208, and 272 T, respectively. The simulated average annual load of fines (clays and silts) agrees well with that measured. The average annual load of sands is slightly overestimated.

Annually-averaged monthly sediment load of fines, sands, and total suspended sediment for each month is shown in Figure 5-45. Most sediment is transported during the snowmelt period from April through June. The simulated sediment loads agree quite well with those measured for this period. The high measured average sediment load for the month of January is caused by channel erosion during January 1997 (see above). The simulated erosion occurred in February 1996, increasing the simulated average sediment load for that month.

Of the total amount of fines delivered to the channel 78% is eroded from the uplands and 22% from the streambanks (Table 5-6). Streambanks contributed 60% of the sands and 53% of the total suspended sediment. Simulated total suspended-sediment loads averaged over the validation period are 241 T/y (41 T/y of fines), compared to 176 T/y calculated at station 10336645. Part of this discrepancy is due to the fact that CONCEPTS loads shown in Table 5-6 represents all sediment inputs along the modeled reach. In fact, some of this material is deposited on the bed during downstream transport.

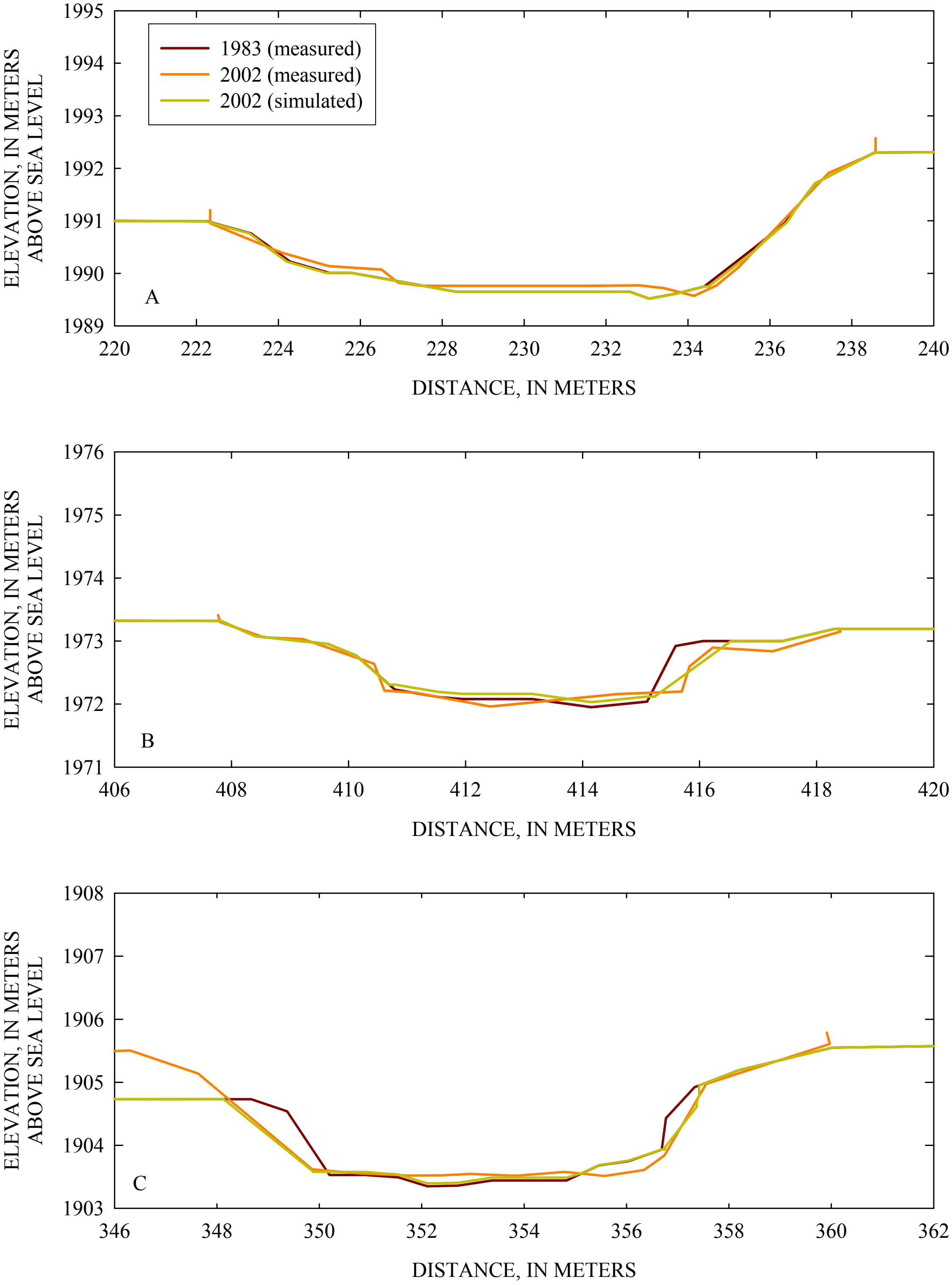


Figure 5-42. Comparison of observed and simulated cross-sectional changes at: A) CONCEPTS cross section 4 and NH60, B) CONCEPTS cross section 6 and NH70, and C) CONCEPTS cross section 13 and NH90.

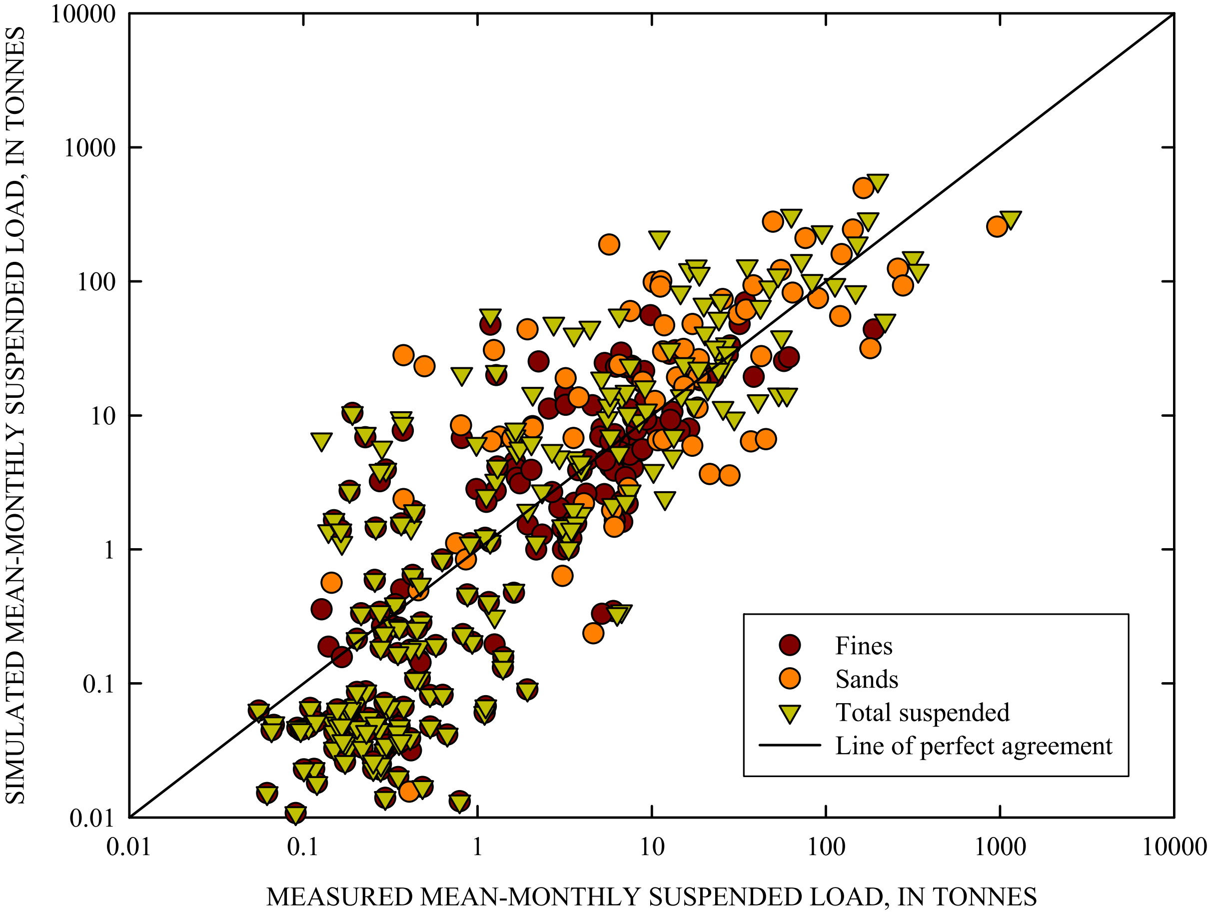


Figure 5-43. Comparison of measured and simulated monthly loads of fines (clay and silts), sands, and total suspended sediments at station 10336645, General Creek.

Table 5-6. Relative contributions of uplands and streambanks to suspended sediment load at the outlet of General Creek for the validation period.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	78	22	48
Sands	40	60	193
Total suspended	47	53	241

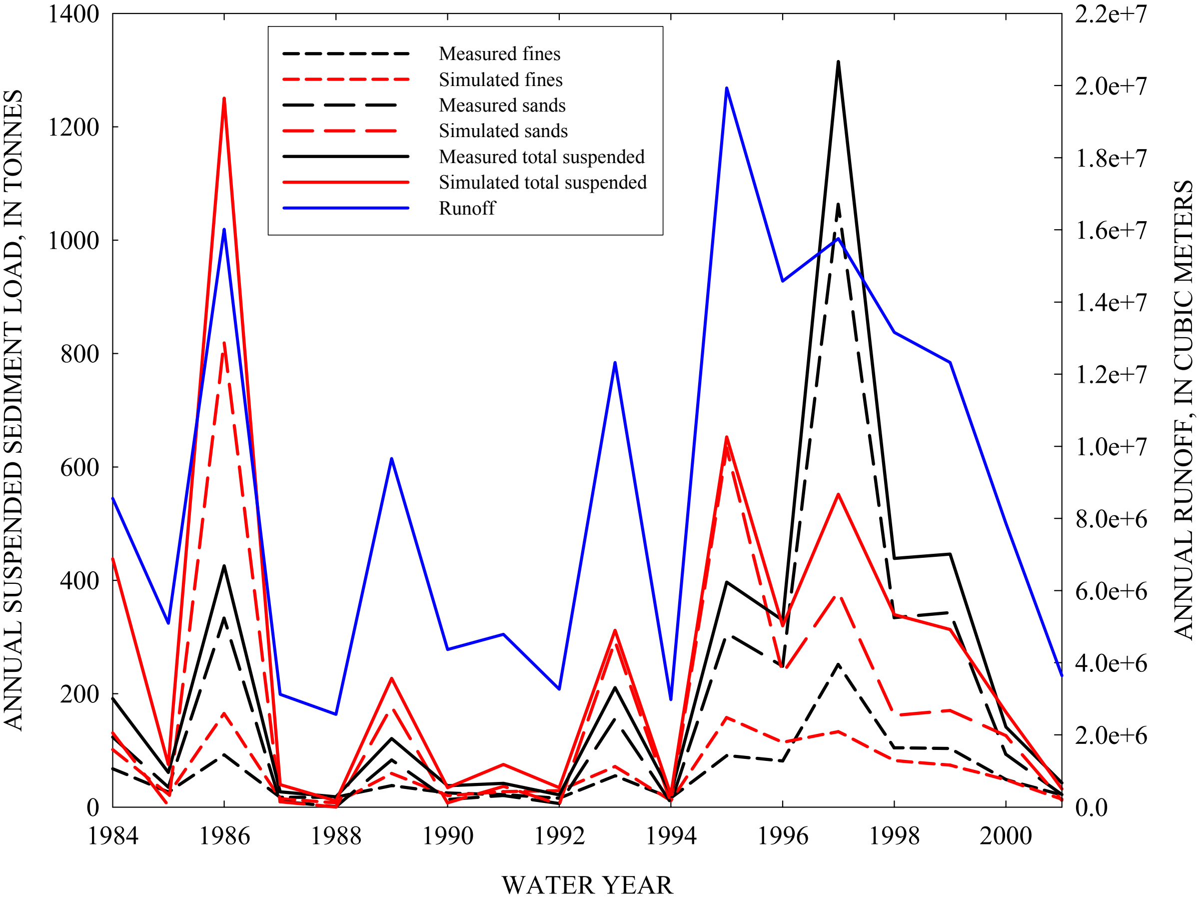


Figure 5-44. Comparison of measured and simulated annual loads at station 10336645, General Creek.

CONCEPTS 50-Year Simulation

A simulation with a 50-year flow record was performed to determine trends in sediment loads. Channel geometry is based on the 2002 cross-section surveys. All physical properties are those determined from the validation. The records of tributary and lateral inflow of water and sediments were constructed in the same way as the validation case. The runoff in years 28 through 50 is the same as in years 1 through 23 of the 50-year flow record, except the large storm event on January 2 of year 22 is not repeated in year 49.

Figure 5-46 shows changes in channel top width and bed elevation over the 50-year simulation period. Measurable changes in top width occurred at cross sections 2 (5 m) and 14 (2 m). Changes in thalweg elevation range from 0.05 m of erosion at cross section 9 to 0.12 m of deposition at cross section 14.

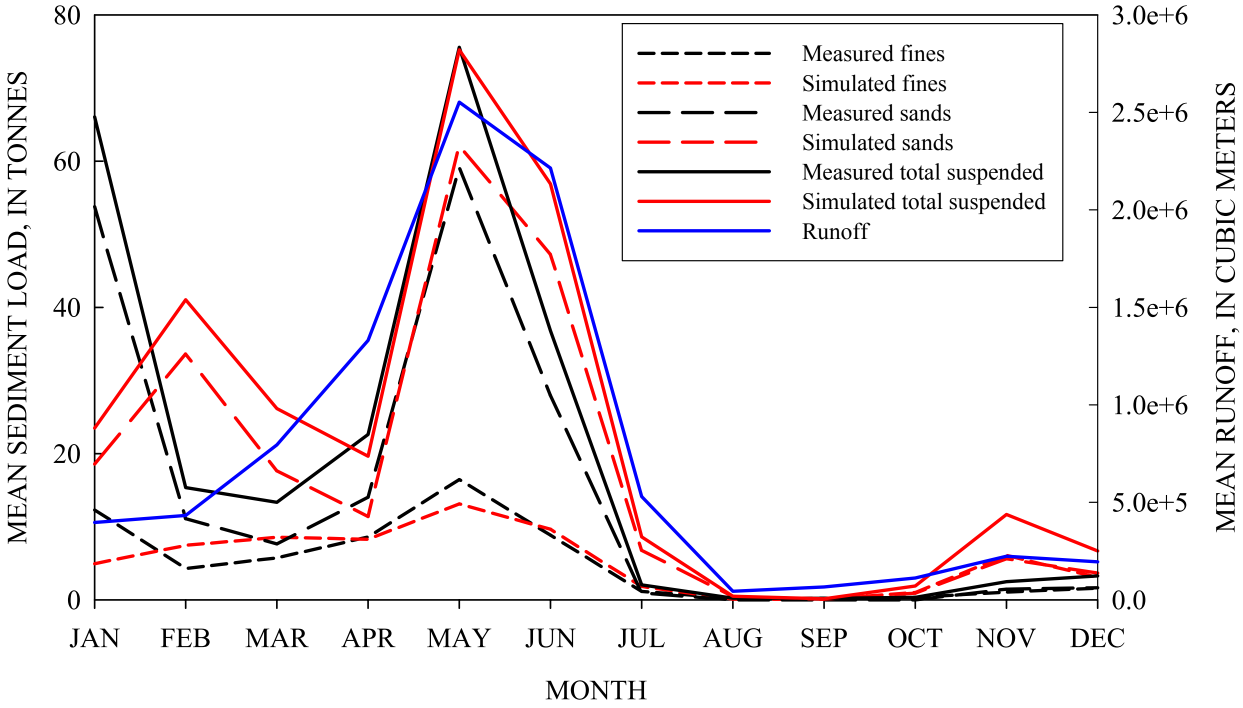


Figure 5-45. Comparison of measured and simulated annually-averaged monthly sediment loads and runoff at USGS gaging station 10336645 in General Creek.

Figure 5-47 shows the simulated annual runoff, and annual loads of fines, sands, and total suspended sediments at the outlet of General Creek. The annual loads in years 1 through 27 are larger than those in years 28 through 50 though annual runoff is the same. However, the annual load in year 38 is slightly larger than the corresponding load in year 11 because of an increase in sands transport. Channel adjustments over the first 27 years have led to a fairly stable-channel configuration, hence reducing the amount of sediments eroded from the channel. Thus, the 1997 runoff event does not seem to have rejuvenated the General Creek channel.

Over the 50-year simulation period, 72% of the total amount of fines delivered to the channel eroded from the uplands and 28% from streambanks (Table 5-7). Streambanks contributed 59% of the sands and 51% of the total suspended sediment.

Table 5-7. Relative contributions of uplands and streambanks to suspended-sediment load at the outlet of General Creek over the 50-year simulation period.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	72	28	51
Sands	41	59	144
Total suspended	49	51	196

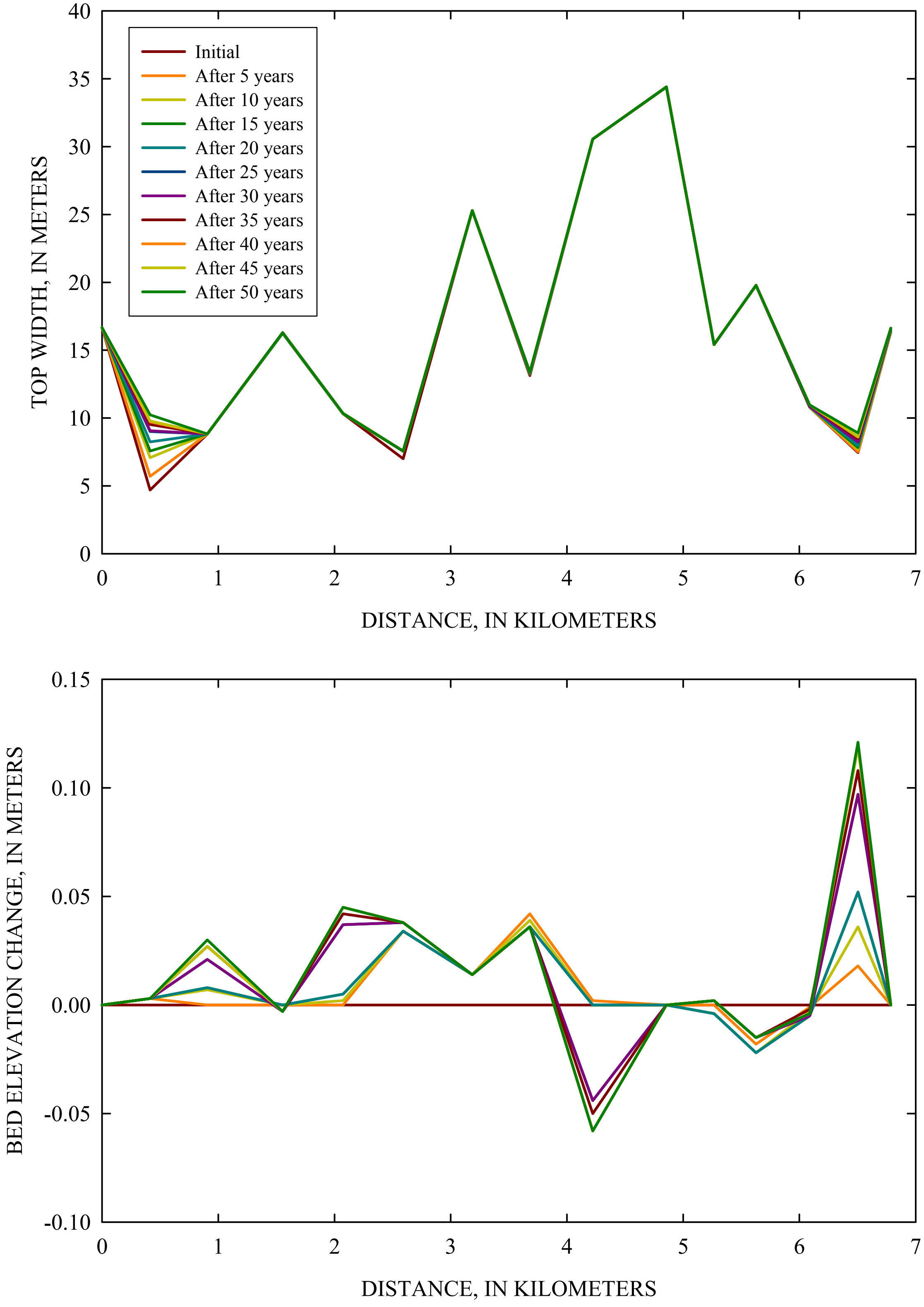


Figure 5-46. Simulated changes in top width and bed elevation along General Creek over a 50-year period.

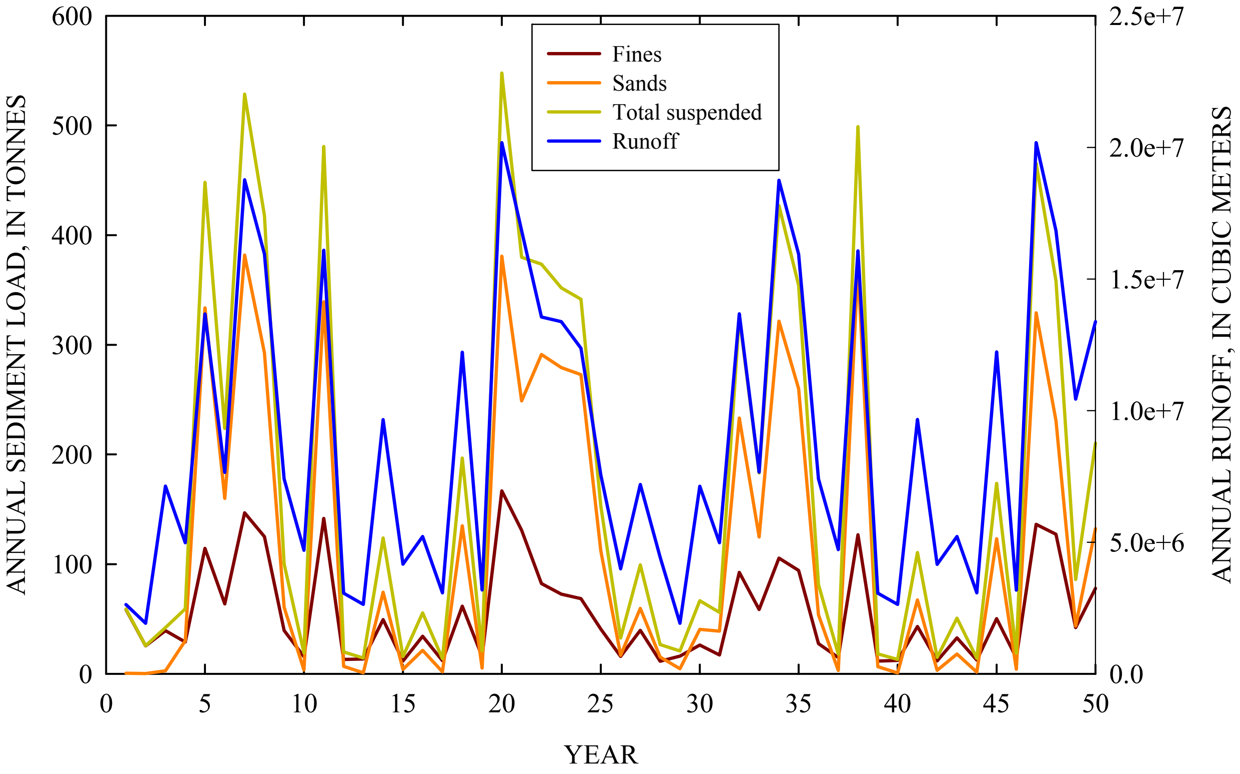


Figure 5-47. Simulated annual runoff and loads of fines, sands, and total suspended sediments at the outlet of General Creek for the 50-year simulation.

5.4.2 Upper Truckee River

AnnAGNPS

Three USGS gaging stations (10336610 at the lower end, 103366092 in the middle, and 10336580 at the upper end) were used to validate AnnAGNPS runoff simulations within the Upper Truckee River watershed. The diversion of water from Echo Lake out of the watershed required that those areas not be included in the AnnAGNPS simulation and thus were not be routed to the outlet.

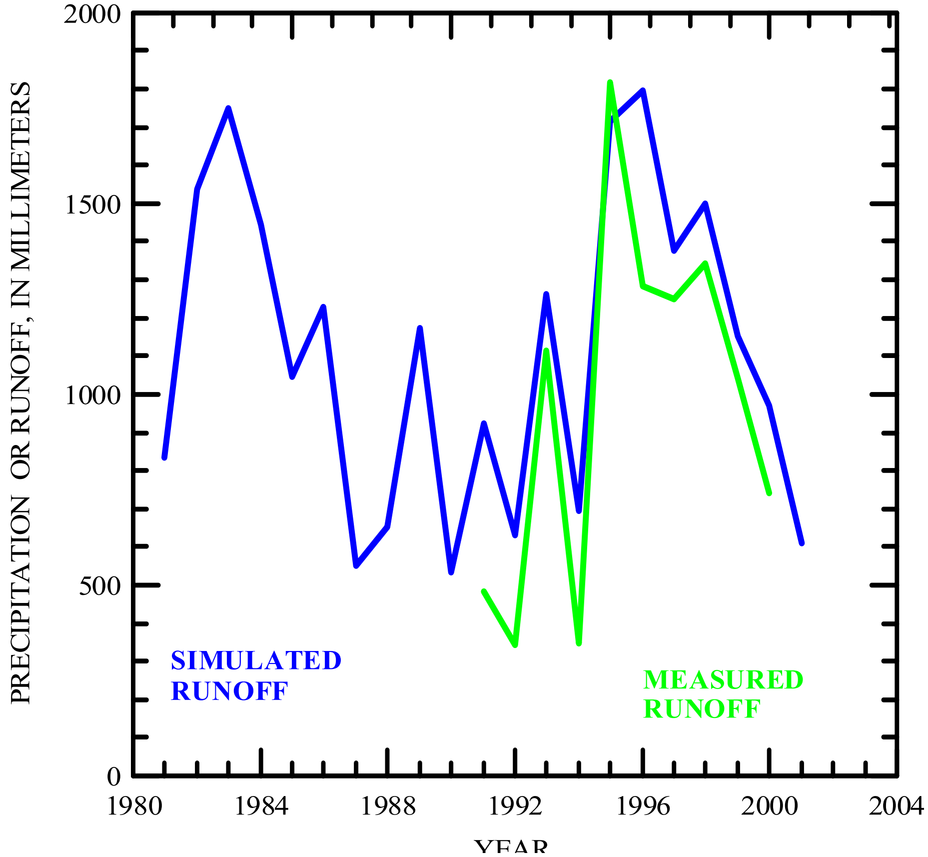


Figure 5-48. AnnAGNPS simulated and measured annual runoff at the upstream station (10336580) of the Upper Truckee River watershed.

Annual Runoff. Simulated annual runoff was determined from 1981 to 2001 at station 10336580, while measured runoff was available from 1991 to 2000 (Figure 5-48). The same years were available for station 103366092 (Figure 5-49). The simulated yearly runoff was determined from 1981 to 2001 at the USGS gaging station #10336610, while measured runoff was available from 1981 to 2000 (Figure 5-50). As with General Creek, simulated annual runoff results compare very well with those measured.

Monthly Runoff. Simulated runoff was compared with measured data from 1991-2000 at the upstream station (10336580; Figure 5-51), mid-reach station (103366092; Figure 5-52), and the downstream station (10336610; Figure 5-53). Monthly runoff volumes were not simulated well (Figure 5-51), particularly during periods of low and moderate flows. We suspect that this is due to over estimation of flows during winter months, thereby leaving an insufficient snowpack for large snowmelt peaks during April through June. Improved climatic information would also improve the model simulations. Also, AnnAGNPS has been designed to estimate long-term impacts of watershed characteristics using some input parameters that are developed as average annual parameters. While the model attempts to incorporate the variability of the long term parameters, increased variability of the results can occur for individual events or monthly summaries, and will not match as well as annual values.

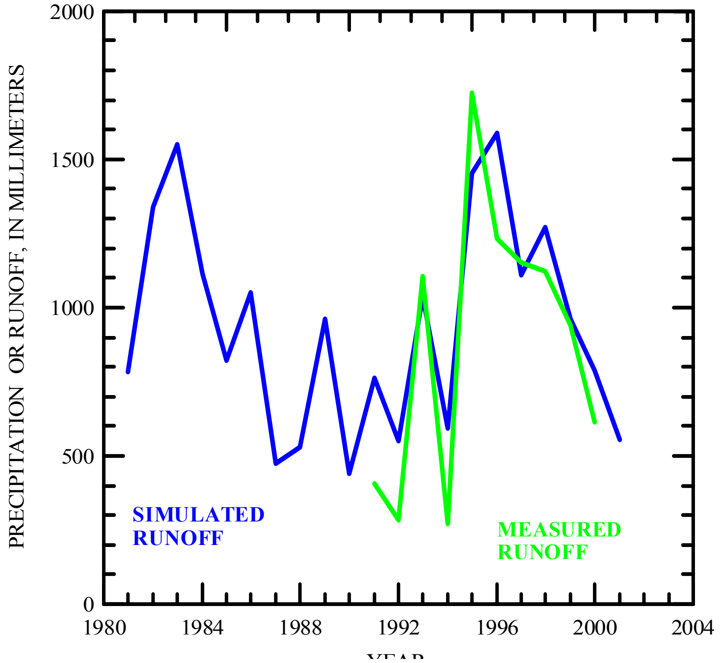


Figure 5-49. AnnAGNPS simulated and measured annual runoff at the mid-reach gaging station 103366092 of the Upper Truckee River watershed.

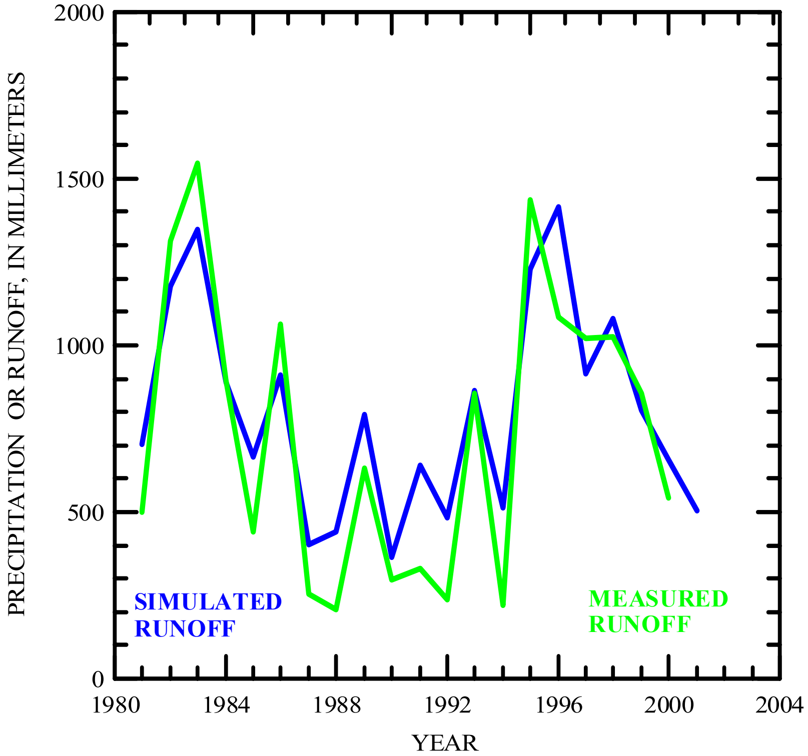


Figure 5-50. AnnAGNPS simulated and measured annual runoff at the downstream station 10336610 of the Upper Truckee River watershed.

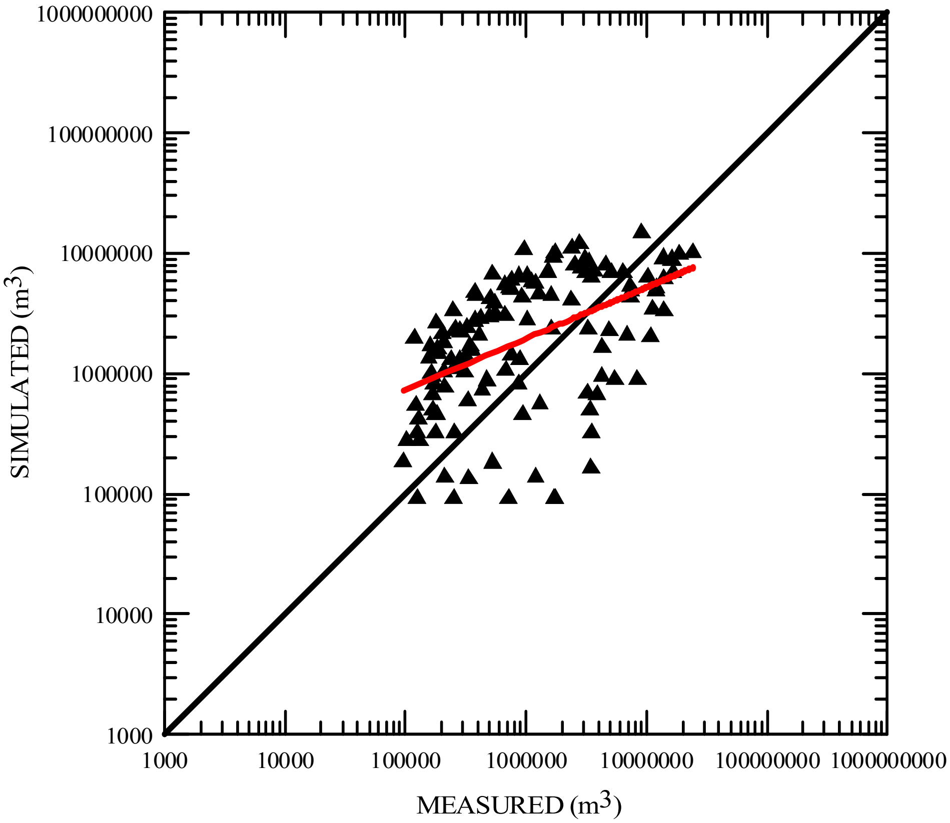


Figure 5-51. AnnAGNPS simulated versus measured monthly runoff during 1991-2000 at upstream station 10336580, Upper Truckee River watershed.

<u>Annual Fine-Sediment Loads</u>. Simulated annual fine-sediment loads were compared to measured data from the three gauging stations in the basin Figure 5-54 to 5-56. The comparisons show that at the upstream station (10336580) fine-sediment contributions from upland sources are proportionally high, relative to total suspended-sediment values measured at the station. With increasing distance downstream, the discrepancy between AnnAGNPS simulated loads and measured (calculated) loads increases due to greater contributions from channel sources that are not simulated by the upland model. These results agree with data on calculated suspended-sediment loads and yields discussed in sections 3.4 and 3.7.

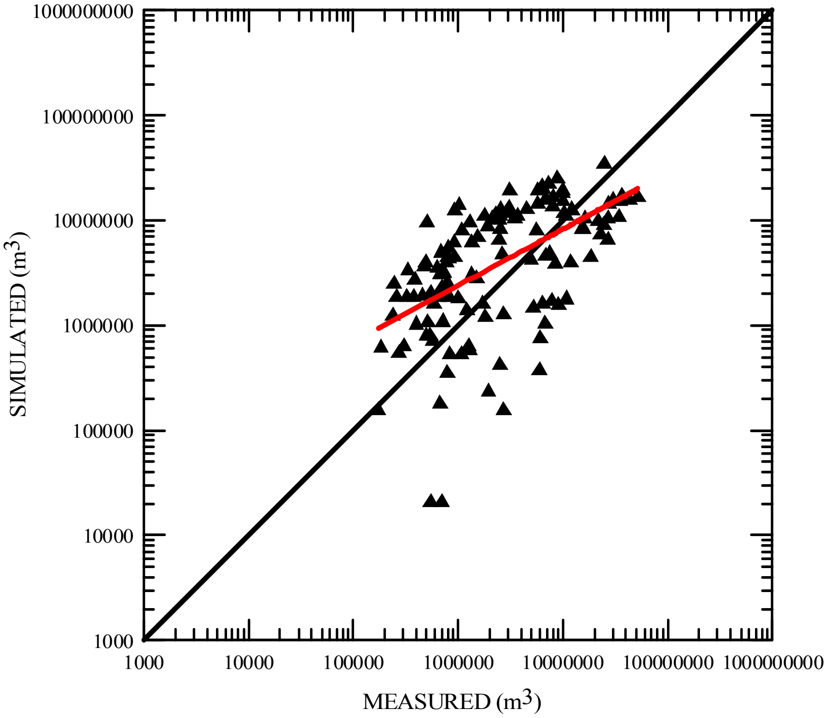


Figure 5-52. AnnAGNPS simulated versus measured monthly runoff during 1991-2000 at mid-reach station 103366092, Upper Truckee River watershed.

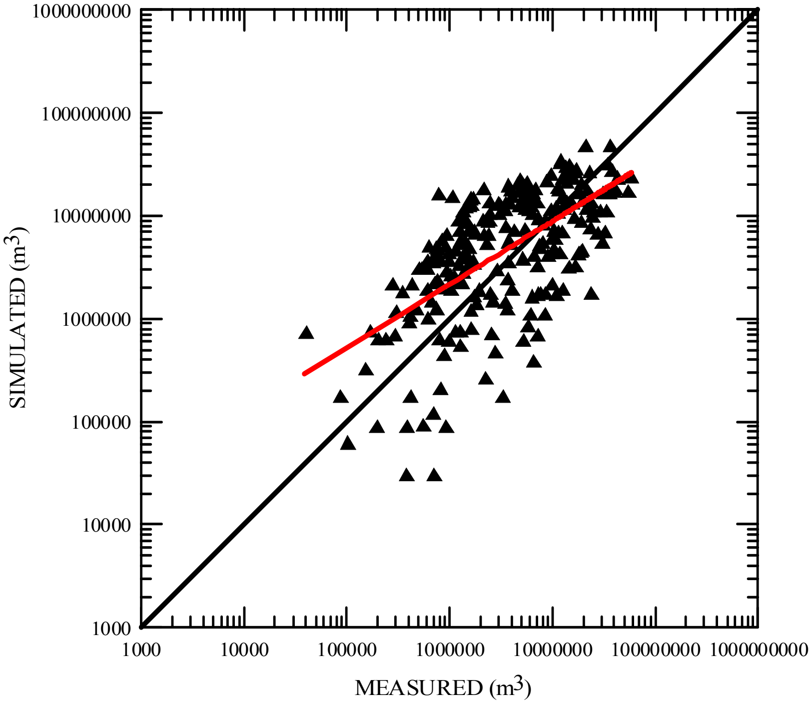


Figure 5-53. AnnAGNPS simulated versus measured monthly runoff during 1981-2000 at the downstream station 10336610, Upper Truckee River watershed.

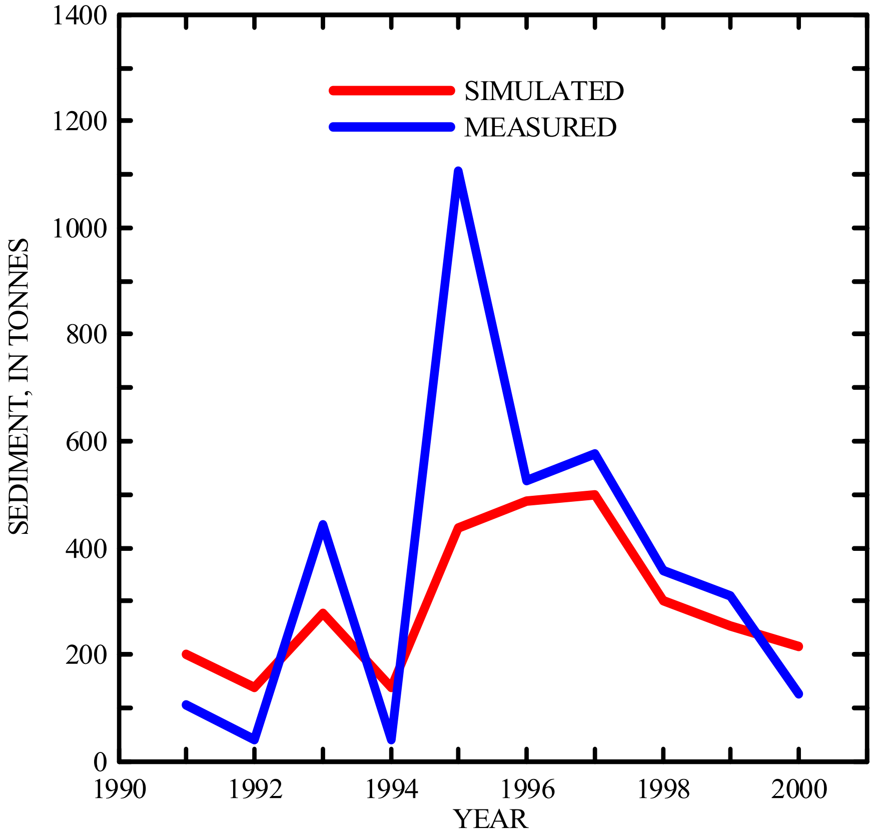


Figure 5-54. AnnAGNPS simulated and measured annual sediment loads at the upstream station 10336580, Upper Truckee River watershed.

Sources. A significant amount of runoff occurs in the upper end of the watershed where the land cover is rock outcrop (Figure 5-57). The fine sediment yield that reaches the edge of each AnnAGNPS cell also shows considerable variability throughout the watershed, but generally higher sediment yield values occur in the upper end of the watershed (Figures 5-58 and Figure 5-59).

Recurrence Interval for the Annual Maximum Instantaneous Peak Discharge. Tables 5-8 through 5-10 list the observed annual peak discharges at the USGS gaging stations 10336580, 103366092, and 10336610, respectively, and the annual (water year) peak discharges computed by AnnAGNPS routed to CONCEPTS. The simulated annual peak discharges are about 75 percent larger than those observed. The 2-year, 5-year, 10-year, and 20-year peak discharges calculated from the observed annual peaks are 11.2, 21.4, 31.9, and 45.9 m^3/s, respectively.

At the mid-reach station (103366092) simulated annual-peak discharges agree better for the less frequent, large runoff events, but are still far too high for the more frequent, moderate runoff events. The 2-year, 5-year, 10-year, and 20-year peak discharges calculated from the observed annual peaks are 23.9, 53.3, 84.3, and 125.5 m^3/s, respectively. The corresponding peak discharges computed by AnnAGNPS routed through CONCEPTS are 37.8, 70.8, 105.3, and 152.0 m^3/s, respectively.

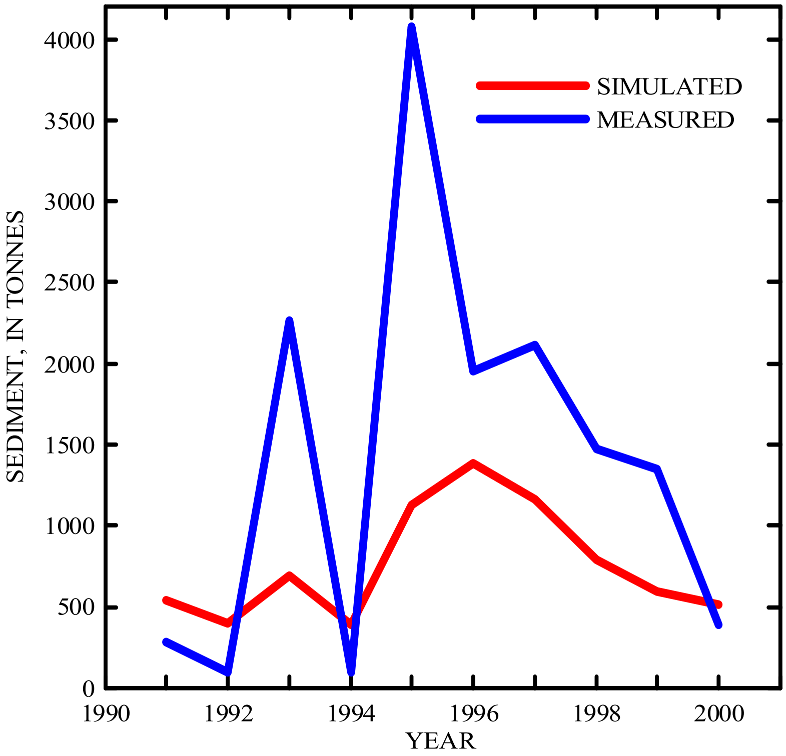


Figure 5-55. AnnAGNPS simulated and measured yearly sediment loads at the mid-reach station 103366092, Upper Truckee River watershed.

At the downstream, index station (10336610) the agreement between observed and simulated annual peak discharges worsens. The observed peak discharges reduce between stations 103366092 and 10336610, whereas the simulated peak discharges increase. The 2-year, 5-year, 10-year, and 20-year peak discharges calculated from the observed annual peaks are 21.7, 48.7, 75.8, and 110.6 m^3/s, respectively. The corresponding peak discharges computed by: 1) AnnAGNPS routed through CONCEPTS are 52.8, 90.3, 124.5, and 166.1 m^3/s, respectively.

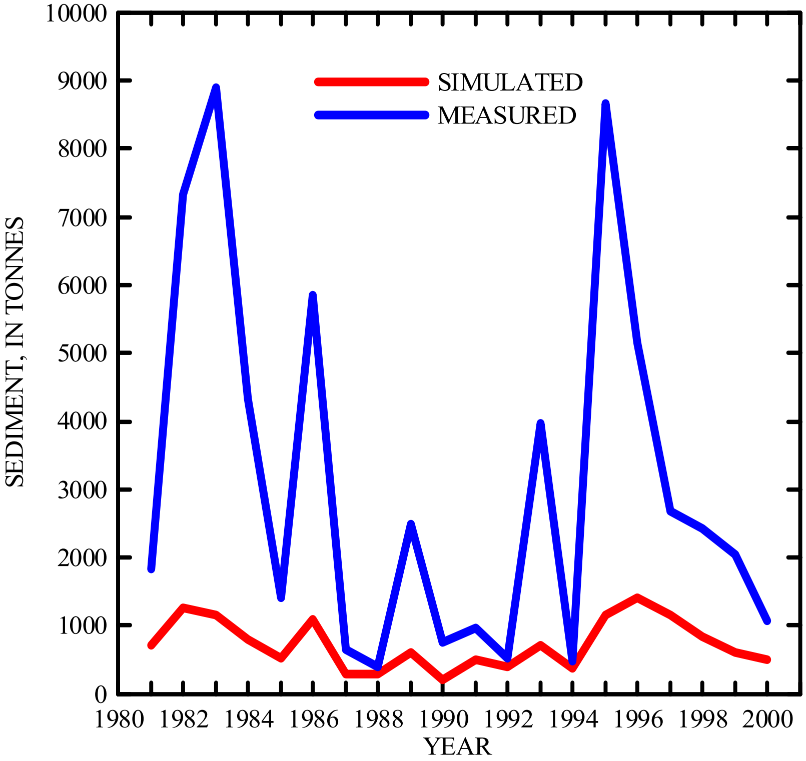


Figure 5-56. AnnAGNPS simulated and measured yearly sediment loads at the downstream station 10336610, Upper Truckee River watershed.

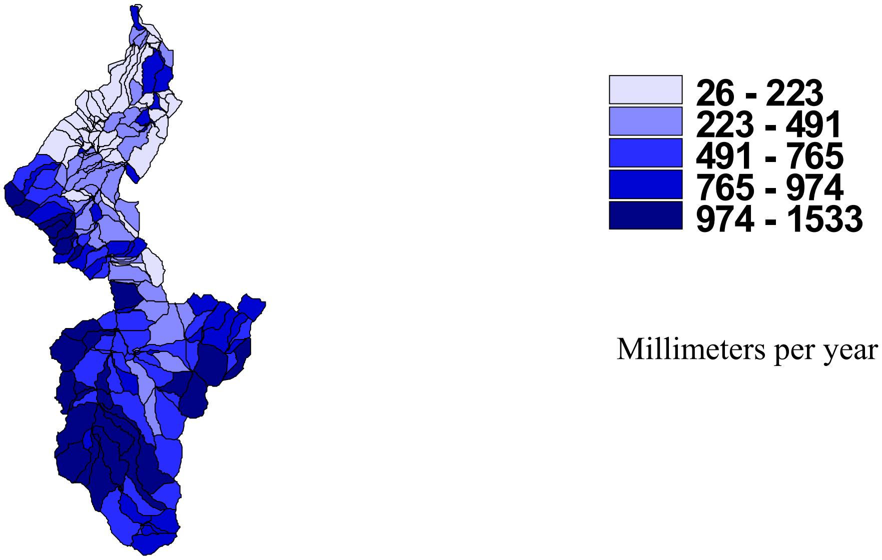


Figure 5-57. Average annual runoff simulated from AnnAGNPS for each cell on Upper Truckee River watershed.

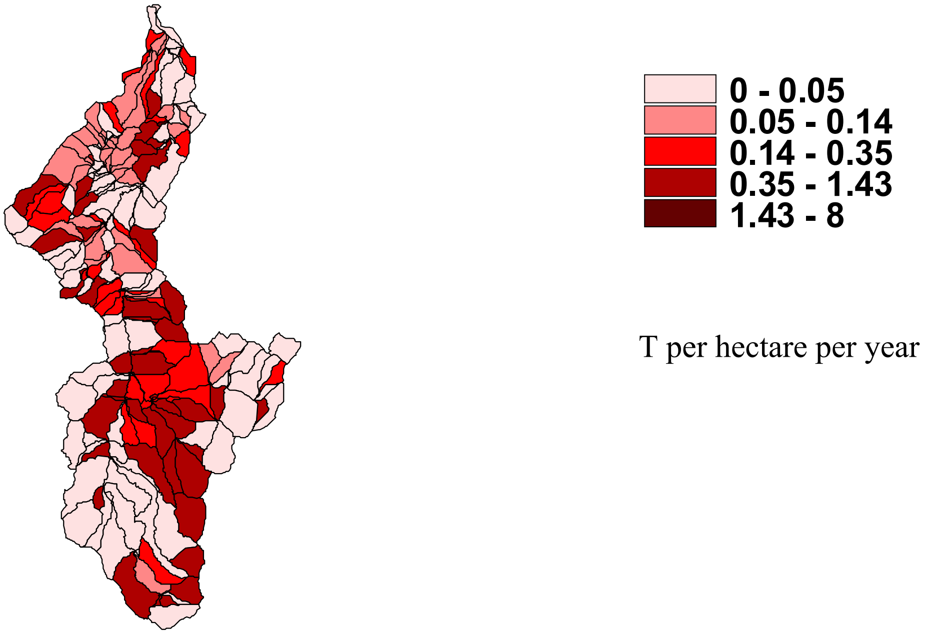


Figure 5-58. Average annual erosion simulated from AnnAGNPS for each cell on Upper Truckee River watershed.

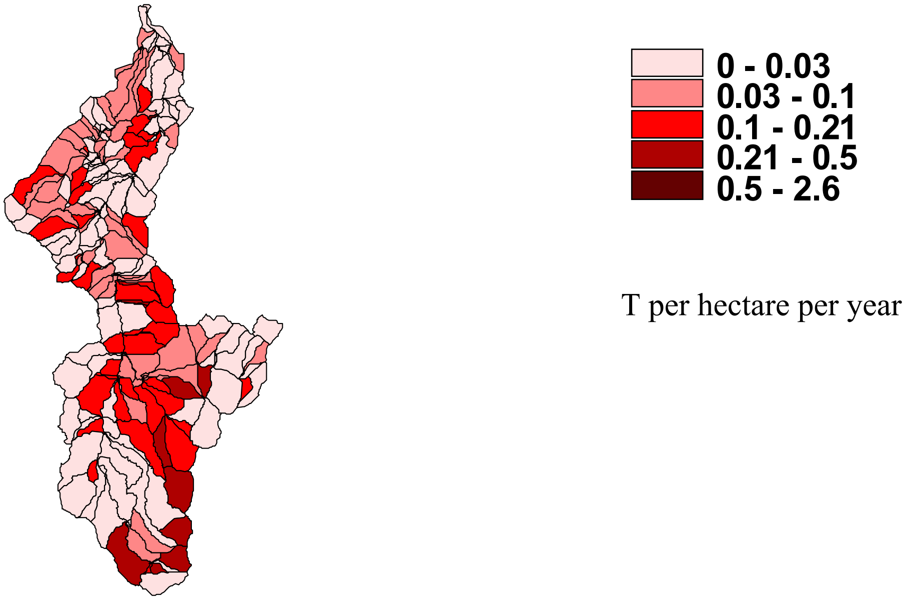


Figure 5-59. Average annual sediment yield simulated from AnnAGNPS for each cell on Upper Truckee River watershed.

Table 5-8. Comparison of measured and simulated annual peak discharge at USGS gaging station 10336580. Values are in cubic meters per second.

Water year	Observed	Water year	Observed
1991	8.72	1997	56.92
1992	4.59	1998	10.96
1993	13.20	1999	15.01
1994	5.75	2000	12.40
1995	15.55	2001	6.94
1996	26.76		

Table 5-9. Comparison of measured and simulated annual peak discharge at USGS gaging station 103366092. Values are in cubic meters per second.

Water year	Observed	CONCEPTS	Water year	Observed	CONCEPTS
1991	14.47	47.75	1997	144.98	182.47
1992	8.18	33.92	1998	24.15	43.78
1993	45.31	30.60	1999	34.83	27.81
1994	7.59	16.66	2000	23.50	28.06
1995	34.83	71.74	2001	9.97	22.31
1996	65.70	87.71			

Table 5-10. Comparison of measured and simulated annual peak discharge at USGS gaging station 10336610. Values are in cubic meters per second.

Water year	Observed	CONCEPTS	Water year	Observed	CONCEPTS
1981	9.97	51.15	1991	11.38	67.26
1982	72.21	125.41	1992	8.04	33.34
1983	36.81	55.01	1993	20.64	57.63
1984	39.08	69.80	1994	6.80	25.27
1985	13.00	42.44	1995	41.34	89.69
1986	77.59	150.53	1996	50.40	109.15
1987	15.09	28.23	1997	155.18	210.94
1988	4.81	23.14	1998	41.91	47.15
1989	16.85	51.50	1999	28.88	38.76
1990	6.68	36.17	2000	24.07	41.47

CONCEPTS Validation

Calculated suspended-sediment loads at stations 103366092 and 10336610 (see section 3.4) and the observed changes at cross sections 19 through 26 between 1992 and 2002 were used to validate CONCEPTS for the period from January 1981 through September 2001. Figures 5-60 through 5-63 show the results of the validation.

Changes in cross section geometry. In general, simulated changes in bed elevation along the Upper Truckee River are negligible, although there is 0.5 m of deposition at cross sections 24 and 44. Channel width adjustment is minor above river kilometer 18. There is approximately 1 m of widening between cross sections 12 and 15 and cross sections 38 and 44. Significant widening, up to 6 m, is simulated between cross sections 19 and 26. Figure 5-60 compares simulated cross-sectional changes at cross sections 19, 23, and 26 with those observed between 1992 and 2002. The simulated changes agree quite well with those observed. The simulated cross-sectional changes at cross sections 20, 21, 22, 24, and 25 (not plotted) compare fairly poorly with those observed. The channel segment containing these cross sections is highly sinuous. As a consequence, flow patterns are highly complex (three-dimensional) and cannot be captured by a one-dimensional flow model like CONCEPTS. For example, Figure 5-60C shows the flow-induced scour of the pool near the left bank of cross section 26.

Sediment Load. Figure 5-61 compares measured and simulated monthly loads of fines (clay- and silt-sized particles), sands, and total suspended sediments. The points plot around the line of perfect agreement. The observed scatter is to be expected in light of the variability between measured and simulated mean-monthly runoff (Figures 5-52 and 5-53). At station 103366092 the r^2 value for total suspended sediments is 0.40. At station 10336610 the r^2 values for the fines, sands, and total suspended sediments are respectively 0.45, 0.35, and 0.39.

Generally, annual loads appear to be correlated with annual runoff (Figure 5-62). Years with low runoff correspond to years with low annual sediment loads. The simulated annual load at gaging station 103366092 agrees quite well with that measured. However, the annual load in 1993 and 1995 is underpredicted. Figure 5-62A indicates that significant channel adjustments (bank widening) are simulated in 1997, because annual suspended-sediment load is relatively large. Between 1991 and 2001 the measured average annual total suspended-sediment load was 1287 T at station 103366092. The corresponding simulated average-annual load of total suspended sediment is 1251 T.

Between 1981 and 2001 the measured average annual fine, coarse, and total suspended sediment loads were 1258, 1700, and 2958 T/y, respectively at the downstream, index station 10336610. The corresponding simulated average annual loads are 1486, 2814, and 4300 T/y, respectively. The annual loads in 1986 and 1995 are underpredicted, whereas the annual loads for the low runoff years 1987 through 1992 are overpredicted (Figure 5-62B). It appears that too much sediment is transported at low discharges in the simulation. This discrepancy is mainly attributable to the high sand loads.

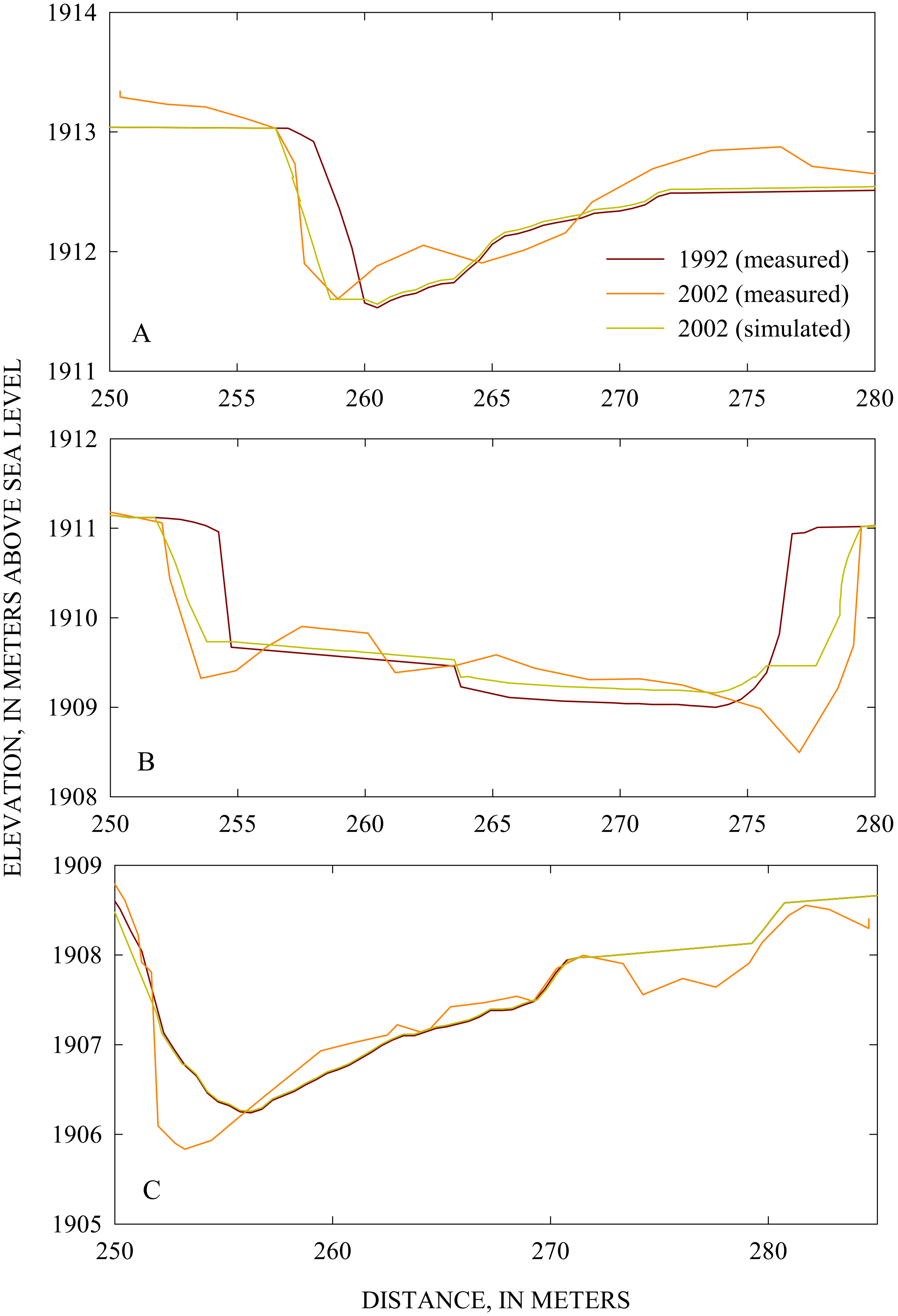


Figure 5-60. Comparison of observed and simulated cross-sectional changes at: A) CONCEPTS cross section 19 and California Parks 2M, B) CONCEPTS cross section 23 and California Parks 7M, and C) CONCEPTS cross section 26 and California Parks 10M.

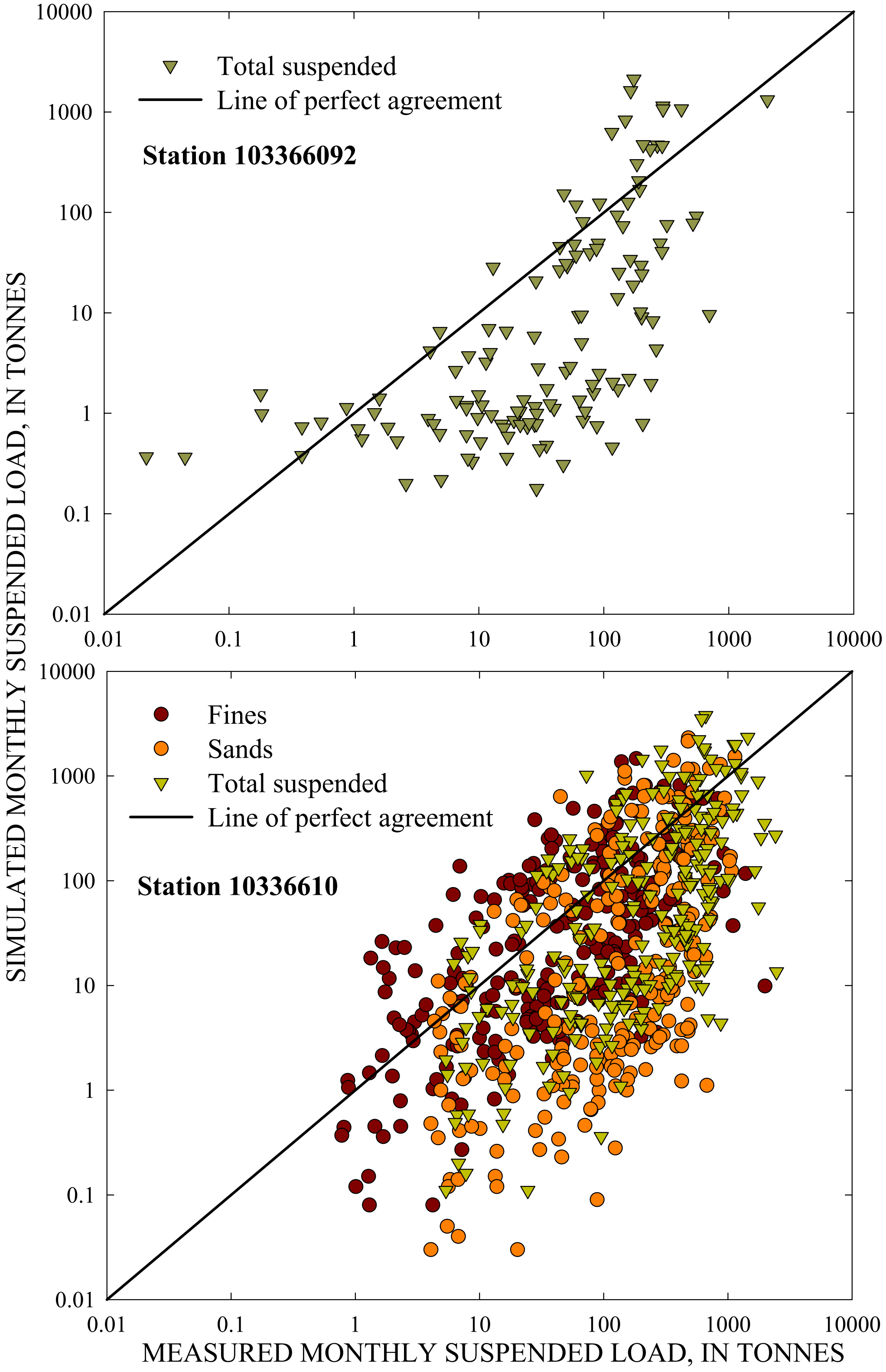


Figure 5-61. Comparison of measured and simulated mean-monthly total suspended sediments for USGS Gages 103366092 (A) and 10336610 (B), for the periods 1991-2001 and 1981-2001, respectively.

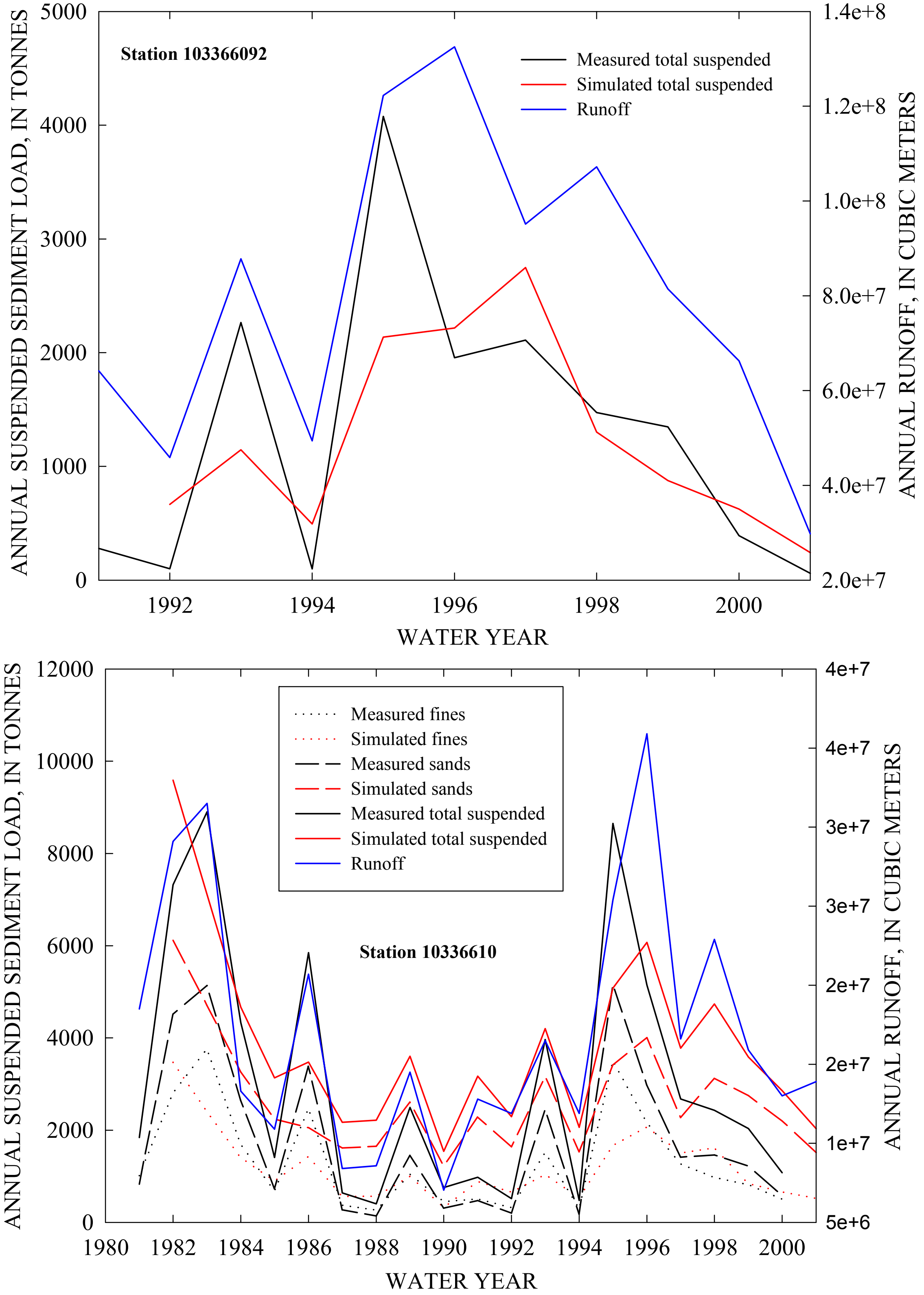


Figure 5-62. Comparison of measured and simulated annual loads at mid-reach gage 103366092 (A) and downstream gage 10336610 (B) for the period of 1991-2001 and 1981-2001, respectively.

Table 5-11. Relative contributions of uplands and streambanks to suspended sediment load during validation period, Upper Truckee River.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	49	51	782
Sands	10	90	2110
Total suspended	21	79	2892

Annually-averaged monthly sediment load of fines, sands, and total suspended sediment are shown in Figure 5-63. It shows that runoff in the fall and winter is relatively large, and that during spring it is relatively low. Consequently, the sediment loads in fall and winter are also high, whereas it is too small in spring. This may partly explain the considerable scatter in Figure 5-61. It appears that simulated snowfall in the fall and winter periods melts too early due to overly warm temperatures at high elevations.

Of the total amount of fines delivered to the channel 49% is eroded from the uplands and 51% from the streambanks (Table 5-11). Streambanks are the principal source of sediments contributing 90% of the sands and 79% of the total suspended sediment over the validation period. About half of the fines emanating from the Upper Truckee River come from streambanks, the rest from uplands. Median, annual loadings of fines at the downstream, index station (10336610; 1010 T/y) compare well simulated values of 782 T/y (Table 5-11).

CONCEPTS 50-Year Simulation

A simulation with a 50-year flow record was performed to determine temporal trends in sediment loads. The channel geometry is the same as in the validation simulation, except the geometry of cross sections 19 through 26 is replaced by that surveyed in 2002. All physical properties are those determined from the validation. The records of tributary and lateral inflow of water and sediments were constructed in the same way as for the validation case. The runoff in years 22 through 42 is the same as in years 1 through 21 of the 50-year flow record, except the large storm event on January 2 of year 17 is not repeated in year 38. The runoff in years 43 through 50 is the same as in years 1 through 8.

Changes in channel top width and bed elevation over the 50-year simulation period are shown in Figure 5-64. Channel top-width changes significantly at cross sections 24 (34 m), 22 (12 m), and 19 (8 m) and represent the principle form of channel change over the next 50 years. The average change in top width is 2.7 m for the 23.4 km reach. Changes in thalweg elevation range from 0.2 m of erosion at cross section 20 to 1.1 m of deposition at cross section 24, thus channel depths will generally decrease over the 50-year simulation period.

Although runoff volumes are repeated for years 1-21 and 22-42, and 43-50, suspended-sediment loads decrease over the period, not withstanding another simulated January 1997 runoff event. Figure 5-65 shows the simulated annual runoff, and annual loads of fines, sands, and total suspended sediments at the outlet of the Upper Truckee River. Channel adjustments in the first 23 years comprise 58 percent of the total change in the 50-year simulation.

Streambanks are the principal source of sediments, contributing 80% of the sands and 66% of the total suspended sediment. Table 5-12 lists the sources of fines and sands delivered to the channel outlet and their relative contributions. Of the total amount of fines delivered to the channel over the 50-year simulation period, 63% is eroded from the uplands and 37% from the streambanks.

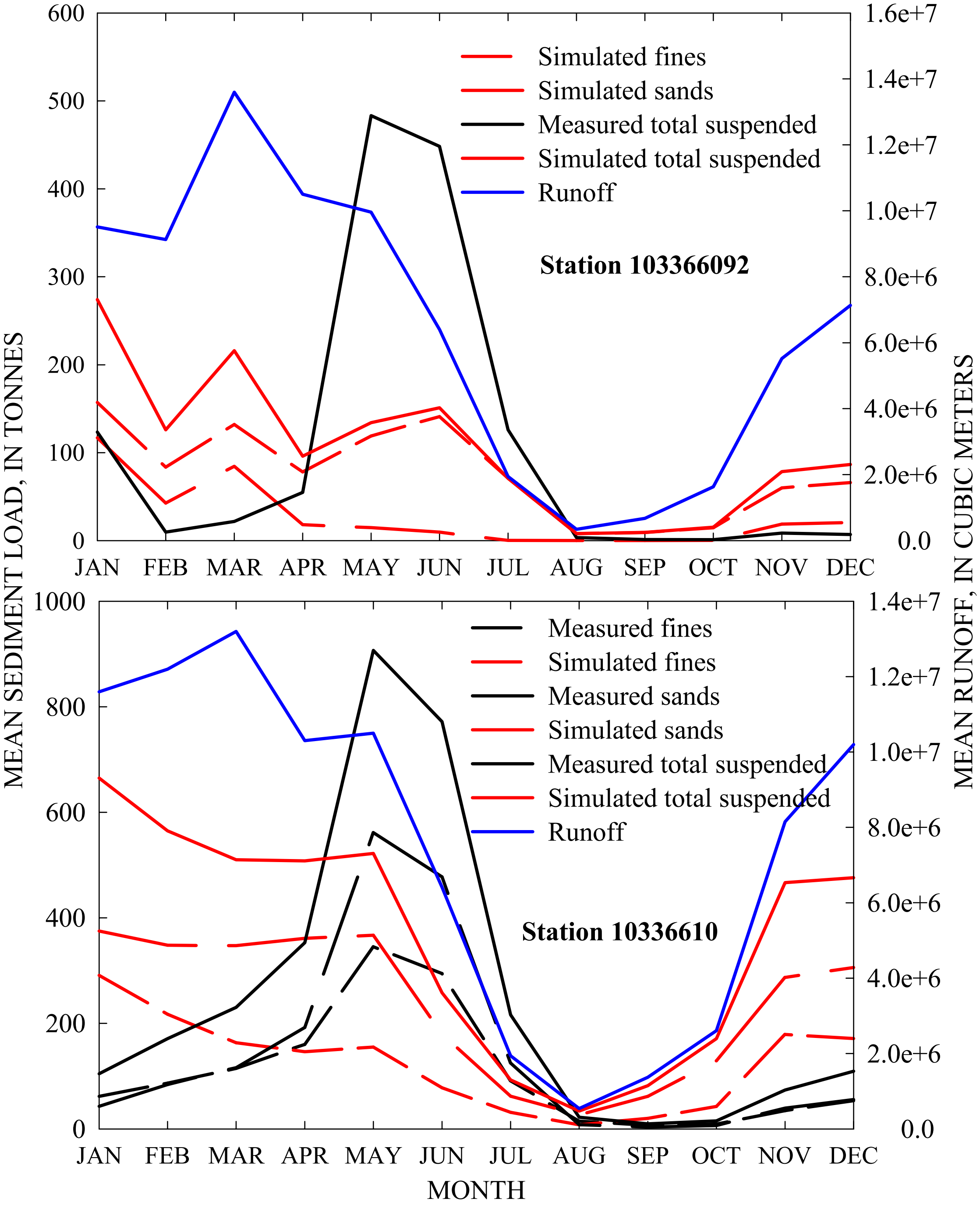


Figure 5-63. Comparison of measured and simulated annually-averaged monthly sediment loads and runoff for stations 103366092 (A) and 10336610 (B).

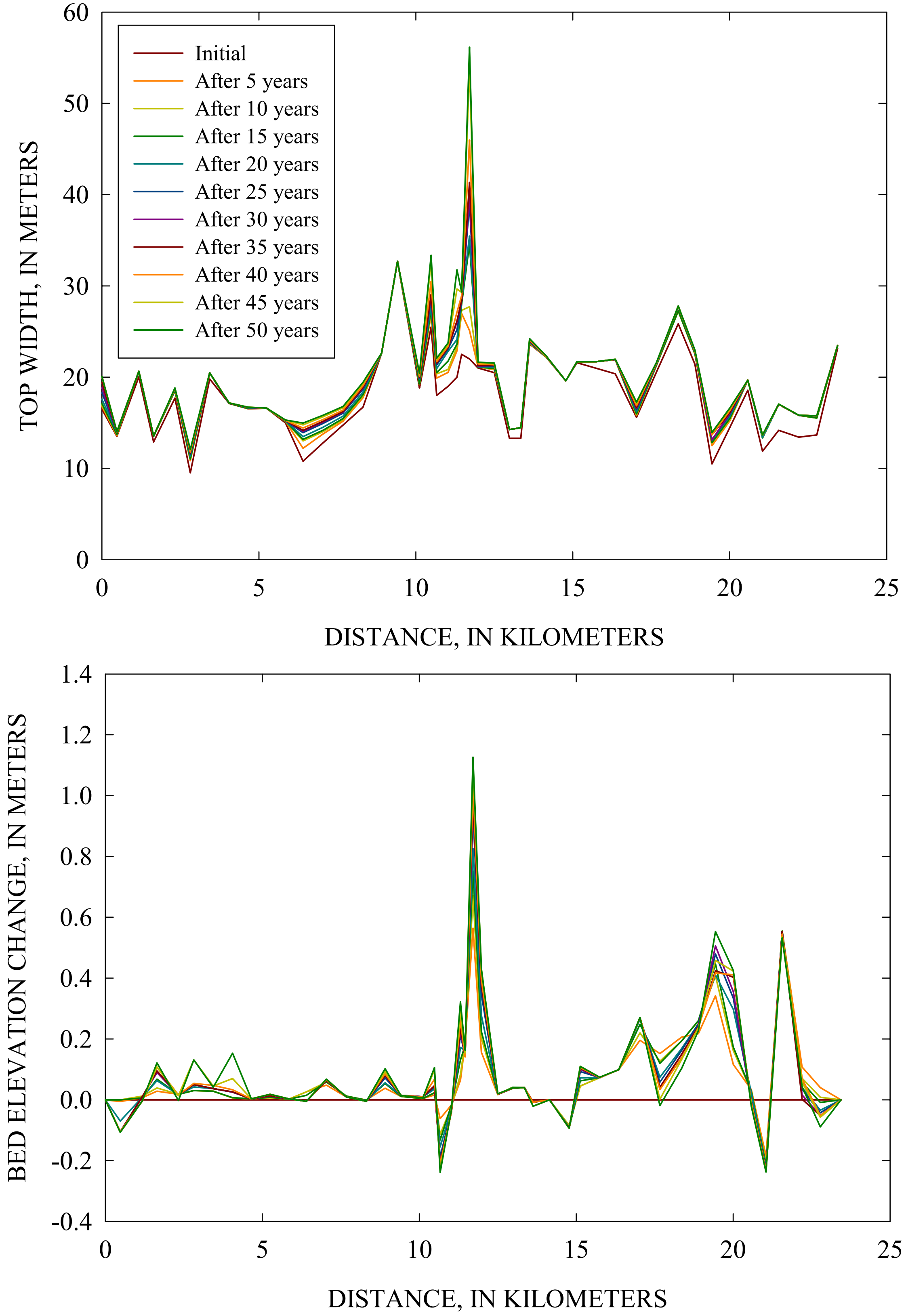


Figure 5-64. Simulated changes in bank top-width and bed elevation of the Upper Truckee River over a 50-year period.

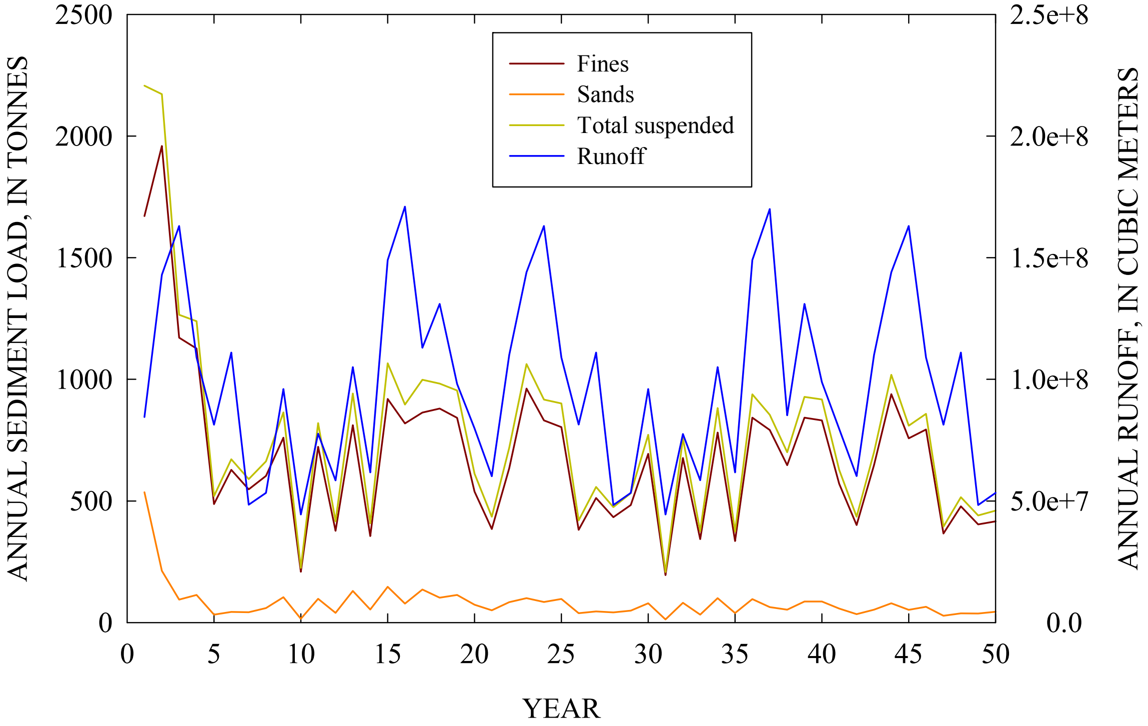


Figure 5-65. Simulated annual runoff and loads of fines, sands, and total suspended sediments delivered to the lake for the 50-year period.

Table 5-12. Relative contributions of uplands and streambanks to suspended sediment load over the 50-year simulation period.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	63	37	803
Sands	20	80	1714
Total suspended	34	66	2517

5.4.3 Ward Creek

AnnAGNPS

Three gaging stations (10336676 at the lower end, 10336675 in the middle and 10336674 at the upper end) are used to validate simulations of AnnAGNPS within the Ward Creek watershed. There were several techniques used to evaluate the performance of AnnAGNPS in the Ward Creek watershed by comparing annual and monthly runoff and sediment, as well as an evaluation of the sources of the runoff and sediment within the watershed.

Annual Runoff. Simulated annual runoff was determined from 1980 to 2001 at stations 10336674 10336675, while measured runoff was available from 1992 to 2000 (Figures 5-66 and

5-67). Simulated annual runoff was determined from 1980 to 2001 at the downstream, index station 10336676, while measured runoff was available from 1980 to 2000 (Figure 5-68). As with the Upper Truckee River watershed simulations, simulated annual runoff compares well with measured values.

Monthly Runoff. The simulated monthly runoff was compared with the measured for all months from 1992-2000 at the USGS gaging station #10336674 (Figure 5-69) and at USGS gaging station #10336675 (Figure 5-70). The simulated monthly runoff was compared with the measured for all months from 1980-2000 at the USGS gaging station #10336676 (Figure 5-71). Although the graphs show reasonable agreement between absolute values, monthly values are still somewhat overestimated during the winter months probably due to problems with temperature gradients.

Annual Fine-Sediment Loads. Simulated annual fine-sediment loads were compared to calculated annual fine-sediment transport at the three stations in the watershed (Figures 5-72 to 5-74). Results show that at the upstream-most station (10336674) fine-sediment contributions from upland sources was higher than the lower gages. This is in general agreement with observations of Stubblefield (2002) and the load calculations for these gages in section 3.4. As with the simulations of the other watersheds, the proportion of sediment from upland areas making up the total suspended-sediment load passing downstream stations decreases with increasing distance from the headwaters as a probable result of more channel erosion occurring downstream.

Sources. A significant amount of runoff occurs in the upper end of the watershed where the land cover is rock outcrop (Figure 5-75). Total erosion and fine-sediment yield that reaches the edge of each AnnAGNPS cell shows considerable variability throughout the watershed, but is generally higher in the upper end of the watershed owing to steeper slopes and unconsolidated geologic formations (Figure 5-77). These have been noted by Stubblefield (2002) and others, and are documented in this report with the short period of loadings data from station 10336670.

Recurrence Interval for the Annual Maximum Instantaneous Peak Discharge. Tables 5-13 through 5-15 list the observed annual peak discharges at stations 10336674, 10336675, and 10336676, respectively, with the simulated, annual peak discharges computed by AnnAGNPS routed downstream by CONCEPTS. Simulated annual peak discharges are about 50 percent larger than those observed. The 2-year, 5-year, 10-year, and 20-year peak discharges calculated from the observed annual peaks are 6.6, 13.7, 20.1, and 27.6 m^3/s, respectively.

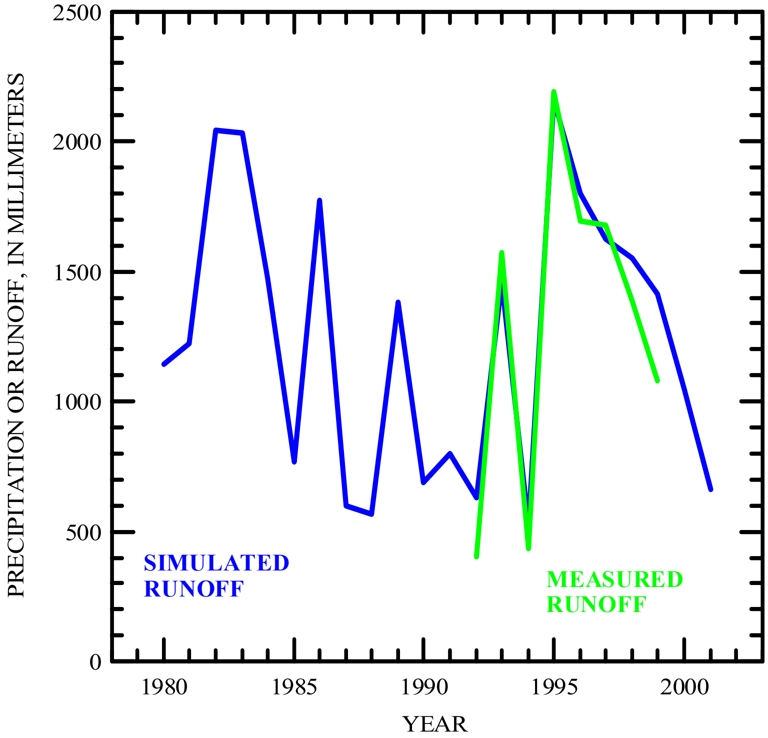


Figure 5-66. AnnAGNPS simulated and measured annual runoff at station 10336674, Ward Creek watershed.

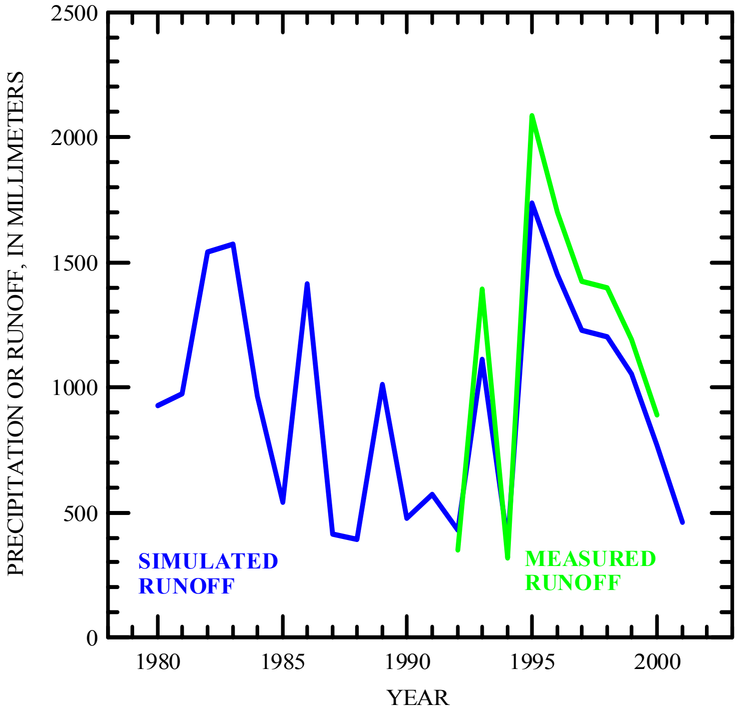


Figure 5-67. AnnAGNPS simulated and measured annual runoff at station 10336675, Ward Creek watershed.

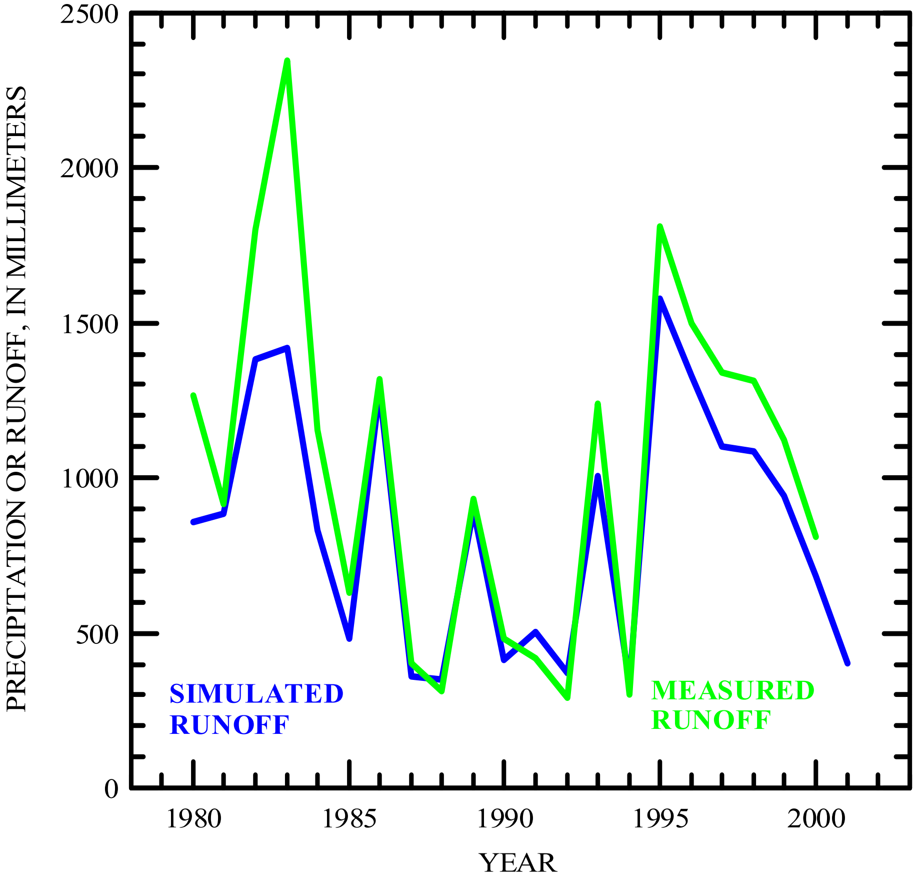


Figure 5-68. AnnAGNPS simulated and measured annual runoff at station 10336676, Ward Creek watershed.

At USGS gaging station 10336675 the simulated annual peak discharges agree better for the less frequent large runoff events, but are still much too big for the more frequent moderate runoff events. The simulated peak discharge (66.4 m^3/s) for the January 1-2, 1997 runoff event agrees very well with that observed (67.1 m^3/s). The 2-year, 5-year, 10-year, and 20-year peak discharges calculated from the observed annual peaks are 9.3, 21.9, 35.8, and 55.1 m^3/s, respectively. The corresponding simulated peak discharges are: 10.5, 23.6, 38.7, and 60.9 m^3/s, respectively.

At USGS gaging station 10336676 the agreement between observed and simulated annual peak discharges worsens for annual peak discharges falling within the 1- to 2-year recurrence interval. The observed peak discharges reduce between stations 10336675 and 10336676, whereas the simulated peak discharges increase very slightly. The 2-year, 5-year, 10-year, and 20-year peak discharges calculated from the observed annual peaks are 7.9, 19.7, 33.1, and 51.8 m^3/s, respectively. The corresponding simulated peak discharges are: 11.9, 25.1, 39.2, and 58.6 m^3/s, respectively.

Table 5-13. Comparison of measured and simulated annual peak discharge at USGS gaging station 10336674. Values are in cubic meters per second.

Water year	Observed	Water year	Observed
1992	1.44	1997	34.6
1993	8.95	1998	6.29
1994	2.27	1999	7.48
1995	6.65	2000	7.42
1996	12.29	2001	5.66

Table 5-14. Comparison of measured and simulated annual peak discharge at USGS gaging station 10336675. Values are in cubic meters per second.

Water year	Observed	CONCEPTS	Water year	Observed	CONCEPTS
1992	2.86	4.00	1997	67.1	66.4
1993	11.8	8.06	1998	9.54	22.2
1994	2.46	4.84	1999	11.0	8.93
1995	10.5	18.4	2000	12.4	7.61
1996	24.5	29.0	2001	4.96	5.08

Table 5-15. Comparison of measured and simulated annual peak discharge at USGS gaging station 10336676. Values are in cubic meters per second.

Water year	Observed	CONCEPTS	Water year	Observed	CONCEPTS
1981	4.19	9.44	1992	3.11	4.08
1982	51.0	44.3	1993	13.1	8.81
1983	18.0	15.91	1994	2.58	5.69
1984	9.94	29.2	1995	14.5	20.9
1985	4.64	9.40	1996	28.9	31.1
1986	24.4	50.1	1997	71.6	72.6
1987	3.20	6.87	1998	10.5	26.3
1988	1.36	5.70	1999	11.2	9.44
1989	6.03	13.3	2000	12.2	7.59
1990	2.46	5.75	2001	5.72	5.39
1991	3.37	8.70			

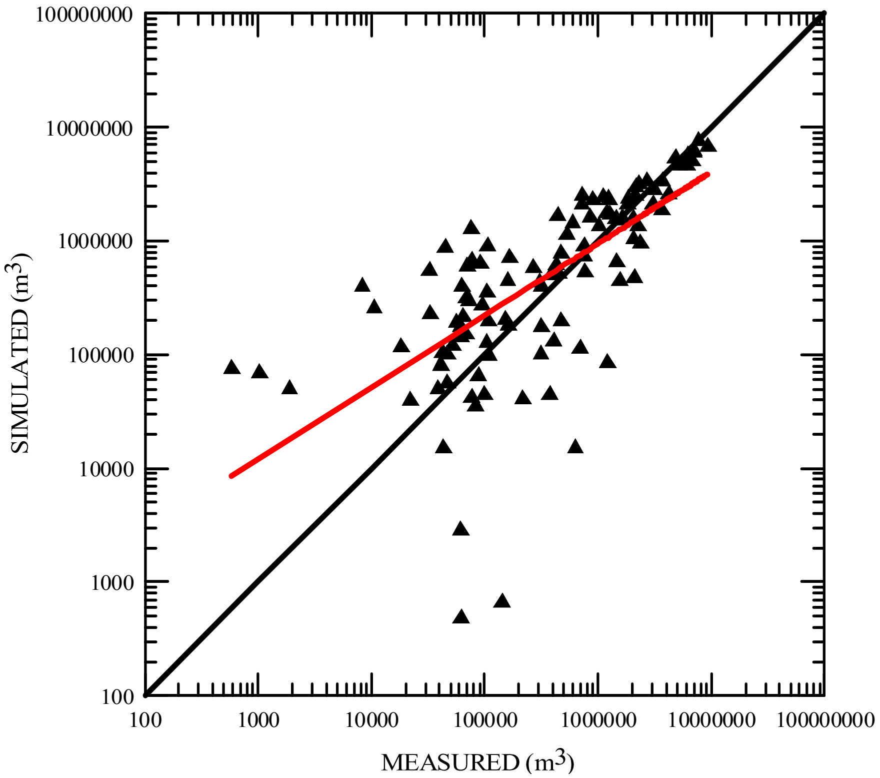


Figure 5-69. AnnAGNPS simulated versus measured monthly runoff during 1991-2000 at the upstream station 10336674, Ward Creek watershed.

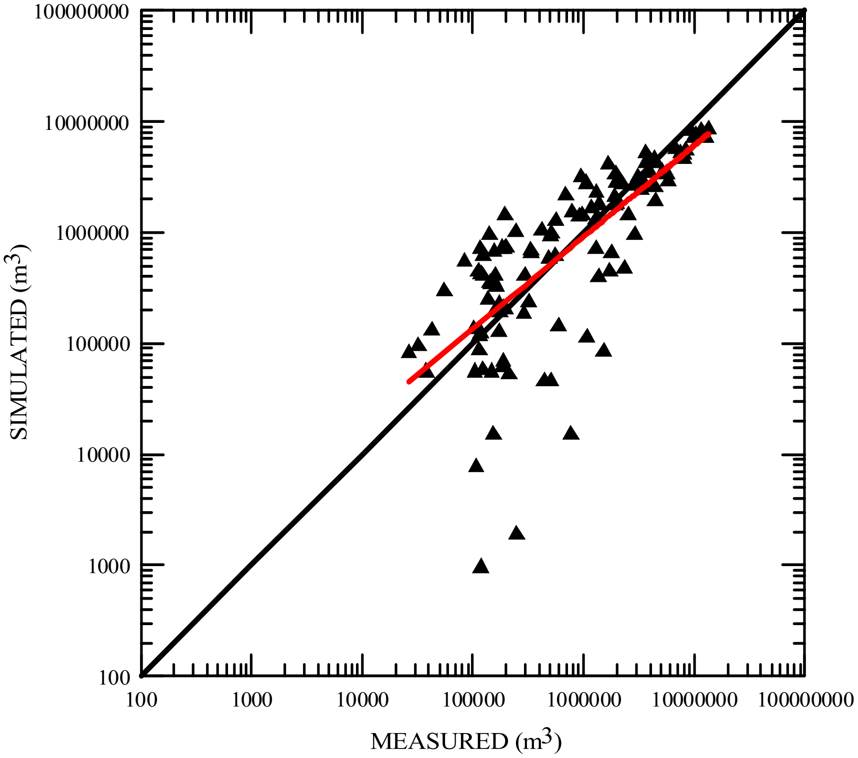


Figure 5-70. AnnAGNPS simulated versus measured monthly runoff during 1991-2000 at the middle station 10336675, Ward Creek watershed.

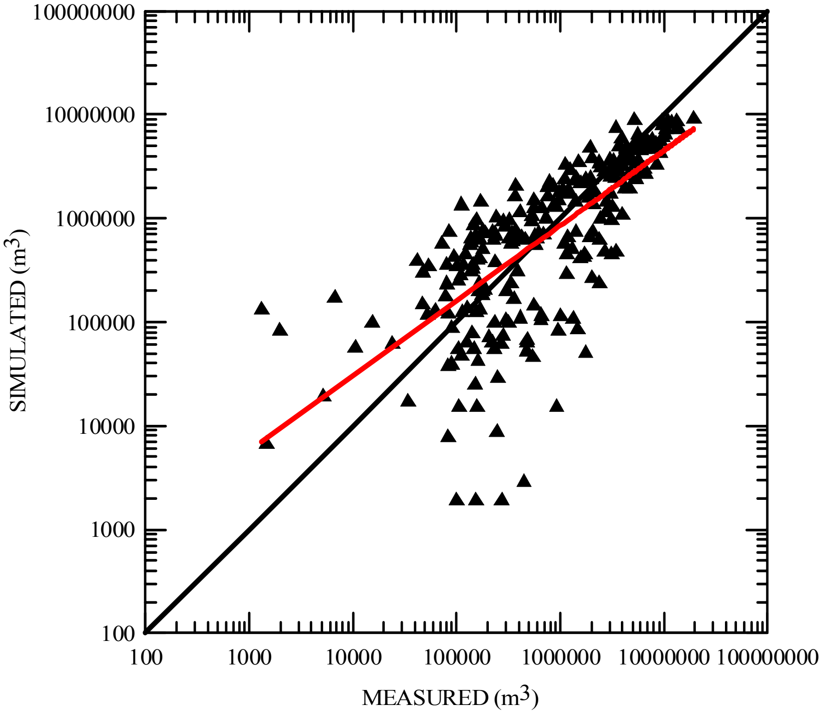


Figure 5-71. AnnAGNPS simulated versus measured monthly runoff during 1981-2000 at the downstream station 10336676, Ward Creek watershed.

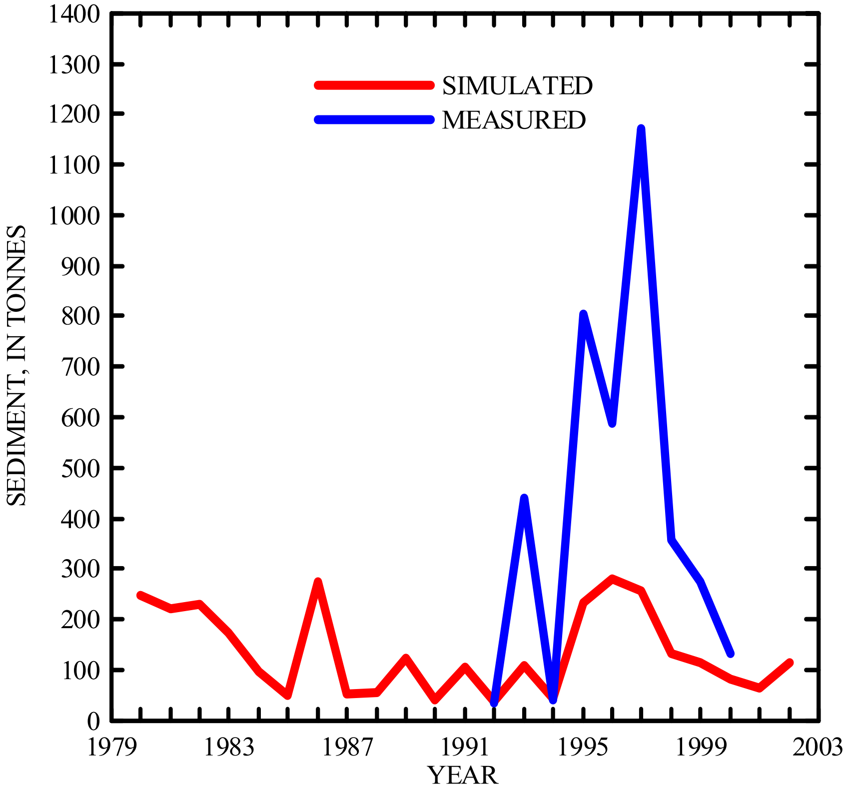


Figure 5-72. AnnAGNPS simulated and measured yearly sediment at the upstream station 10336674, Ward Creek watershed.

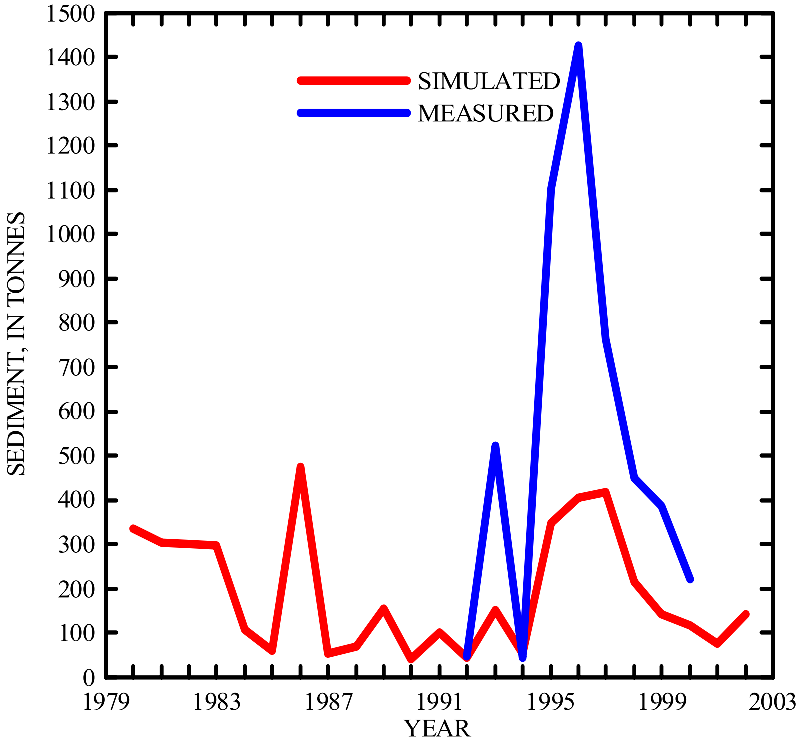


Figure 5-73. AnnAGNPS simulated and measured yearly sediment at the USGS gaging station 10336675, Ward Creek watershed.

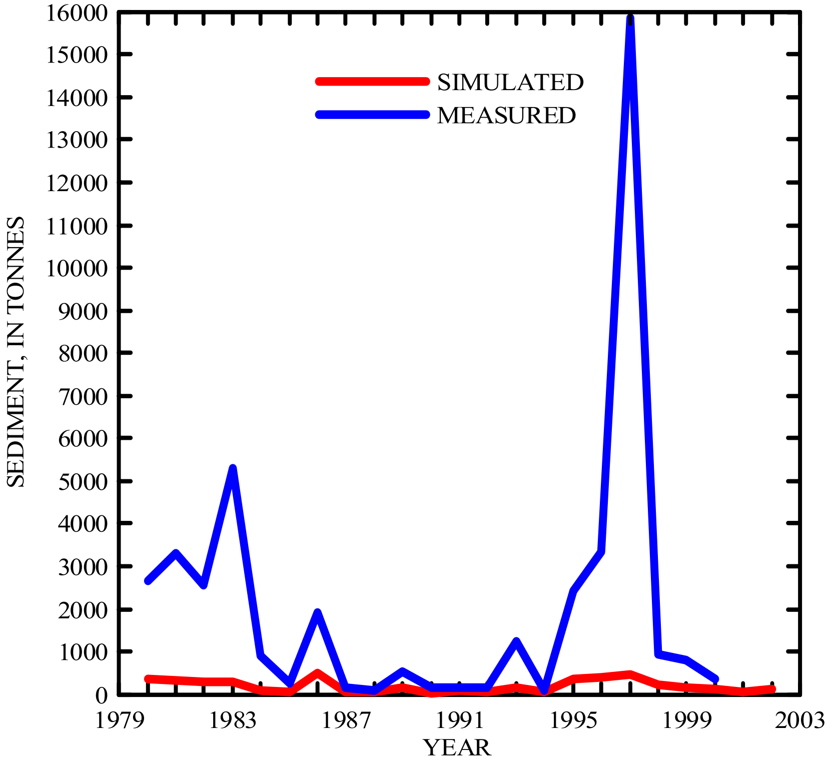


Figure 5-74. AnnAGNPS simulated and measured yearly sediment at the downstream station 10336676, Ward Creek watershed.

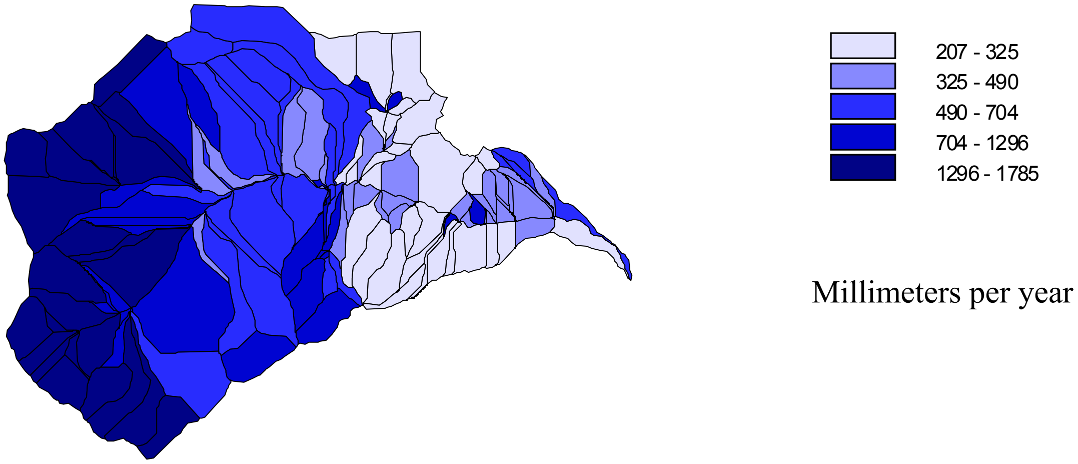


Figure 5-75. Average annual runoff simulated from AnnAGNPS for each cell on Ward Creek watershed.

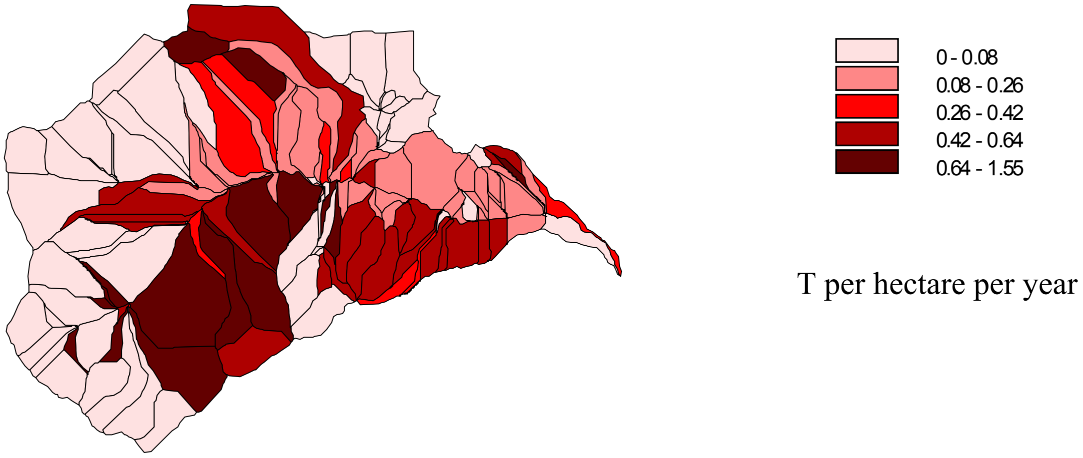


Figure 5-76. Average annual erosion simulated from AnnAGNPS for each cell on Ward Creek watershed.

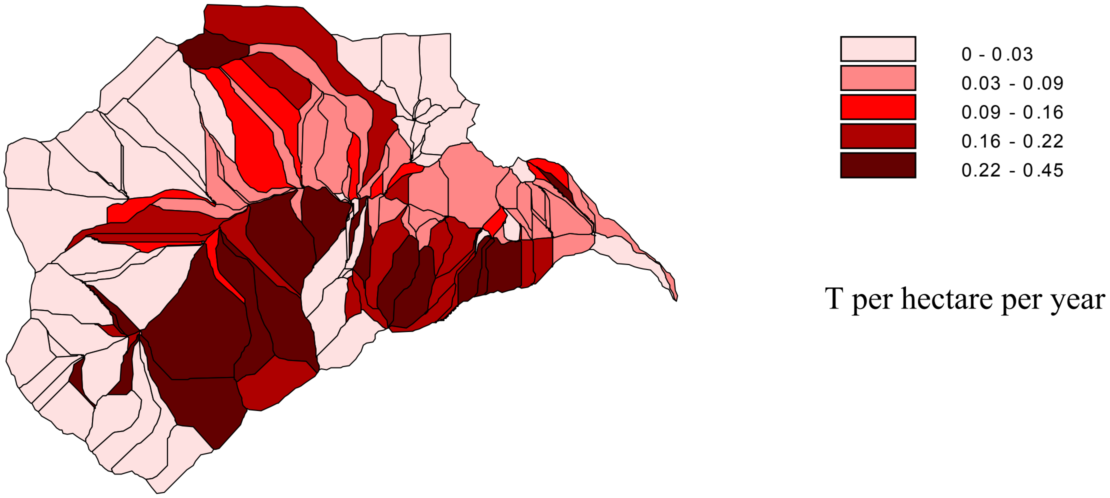


Figure 5-77. Average annual sediment yield simulated from AnnAGNPS for each cell on Ward Creek watershed.

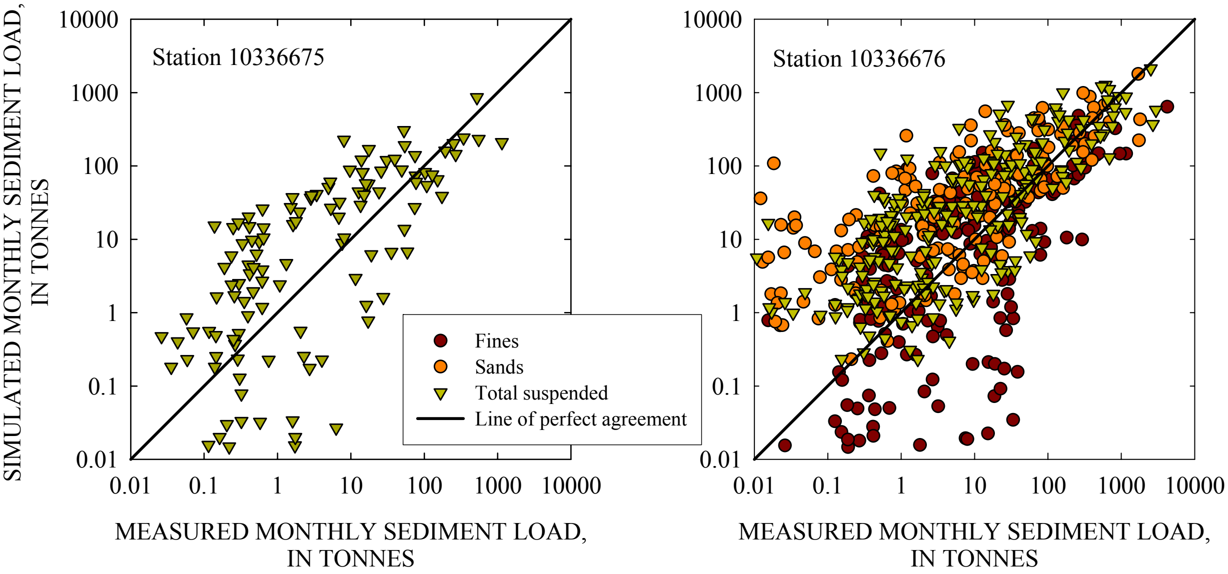


Figure 5-78. Comparison of measured and simulated mean-monthly loads of fines (clay and silts), sands, and total suspended sediment at Ward Creek.

CONCEPTS Validation

Estimated sediment loads at stations 10336675 and 10336676 (see section 3.4) were used to validate CONCEPTS for the period from January 1981 through September 2001. Figures 5-79 through 5-80 show the results of the validation. Simulated annual peak discharges are listed in Tables 5-14 and 5.15 and discussed above.

Sediment Load. Figure 5-80 compares measured and simulated mean-monthly loads of fines (clay- and silt-sized particles), sands, and total suspended sediments. The points plot around the line of perfect agreement. The observed scatter is to be expected in light of the variability between measured and simulated mean-monthly runoff. At station 10336675 the r^2 value for total suspended sediments is 0.41. At station 10336676 the r^2 values for fines, sands, and total suspended sediments are 0.41, 0.52, and 0.56 respectively.

Generally, annual loads appear to be correlated with annual runoff (Figure 5-79). Years with low runoff correspond to years with low annual sediment loads. Increased measured loads in 1997 are caused by channel erosion, particularly bank widening during the January 1997 runoff event. Between 1992 and 2001 the measured average-annual total suspended sediment load was 504 T at gaging station 10336675. The corresponding simulated average annual load of total suspended sediment is 530 T. The simulated annual loads in 1995 and 1996 are smaller than those measured. However, simulated loads were already underestimated by AnnAGNPS at the upstream boundary of the model (station 10336674, see AnnAGNPS simulation). The simulated annual load in 1997 is larger than that measured and may be a function of either (1) the accuracy of the calculated load at the gage because it is much smaller than the annual load at the upstream station (10336674), and/or (2) as observed by Stubblefield (2002) and discussed in section 4.6.3, significant streambed deposition occurs between these two stations.

Between 1981 and 2001 the measured, average-annual fine, coarse, and total suspended sediment loads were 713, 1217, and 1930 T, respectively at the downstream, index station 10336676. The corresponding simulated average annual loads are 409, 1009, and 1418 T, respectively. The discrepancy between measured and simulated suspended load at station 10336676 is due to a large calculated sediment load on January 2, 1997. Omitting water year 1997 from the measured average annual load yields 523, 700, and 1223 T for fine, sand, and total suspended sediment load, respectively. The corresponding simulated average annual loads are 371, 923, and 1293 T, respectively. The simulated average annual load of fines (clays and silts) is underestimated whereas that of sands is overestimated.

Most sediment is transported during the snowmelt period from April through June (Figure 5-80). The simulated sediment loads during this period are somewhat under-predicted and is related to too much runoff in the fall and winter, and hence too little during the snowmelt period.

Streambanks are the principal source of suspended sediment, contributing 86% of the sands and 66% of the total suspended sediment. Table 5-16 lists the sources of fines and sands delivered to the channel outlet and their relative contributions. Of the total amount of fines delivered to the channel 79% is eroded from the uplands and 21% from the streambanks.

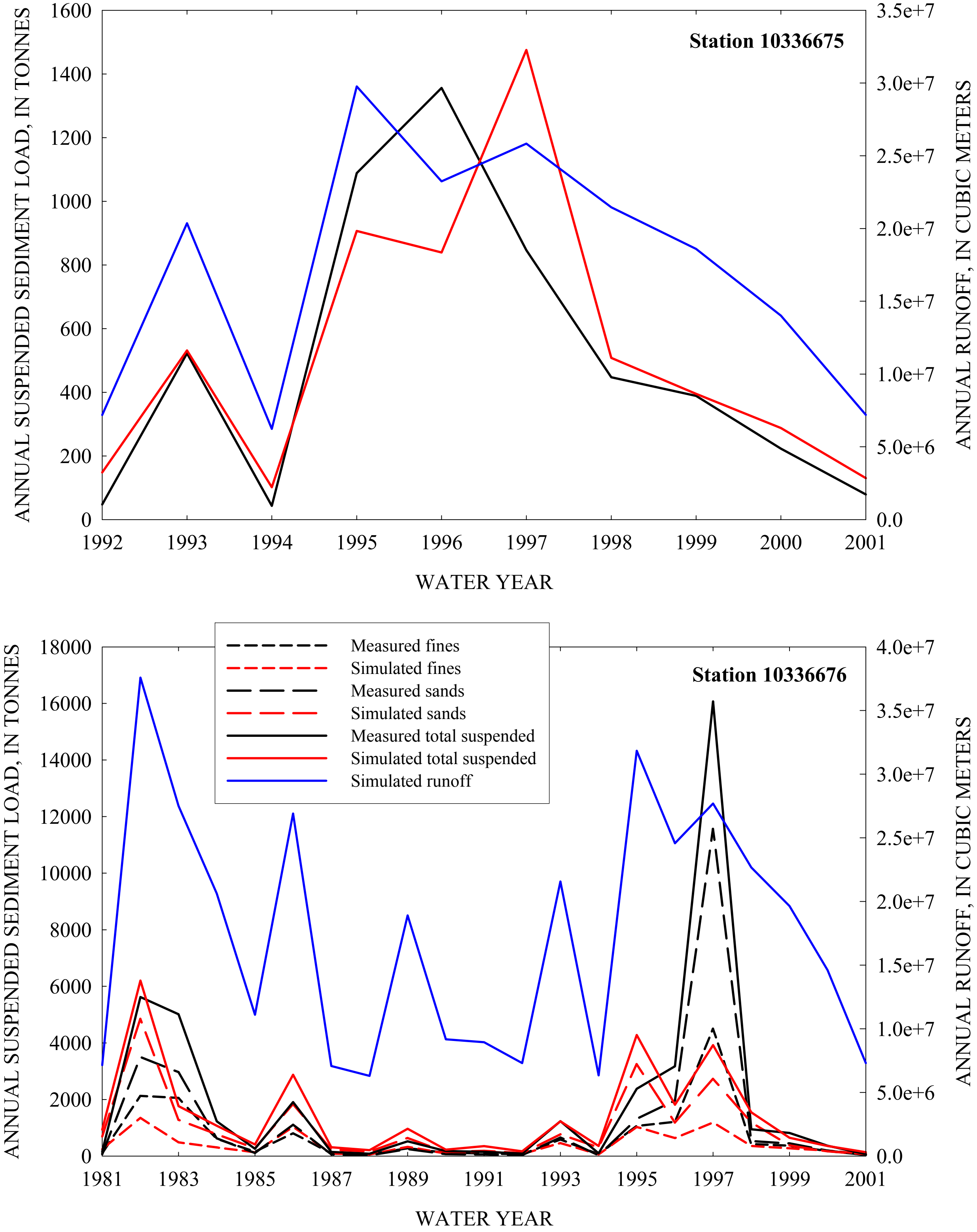


Figure 5-79. Comparison of measured and simulated annual loads at Ward Creek.

Table 5-16. Relative contributions of uplands and streambanks to suspended sediment load at the outlet of Ward Creek for the validation simulation.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	79	21	210
Sands	14	86	485
Total suspended	34	66	695

50-Year Simulation

A simulation with a 50-year flow record was performed to determine trends in sediment loads. The channel geometry is based on the 2002 cross section survey. All physical properties are those determined from the validation. The records of tributary and lateral inflow of water and sediments were constructed in the same way as the validation case. The runoff in years 24 through 46 is the same as in years 1 through 23 of the 50-year flow record, except the large storm event on January 2 of year 18 is not repeated in year 41 (see AnnAGNPS section). The runoff in years 47 through 50 is the same as in years 1 through 4.

Figure 5-81 shows the changes in channel top width and bed elevation over the 50-year simulation period. Top width changes only significantly at cross sections 2 and 14. Changes in thalweg elevation range from 0.05 m of erosion at cross section 9 to 0.12 m of deposition at cross section 14.

Figure 5-82 shows the simulated annual runoff, and annual loads of fines, sands, and total suspended sediments at the outlet of Ward Creek. The annual loads in years 1 through 23 are larger than those in years 24 through 50 though annual runoff is the same. Channel adjustments in the first 23 years are larger than those in years 24 through 50.

Table 5-17 lists the sources of fines and sands delivered to the channel outlet and their relative contributions. Of the total amount of fines delivered to the channel 84% is eroded from the uplands and 16% from the streambanks. Streambanks are the principal source of sediments, they contributed 86% of the sands and 61% of the total suspended sediment. Upland sources, however, are the main source of fine-grained materials from the watershed (Table 5-17).

Table 5-17. Relative contributions of uplands and streambanks to suspended sediment load at the outlet of Ward Creek for the 50-year simulation.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	84	16	200
Sands	14	86	353
Total suspended	39	61	553

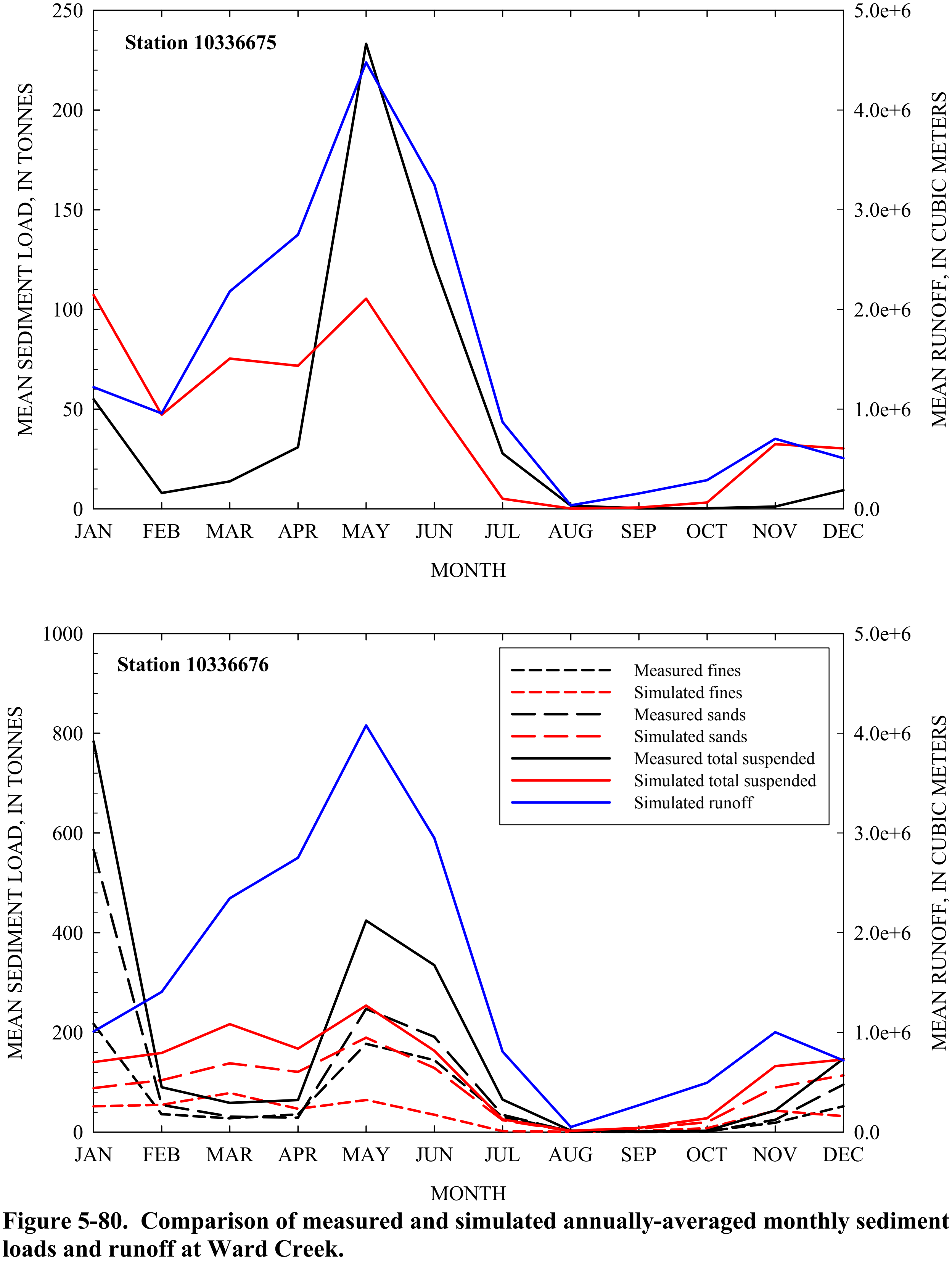


Figure 5-80. Comparison of measured and simulated annually-averaged monthly sediment loads and runoff at Ward Creek.

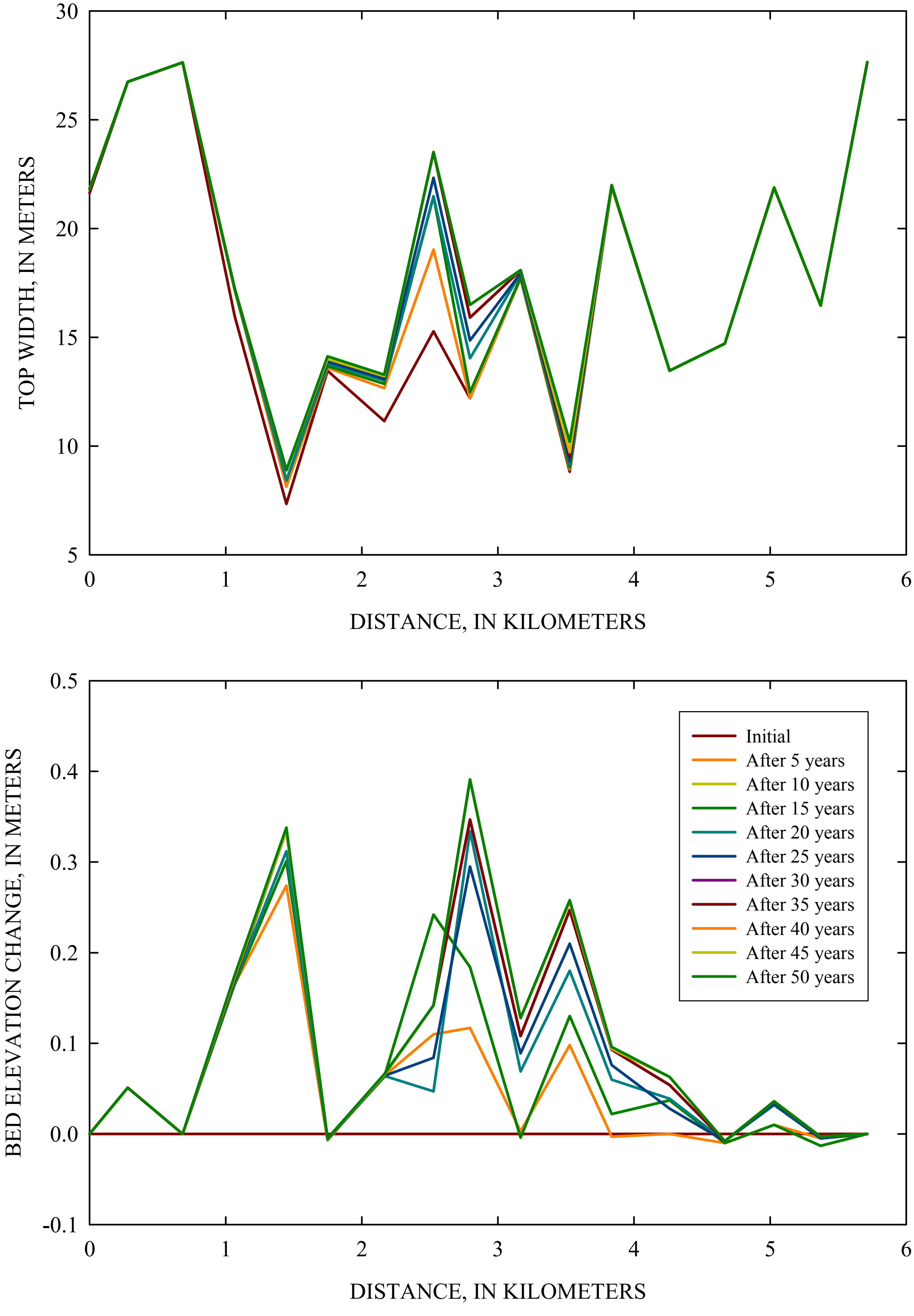


Figure 5-81. Simulated changes in bank top-width and bed elevation of Ward Creek over a 50-year period.

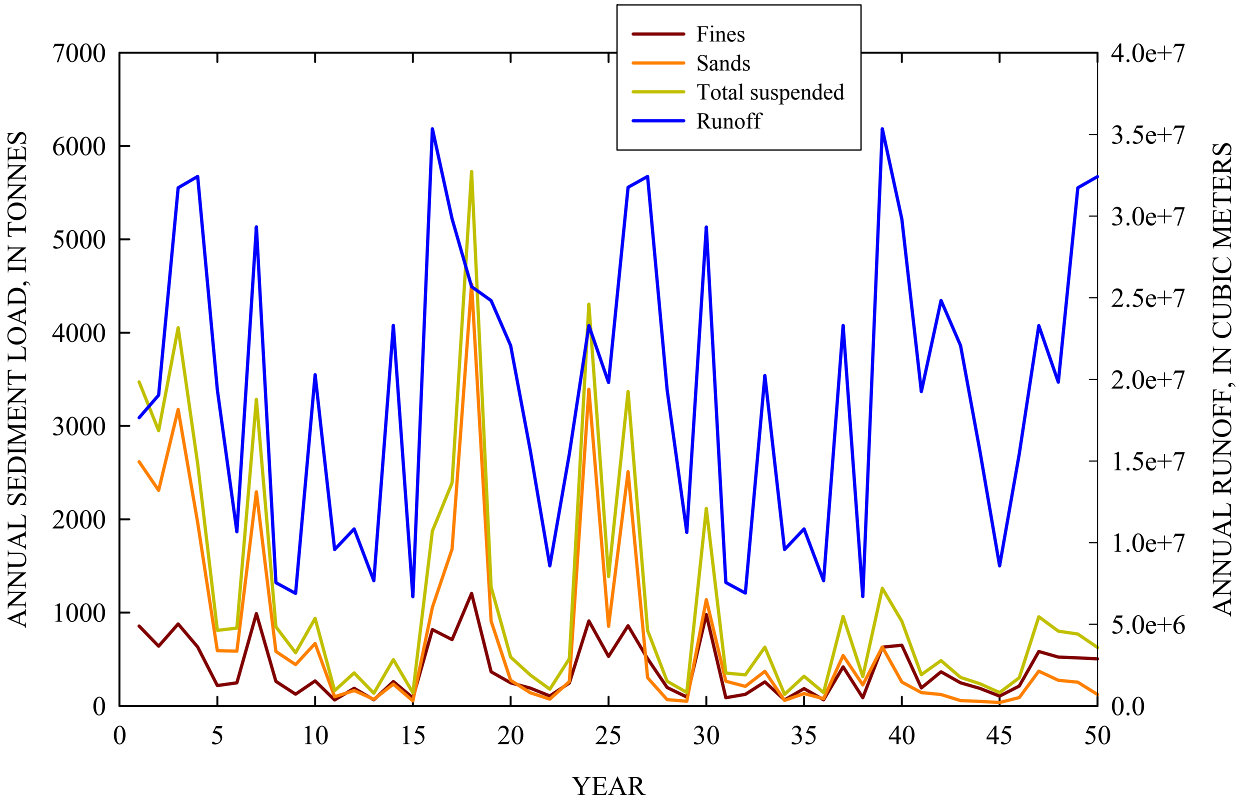


Figure 5-82. Simulated annual runoff and loads of fines, sands, and total suspended sediments at the outlet of Ward Creek for the 50-year simulation.

5.5 Summary

The USDA watershed and channel evolution models AnnAGNPS and CONCEPTS were used to simulate the sediment loadings to Lake Tahoe from General and Ward Creeks, and the Upper Truckee River over a 50-year period. The models were validated using: (1) discharges and sediment loads measured at USGS gaging stations in the three watersheds (Chapter 3), and (2) measured changes in cross-sectional geometry at selected reaches of General Creek and the Upper Truckee River (Chapter 4).

Climate information, particularly precipitation and temperature, is the most important factor to accurately simulate runoff. Unfortunately, the current climate data available for the Lake Tahoe Basin are inadequate for detailed numerical modeling in some watersheds. A 50-year numerical simulation of climate produced by a concurrent study was not available for this research. For instance, there is no climate station located within the General Creek watershed. Precipitation and temperature at the Tahoe City climate station were used to represent the weather at General Creek watershed. For the Upper Truckee River watershed, accurate climate data are only available for its western-most region near Echo Lake. Climate data from Hagan's Meadow climate station (Trout Creek watershed) were used to complement the available data within the Upper Truckee River watershed. Both these stations are at high elevations (2440 m). Historic climate data at lower elevations in the Upper Truckee River watershed are limited to a few months that describe precipitation at the airport. The available climate data for Ward Creek watershed are better than for the other two watersheds.

Comparisons between simulated and measured data at the USGS gaging locations were made based on monthly and yearly totals to avoid the uncertainties involved with comparisons of individual dates. Also, AnnAGNPS has been designed for applications of long-term simulations; hence, individual event-based comparisons may distort how well the model actually performs.

The validation period for General Creek is 1981 to 2001. Cross-section surveys were carried out in 1983 and 2002. Simulated runoff volumes are lower than measured for General Creek (Figures 5-34 through 5-36), whereas peak discharges are high (Table 5-5). The applied precipitation used by the model was most likely too low at the upper end of the watershed. Simulated morphological changes and sediment loads agree very well with those estimated (Figures 5-42 through 5-45).

Average, annual suspended load at the downstream, index station (10336645) is 238 T, whereas AnnAGNPS and CONCEPTS simulated an average annual suspended load of 272 T. The difference is caused by an overestimation of the sand transport, which may be due to the model assumption that all sand-sized particles (diameter between 0.063 and 2 mm) are being transported in suspension. Still, these results are with 14%, an exceptional result given all of the inherent uncertainties.

Based on the simulation results, 78% of the fine suspended load (clay and silt) at the mouth of General Creek is contributed from the uplands and 22% from the channel (Table 5-6). The coarse suspended load (sands) is mainly generated in the channel (60%). The simulated annual volumetric change in channel geometry per unit of channel length is 10.6 m^3/yr/km. This agrees quite well with that calculated from the surveyed change in cross section geometry (14.6 m^3/y/km). The simulated percentage of fine sediments (clay and silt) eroded from the channel is 8.5%, whereas the survey-based percentage of eroded fine sediments is 10.3%.

The 50-year simulation of General Creek predicts that 195 T/y of sediments are discharged into Lake Tahoe (Table 5-7). Of this total, 51 T/y are clays and silts. Results presented in Tables 5-6 and 5-7 show that the average-annual suspended load for the 50-year simulation is smaller than that for the validation. The reduction is mainly in the sand fraction, which are mainly streambank contributions. Hence, it can be concluded that the channel adjustment has led to a more stable channel, and therefore reduced streambank erosion. The same is true for the Upper Truckee River (Tables 5-11 and 5-12) and Ward Creek (Tables 5-16 and 5-17).

The validation period for the Upper Truckee River is 1981 to 2001. Cross section surveys for a highly active reach upstream of the airport were carried out between 1992 and 2002. Simulated runoff volumes (Figures 5-48 through 5-50) and annual peak discharges (Tables 5-8 through 5-10) along the Upper Truckee River are high compared to measured. The annual loads of suspended sediments are predicted fairly well at the mid-reach station (103366092) near Myers (Figure 5-62A). The simulated average annual load of suspended sediments is 1287 T compared with 1250 T measured. Simulated sand transport was higher than measured (2814 T versus 1700 T) at the downstream station (10336610) in South Lake Tahoe (Figure 5-62B), whereas the simulated average, annual fine-suspended load (1486 T) compares well with that measured (1258 T). Further, there is too much sediment transport during the fall and winter period, and too little during the spring (snowmelt) season (Figure 5-63).

Streambanks are the major source of sediments based on simulation results at the mouth of the Upper Truckee River: 51% of the fine suspended load (clay and silt), 90% of the coarse suspended load (sands), and 79% of the total suspended load (Table 5-11). Simulated changes in bank-widening rates were reasonably good along the surveyed reach (between river km 11.7 and 13.7) (Figure 5-60). Difficulties were encountered in simulating toe erosion and incision in the reach on outside bends because CONCEPTS is a one-dimensional model.

The 50-year simulation of the Upper Truckee River predicts that annually 770 T/y of sediment will be discharged to Lake Tahoe. Of this total, 690 T/y are clays and silts. The majority of sediments (60%) are generated in the first 25 years when channel erosion, particularly bank widening is most active. Almost two-thirds of the total suspended-sediment is simulated to come from streambank erosion. Of the total mass of fine-grained sediments delivered to the lake over the 50-year simulation period, 37% are from streambanks, with the balance from upland sources.

The validation period for Ward Creek is 1981 to 2001. Simulated runoff volumes are lower than measured (Figures 5-67 and 5-68), but annual peak discharges are predicted fairly well (Tables 5-13 through 5-15). The simulated average annual suspended sediment load agrees quite well with those calculated from measured data (Figure 5-80): (1) 504 T (measured) versus 530 T (simulated) at USGS gaging station 10336675, and (2) 1223 T (measured) versus 1293 T (simulated) at USGS gaging station 10336676. The suspended load in water year 1997 has been omitted from the latter values, because the measured value for that year seems to be extremely large and may not be realistic. Based on the simulation results, 79% of the fine suspended load (clay and silt) at the mouth of Ward Creek is contributed from the uplands and 21% from the channel (Table 5-16). The coarse suspended load (sands) is mainly generated in the channel (86%).

The 50-year simulation of Ward Creek predicts that annually 1150 T of sediments are discharged into Lake Tahoe. Of this total, 400 T are clays and silts, delivered primarily from upland sources (84%). The majority of sediments (70%) are generated in the first 25 years when channel erosion is more active.

Following the January 1997 runoff event, measured sediment loads for a given discharge were generally lower in most index stations (Chapter 3). The effect of this event on modeled annual sediment loads is masked however, because of the stochastic nature of runoff events and continued channel adjustments.

The differences between simulated and measured runoff from the three watersheds can be significantly reduced with improved climate data, mainly precipitation and temperature. Precipitation and temperature are highly dependent on weather patterns and elevation (see Figures 5-20 and 5-21), and therefore, vary widely across each watershed. Precipitation will affect runoff volume, whereas temperature will determine whether precipitation occurs as rain or snow, and the timing of snowmelt. Hence, both simulated runoff volume and timing of runoff could be improved with better climate data, reducing the differences between measured and simulated runoff. Figure 5-30 shows that snowmelt can be represented by a triangular hydrograph superimposed on a certain base flow. However, AnnAGNPS and CONCEPTS do not simulate a base flow. Consequently, the constructed triangular hydrographs may have higher than expected peaks. Determining the base flow during snowmelt may therefore lead to improved prediction of annual peak discharges.

The AnnAGNPS simulations of the three watersheds provided an indication of where in the watershed runoff was generated and fine sediment was produced. The measured data at the gaging stations provided a means to calibrate the amount of sediment being transported at those specific points in comparison with the simulations of the AnnAGNPS and CONCEPTS integration of loadings. Runoff volumes at each gaging station can be used in the validation of AnnAGNPS since no other flow was produced within the channel. Validation of the sediment produced from the uplands of the watershed is very difficult because of the lack of measured upland sediment data. However, the combination of AnnAGNPS with CONCEPTS reproduced well both the sediment at the gaging stations and the observed cross-section changes. This then suggests that the distribution of the sources of sediment is also satisfactorily simulated.

Results of the numerical simulations provide information as to where the fine sediments are being eroded. A summary of the relative contributions from upland and channel sources is shown in Table 5-18. Note that channel erosion dominates total suspended-sediment loads but that the relative proportion of fine-grained loadings emanating from upland sources is greater for the two western streams. The Upper Truckee River still has the majority of its fine-grained loadings derived from its channel banks.

Table 5-18. Upland versus channel sources of total and fine-grained suspended sediment for the three modeled watersheds during the validation periods. All data expressed as a percent.

	Source	**General Creek**	**Ward Creek**	**Upper Truckee River**
Total Suspended	Uplands	47	34	21
	Channel	53	66	79
Suspended Fines	Uplands	72	79	49
	Channel	28	21	51

6 GIS ANALYSIS OF EROSION POTENTIAL FROM UPLAND AREAS

6.1 Introduction

Measurements of stream discharge and suspended-sediment concentrations provide a mechanism to calculate sediment transport rates and loadings to Lake Tahoe. A network of stream gages around the Lake Tahoe watershed has proved to be extremely valuable in evaluating sediment contributions from different tributary watersheds. Obtaining quantitative information on the sources of this sediment is a challenge and is one of the critical issues facing the region as potential erosion-control measures and mitigation strategies are considered. Work by Kroll (1976), Glancy (1988), and Hill and Nolan (1991) have provided some information on the relative role of upland-erosion processes on downstream suspended-sediment loads. Results from erosion-plot measurements in the early 1980's in four watersheds show that upland erosion is secondary to erosion from channels (Hill and Nolan, 1991). However, several upland areas in the Lake Tahoe Basin have been identified as major sources of sediment including Ward and Third Creeks (Glancy, 1988; Stubblefield, 2002). The purpose of our basinwide analysis of upland-erosion potential was to determine whether certain climatic and upland parameters could be used to account for differences in total suspended-sediment loads at gaged stations and then extrapolated to other watersheds where no such data were available.

6.2 Data Availability and Preparation

Digital data used for the upland erosion-potential analysis was provided by the Tahoe Research Group (TRG). These data consisted of raster and vector layers based on a 1998 coverage for the entire Lake Tahoe Basin. Layers used for this analysis included soils, landuse, streams, roads and trails, geology, and a Digital Elevation Model (DEM) used to create a slope-steepness layer. Additionally, a raster layer representing mean-annual precipitation within the Lake Tahoe Basin was combined with the files provided by the TRG.

It was necessary for all the layers to be in raster format because of the spatial characteristics of the analysis. Vector layers were converted to raster allowing for easier manipulation of the data. Conversion of layers from vector to raster formats was performed using ArcView 8.3. Eight layers were used in the analysis based on the availability of digital data files and their potential utility in selecting functional parameters that could be derived from the data. Layers that were used included soils, landuse/landcover, geology, roads, streams, trails, precipitation and slope. Preparation of the soils, landuse/landcover, geology, roads, trails and stream layers required a three-step process:

(1) editing the layer-attribute table to include the erodibility factor (*k*);
(2) classifying the layer based on erodibility; and
(3) converting the layer to a raster.

This three-step approach was slightly different for some of the layers and is discussed in the section of each individual layer.

When converting a polygon vector layer to a raster, ArcView uses attribute values of the vector layer from the attribute table. Therefore, each cell in the new raster will have the same value from the attribute table assigned before conversion. When vector layers were converted to raster format they were assigned different resolutions. Streams, trails and unpaved roads had a 5 by 5 m resolution. Soils, landuse/landcover, paved roads, geology and slope layers were converted to a 10 by 10 m grid layer. The mean annual-precipitation raster was created with a resolution of 20 by 20 m.

Before adding the raster layers, each was paramerterized so that the range of each variable was equal. The reclassification assured objectivity between layers and served to avoid biasing results when the layers were combined. A scale of 1 to 5 was selected for each variable comprising the classification. Most layers did not need to be classified because their potential-erodibility class was assigned to them before rasterization. The soils layer needed be reclassified because absolute values of the *k*-factors were one to two orders of magnitude less than other assigned values. The soils-classification process is explained in the *k*-factor section. The scale for all layers comprising the potential-erosion analysis ranged from 1 to 5 with 1 being the least erodible and 5 the most erodible.

6.2.1 Soil-erodibility factor (k-factor)

As an index of the potential for entrainment of soil particles from upland areas, an erodibility factor was included in the analysis. Before converting the soils vector layer to a raster, the Lake Tahoe Basin soils vector layer was classified by soil erodibility factor or *k*-factor. The *k*-factor indicates the degree of detachment of the soil under the effect of rainfall or surface runoff (Renard *et al*, 1997). Soils with similar or different characteristics were unified according to a common *k*-factor. Values of soil *k*-factor in the Lake Tahoe Basin ranged from 0.01 to 0.24. The layer was converted to a 10 by 10 m resolution raster. The *k*-factor values of this new raster were then separated into 5 equal intervals. Intervals were determined by subtracting the lowest from the highest *k*-factors, then dividing this product by 5, the number of intervals. This new layer did not contain integer values for *k*-factor and needed to be reclassified before it was be used in the analysis. Table 6-1 shows how the original k-factors were sub-divided and reclassified for the raster layer.

Soils with the lowest *k*-factor were encountered in the southwest, and somewhat in the west and northeast parts of the basin. Lowlands along the Upper Truckee River, General and Incline Creeks show intermediate erodibility values. Higher erodibility factors were encountered on the east slopes of the Lake Tahoe Basin. Areas with the highest *k*-factor values were encountered in the northwest, north and partially in the south and east slopes of the Lake Tahoe Basin. Figure 6-1 represents soil categories and the soils *k*-factor distribution throughout the Lake Tahoe Basin.

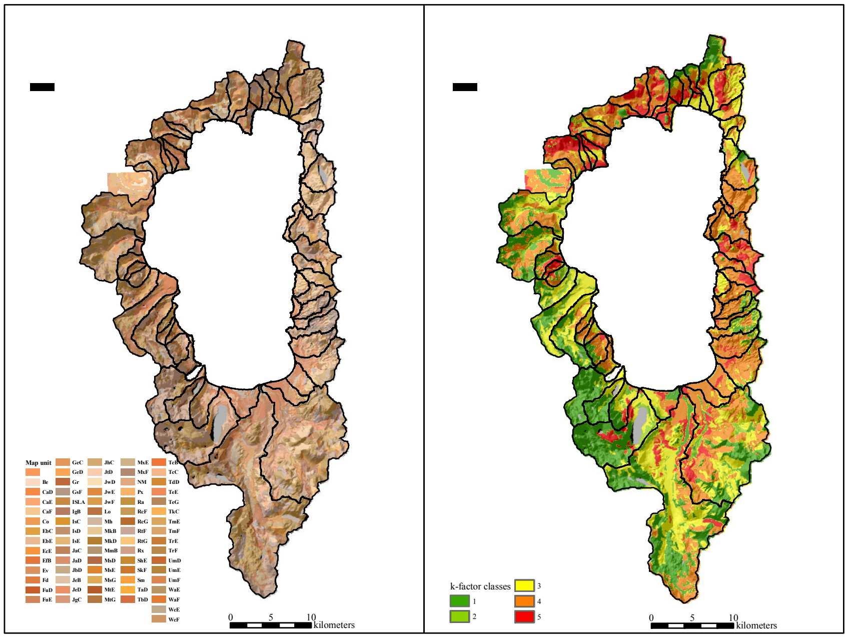


Figure 6-1. Distribution of soils categories (left) and assigned class values for soil-erodibility (*k*-factor) (right).

Table 6-1. Original Soil *k*-factors and assigned soils *k*-factor

Soil *k*-factor	Soil *k*-factor intervals	Assigned erodibility class
0.01	0.01-0.056	1
0.05		
0.1	0.056-0.102	2
0.15	0.102-0.150	3
0.17	0.151-0.194	4
0.24	0.194-0.24	5

6.2.2 Land use

Differences in the surface characteristics or treatments can have a profound effect on erosion rates. To account for these differences a land use/land cover layer was used. The attribute table for this layer contained three fields with different levels of land use/land cover classification. These classification levels increased in number and complexity dividing the land use into 4, 11 and 22 classes. The larger the number of classes the more complex the classification. The simplest classification was the most general. The other two classifications included further subdivisions of the four basic classes. Land use/land cover Label 1 included 4 classes, Label 2 Included 11 classes and Label 3 included 22 classes. Table 6-2 shows the three levels of land use/land cover classification.

Table 6-2. Land use/land cover classification levels (LULC).

LULC Label 1	LULC Label 2	LULC Label 3
Developed	Non-residential developed, Residential, Mixed urban	Mixed urban, Commercial, Communications/utilities, Institutional, Agriculture/livestock, Transportation, Recreation, Residential, Single-family residential, Multi-family residential
Vegetated	Forest, Herbaceous, Vegetated, Wetland	Coniferous, Deciduous, Coniferous deciduous mixed, Brush/ shrub land, Natural Herbaceous, Vegetated, Wooded wetland, Herbaceous wetland
Bare	Mixed bare, Quarries/ strip mines/ Gravel pits, Perennial ice/snow	Mixed bare, Perennial ice/snow, Quarries/ strip mines/ Gravel pits,
Water	Open water	Open water

Land use/land cover vector layer classified by LULC Label-2 was used in the analysis. The attribute table of this layer was edited to include erodibility factors for the 11 classes. Assigned erodibility values varied from 1 to 5 for land use/land cover classes with a value of 0 for water bodies (Table 6-3). The erodibility factor value was used when converting the land use/land cover layer to a 10 by 10m resolution raster. The raster representing the Label-2 land use/land cover classified by erodibility factor is shown in Figure 6-2.

Table 6-3. Land use/land cover erodibility potential.

Land use/Land cover Label 2 classification	Assigned erodibility class
Open Water, Perennial Ice/Snow	0
Forest, Wetland	1
Vegetated, Herbaceous, Mixed Bare, Urban	2
Residential	3
Non-residential Developed	4
Quarries/Strip Mines/Gravel Pits	5

Erodibility values of 0 were assigned to open water represented by Lake Tahoe and smaller lakes within the basin, and areas under perennial ice and snow. Most of the vegetated areas have the lowest erodibility indexes. Residential and non-residential developed have a higher erodibility index, and quarries and mines have the highest erodibility indexes.

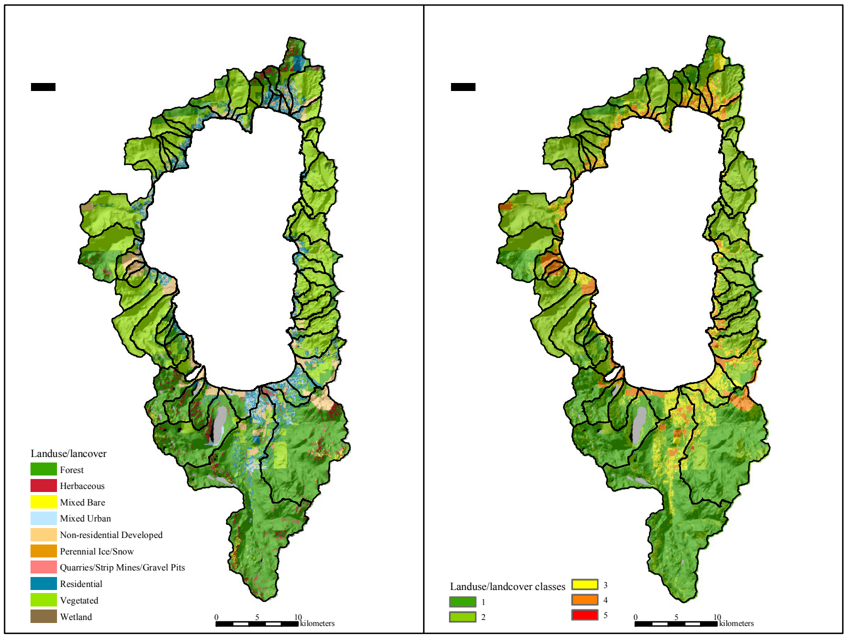


Figure 6-2. Distribution of land use/land cover (left) and assigned class values for potential erodibility based on the characteristics shown in Table 6-3 (right).

6.2.3 Paved and Unpaved Roads, Trails and Streams

The area and density of various types of roads and trails were included as a measure of land disturbance. Roads, trails and stream layers of the Lake Tahoe Basin were also converted to raster format before conducting the GIS analysis. The road layer was subdivided into paved and unpaved roads because of a possible difference in the level of sediment contribution from paved and unpaved roads. Unpaved roads and streams were converted to a 5 by 5 m raster assuming a 5 m average road width. Paved road raster was created with a 10 by 10 m grid resolution. Roads (paved and unpaved), trails and stream grid layers were used to determine road, trail and stream densities by dividing by watershed area or the area above a particular gaging station.

The major concentration of paved roads occurs at the edge of the lake and in populated areas along the lake shoreline. The city of South Lake Tahoe has the greatest concentration of roads. Other cities around the lake also concentrate a great number of paved roads.

Table 6-4. Erodibility classes assigned to roads, trails and streams in the Lake Tahoe Basin.

Feature	Assigned erodibility class
Paved roads	1
Unpaved roads	5
Trails	5
Streams	3

6.2.4 Surficial Geology

Data on the surficial geology of the Lake Tahoe Basin included a digital geologic map of the basin. This digital map, represented by a vector layer, contained detailed descriptions of geology grouped into four main rock types: volcanic, glacial, granitic and alluvial. The erodibility value assigned to each of these simple geologic types are listed in Table 6-5 while the spatial distribution is shown in Figure 6-3.

Table 6-5. Geology-erodibility classes.

Geology	Assigned erodibility class
Granite	1
Metamorphic	2
Glacial	3
Alluvium	4
Volcanic Breccias	5

Granites, granodiorites and metamorphics predominate in most of the east, southeast and parts of the southwest slopes of the basin and have been assigned the lowest erodibility index. Glacial terrains that cover the northwest and part of the south of the basin along the Upper Truckee River Watershed have an intermediate erodibility index. Alluvium, mostly concentrated at the lowlands and outlets of most watersheds principally in the south where they cover an extensive area, the northwest and the north parts of the lake were assigned a higher erodibility potential. Volcanic breccia mostly present in the slopes of Ward, Blackwood, the southernmost tip of Upper Truckee River watersheds and several other watersheds in the north and northeast parts of the basin were assigned the highest erodibility index. This determination was based on suspended-sediment yields from headwater areas of Ward Creek (10336670) that contain unvegetated slopes of this material, and because it has been suggested that they are an important contributor of sediment in Ward and Blackwood watersheds (Stubblefield, 2002).

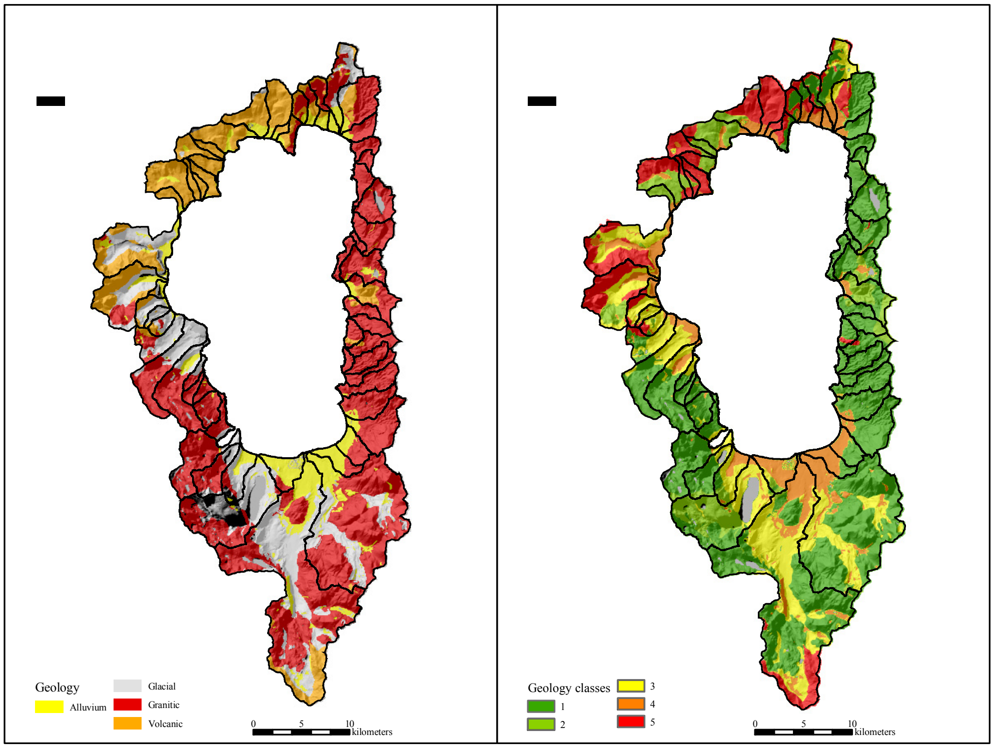


Figure 6-3. Distribution of surficial geology (left) and assigned class values for potential erodibility based on the characteristics shown in Table 6-5 (right).

6.2.5 Slope Steepness

A raster layer that represents topography in the Lake Tahoe Basin was created from a 10 by 10 m resolution USGS digital elevation model (DEM). The units of the digital elevation model showed elevation in feet and were converted to meters to be consistent with the technical literature and the use of metric units in this study. The new metric DEM was used to produce the slope raster used in the analysis (Figure 6-4). Values of elevation of the new raster varied from approximately 1875 to 3320m. Slope was derived from the DEM with angles that ranged from 0 to 72.5 degrees (Table 6-6).

Table 6-6. Slope classes for the Lake Tahoe Basin

Slope intervals (degrees)	Assigned slope erodibility class
0-14.5	1
14.5-29.0	2
29.0-43.5	3
43.5-58.0	4
58.0-72.5	5

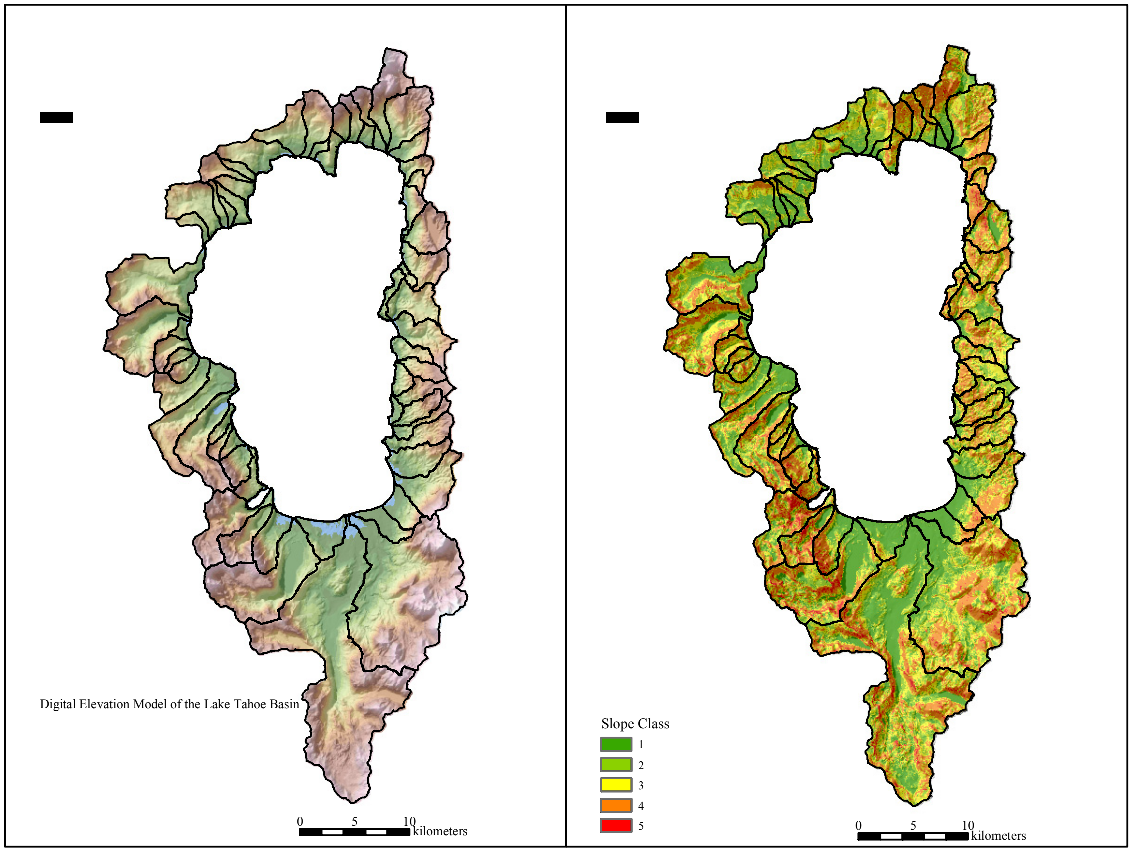


Figure 6-4. The digital elevation model (left) used to derive the slope-steepness layer (right) for the Lake Tahoe Basin.

6.2.6 Mean-annual precipitation

Basinwide data on precipitation characteristics was not readily available, as this study was to use data based on a simulation model being developed concurrently by others. To overcome this obstacle, mean-annual precipitation was screen-digitized from an isopluvial paper map created by Sierra Hydrotech (Sierra Hydrotech, 1986). A point- vector layer was created representing the isopluvial lines (Figure 6-5). Precipitation lines vary from 17 to 80 inches per year in intervals of 3, 5 and 10 inches per year. After all points of an isopluvial line were digitized, the corresponding precipitation value was assigned (Table 6-7). Then, the precipitation layer was completed and a raster representing precipitation was created after conversion of the data to millimeters (Figure 6-5).

Table 6-7. Mean-annual precipitation classes in the Lake Tahoe Basin.

Mean-annual precipitation isopluvial lines	Mean-annual precipitation intervals	Mean-annual precipitation class
17	2-17.6	1
20, 25, 30	33.2	2
35, 40	48.8	3
50, 60	64.4	4

70, 80	80	5

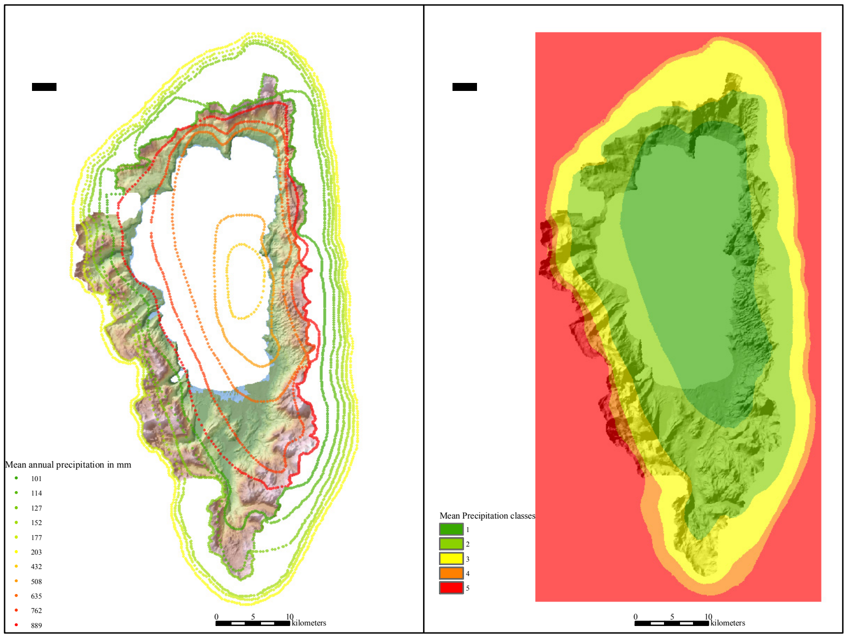


Figure 6-5. Isopluvial lines representing mean-annual precipitation for the Lake Tahoe Basin. Original data digitized from hard copy of Sierra Hydrotech (1986).

6.3 Merging Data Classes: Upland Erosion-Potential Map

Classed data from each of the five parameters were summed for each 10 by 10 m raster providing an upland-erosion potential value for every $100m^2$ area of the entire basin. The sum of the minimum values of erosion potential was 5, and the maximum 25. The graphic result of the sum of raster layers was a map showing areas of varying degrees of upland-erosion potential (Figure 6-6). This map was reclassified and converted to a 1 to 5 scale. Finally, the raster layer was converted to a feature, or vector layer to determine the areas of each of the erosion-potential classes within a given watershed or upstream of a given gaging station. This conversion was made to determine the area that each individual class (1, low erosion potential to 5, high erosion potential) occupied over the entire basin and within each individual watershed. The highest upland-erosion potentials are colored in red with the next highest in orange and yellow, respectively and can be used to identify potentially critical areas (Figure 6-6). Two of the densest concentrations of the high erosion-potential index are in the Homewood and Madden Creek watersheds on the western side of the lake.

The two highest erosion classes were used subsequently to test relations with gaged suspended-sediment loads from index stations. The percent of each watershed area covered in these latter two classes are shown in Table 6-8 ranked from highest percentage to lowest.

Figure 6-6. Map of upland-erosion potential for the Lake Tahoe Basin obtained by summing the classed values of each of the five selected parameters and reclassifying at a scale of 1 to 5. Areas colored in red and orange represent zones of high upland-erosion potential.

6.3.1 Basinwide distribution

The map of upland-erosion potential (Figure 6-6) provides insights into differences in upland–erosion potential across the Lake Tahoe Basin. Some of these, such as the generally green areas (lowest classes) in the eastern quadrant were to be expected as this represents the dry side of the lake where suspended-sediment yields are low. Similar areas, such as in the southwest part of the basin are consistent with the generally low suspended-sediment yields emanating from these watersheds (and documented in Chapter 3). Areas of high upland-erosion potential are concentrated in the northwest parts of the basin, particularly in headwaters areas of Burton, Ward and Blackwood Creeks, as well as in the Homewood and Madden Creek watersheds. Sizeable high erosion-potential areas are also depicted in Third Creek and several other northern quadrant streams.

6.3.2 Determination of Areas Covered By Erosion Classes

Conversion of erosion-class data to areas simplified subsequent analysis between upland-erosion potential and suspended-sediment transport rates calculated from measured flow and sediment-concentration data. Areas occupied by each erosion-potential class were determined within individual watersheds and above gaging stations. Initially, the raster was converted to a vector layer using the convert raster to feature function. This conversion created polygons representing erodibility classes for the entire basin. Secondly, this new vector layer was intersected with the watershed outline layer creating a new set of polygons representing erodibility classes separated by watershed. The areas of each erosion class within a given watershed were added to determine whether the total area calculated by the ArcView zonal-statistics analysis corresponded to the actual area of the watershed. Table 6-8 lists the 63 watersheds draining Lake Tahoe in decreasing order of the percentage of their basin area covered by high erosion classes 4 and 5 (orange and red areas; Figure 6-6).

Table 6-8. Percentage of the area of each watershed draining to Lake Tahoe covered by the two highest upland-erosion potential classes (percentage of red plus orange areas in Figure 6-6).

Watershed	Percent class 4	Percent class 5	Percent of two highest classes
HOMEWOOD CREEK	68.3	4.34	72.7
KINGS BEACH	67.7	0.00	67.7
DOLLAR CREEK	65.5	0.57	66.1
GRIFF CREEK	57.2	0.07	57.2
BARTON CREEK	44.8	5.98	50.7
EAGLE ROCK	47.3	0.00	47.3
BURTON CREEK	43.5	3.29	46.8
MADDEN CREEK	43.4	2.79	46.2
WARD CREEK	40.1	2.82	43.0

LAKE FOREST CREEK	42.0	0.00	42.0
EAST STATELINE POINT	38.0	0.00	38.0
WATSON	37.5	0.38	37.9
TAHOE VISTA	37.4	0.07	37.5
SECOND CREEK	26.7	0.52	27.2
BLACKWOOD CREEK	26.3	0.92	27.2
QUAIL LAKE CREEK	26.0	0.93	26.9
BURNT CEDAR CREEK	25.7	0.45	26.2
FIRST CREEK	23.0	0.00	23.0
CEDAR FLATS	22.5	0.00	22.5
INCLINE CREEK	18.7	0.91	19.7
CAMP RICHARDSON	11.6	0.00	11.6
BIJOU CREEK	8.4	0.00	8.4
CARNELIAN CANYON	7.9	0.00	7.9
UPPER TRUCKEE RIVER	7.9	0.00019	7.9
MKINNEY CREEK	6.7	0.08	6.8
CAVE ROCK	6.1	0.39	6.5
WOOD CREEK	5.1	0.03	5.1
CARNELIAN BAY CREEK	4.6	0.00	4.6
TALLAC CREEK	4.6	0.00	4.6
GENERAL CREEK	3.7	0.00	3.7
BLISS STATE PARK	3.6	0.04	3.6
THIRD CREEK	3.6	0.00	3.6
EAGLE CREEK	3.4	0.02	3.4
LINCOLN CREEK	3.3	0.00	3.3
BIJOU PARK	2.8	0.00	2.8
GLENBROOK CREEK	2.5	0.00	2.5
TAHOE STATE PARK	2.5	0.00	2.5
SIERRA CREEK	2.3	0.00	2.3
PARADISE FLAT	2.1	0.00	2.1
SECRET HARBOR CREEK	2.0	0.00	2.0
CASCADE CREEK	1.5	0.00	1.5
RUBICON CREEK	1.4	0.00	1.4
EDGEWOOD CREEK	1.2	0.00	1.2
TAYLOR CREEK	1.1	0.00098	1.1
MEEKS	1.1	0.00	1.1
TROUT CREEK	0.7	0.00	0.7
SLAUGHTER HOUSE	0.3	0.00	0.3
MARLETTE CREEK	0.2	0.00	0.2
LONELY GULCH CREEK	0.1	0.00	0.1
BURKE CREEK	0.1	0.00	0.1

NORTH LOGAN HOUSE CREEK	0.1	0.00	0.1
MILL CREEK	0.0	0.00	0.0
BLISS CREEK	0.0	0.00	0.0
BONPLAND	0.0	0.00	0.0
DEADMAN POINT	0.0	0.00	0.0
LOGAN HOUSE CREEK	0.0	0.00	0.0
MCFAUL CREEK	0.0	0.00	0.0
NORTH ZEPHYR CREEK	0.0	0.00	0.0
SAND HARBOR	0.0	0.00	0.0
SKYLAND	0.0	0.00	0.0
TRUCKEE RIVER	0.0	0.00	0.0
TUNNEL CREEK	0.0	0.00	0.0
ZEPHYR CREEK	0.0	0.00	0.0

6.3.3 Results

Interpretation of data describing the upland-erosion potential index centers on comparing suspended-sediment transport data calculated at 24 gaging stations (Table 6-9) with the percentage of high-erosion potential classes (percentage of red areas plus orange areas in Figure 6-6) in each basin or upstream of each gaging station. Similar regression characteristics wrere obtained when working with several variables representing annual suspended-sediment transport rates such as load (T/y), yield (T/km^2), and concentration (g/m^3) for both index stations and for areas above all gaging stations. In all cases, three stations plotted anomalously above the fitted regression: Blackwood Creek, Ward Creek and Third Creek, all having substantial contributions from channel sources. The most encouraging results were obtained using suspended-sediment transport data from all stations with median, annual data expressed as annual yields (Figure 6-7); $r^2 = 0.63$. It seems from the data in Figure 6-7 that there may be a threshold value or range of values above which the processes represented by the upland-erosion potential index effects downstream sediment-transport rates causing higher transport.

Readers should be cautioned that the relation depicted in Figure 6-8 should not be used for predictive purposes. Still, the basinwide map of the upland erosion-potential index is useful as a general guide to help identify areas that can produce significant quantities of suspended sediment to Lake Tahoe streams.

Table 6-9. Gaging stations used in analysis of the upland-erosion potential index.

Stream	Station number
Blackwood	10336660
Eagle Rock	103367592
Edgewood	103367585
Edgewood	10336765
Edgewood	10336760
Edgewood Tributary	10336756

General	10336645
Glenbrook	10336730
Grass	10336593
Incline	103366995
Incline	103366993
Incline	10336700
Logan House	10336740
Third	10336698
Trout	10336790
Trout	10336780
Trout	10336775
Trout	10336770
Upper Truckee River	10336610
Upper Truckee River	10336580
Ward	10336676
Ward	10336675
Ward	10336670
Wood	10336692

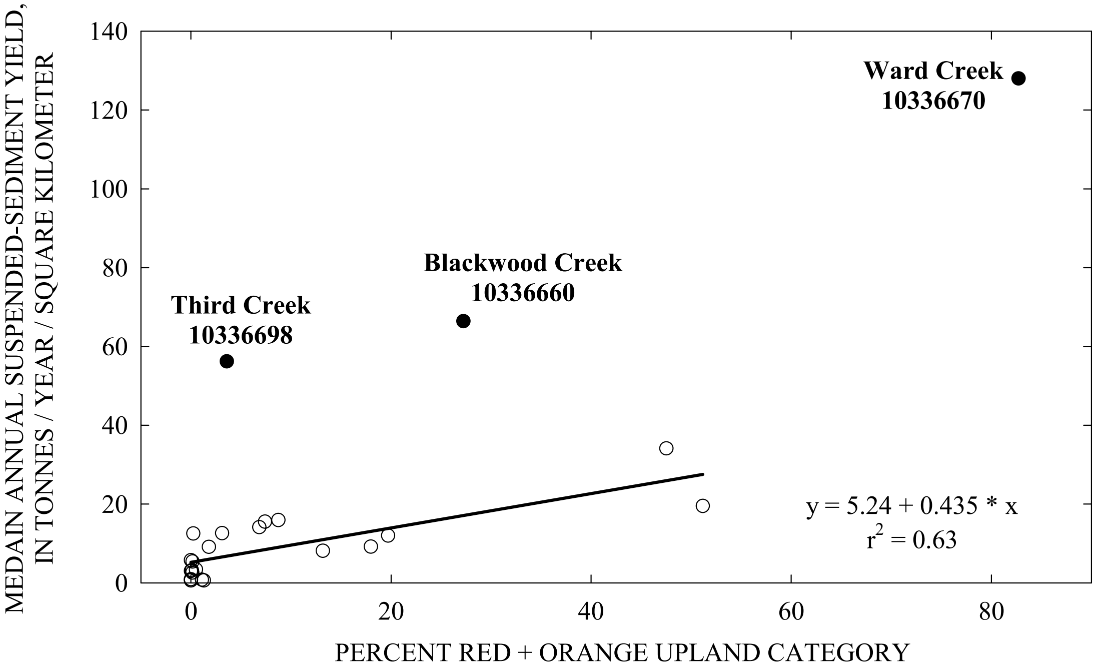


Figure 6-7. Relation between high upland-erosion potential and median, annual suspended-sediment yield.

6.3.4 Limitations of Analysis

A potential problem with one of the underlying assumptions of the analysis in relating the upland-erosion potential index with gaged sediment-transport rates is that upland sources will make up an unknown proportion of downstream sediment loads with the remainder emanating from channel sources. Thus, watersheds with high channel-erosion rates relative to upland contributions may not regress well with an upland-erosion index even if the index is accurately defining upland-erosion potential. Appropriately representing landuse/landcover over the time period of sampling at each downstream gaging station poses additional uncertainty because of land surface changes over the period, particularly in the northern quadrant of the basin. Finally, because the mean- annual precipitation layer had the coarsest resolution, 20 by 20 m, the final raster layer had that resolution.

7 SUMMARY, CONCLUSIONS AND FUTURE RESEARCH

In response to concerns about the declining clarity of Lake Tahoe waters, the Corps of Engineers (CoE), Sacramento District, in cooperation with the CoE Engineer Research and Development Center and the USDA-ARS provided support for a study on sediment loadings and channel erosion in the Lake Tahoe Basin.

7.1 Summary and Conclusions

The study was designed to combine detailed geomorphic and numerical modeling investigations of several representative watersheds with reconnaissance level evaluation of approximately 300 sites to determine which basins and areas were contributing sediment to Lake Tahoe. Numerical modeling of upland- and channel-erosion processes over then next 50 years was conducted using AnnAGNPS and CONCEPTS on three representative watersheds, General and Ward Creeks, and the Upper Truckee River. GIS-based analysis of land use, land cover, soil erodibility, steepness, and geology was used to evaluate upland-erosion across the basin. Channel contributions were determined by comparing cross-sectional geometries of channels originally surveyed in either 1983 or 1992. Sites along General, Logan House, Blackwood, and Edgewood Creeks, and the Upper Truckee River were re-occupied and re-surveyed in 2002. Historical flow and sediment-transport data from more than 30 sites were used to determine bulk suspended-sediment loads (in tonnes) and yields (in tonnes/km^2) for sites all around the lake. Eighteen index stations, defined as those with long periods of flow and sediment-transport data and, located in a downstream position were selected. These stations were used to make comparisons between sediment production and delivery from individual watersheds and between different sides (directional quadrants) of the lake. Fine-grained sediment transport was determined from historical data for 20 sites based on relations derived from particle-size distributions across the range of measured flows.

Suspended-sediment loads and yields vary over orders of magnitude from year to year, from west to east and north to south across the basin. Median annual suspended-sediment loads for index stations range from about 2200 tonnes/yr (T/y) from the Upper Truckee River to 3 T/y from Logan House Creek. Based on the historical data, the largest annual contributors of sediment are in decreasing order, Upper Truckee River (2200 T/y), Blackwood Creek (1930 T/y), Second Creek (1410 T/y), Trout Creek (1190 T/y), Third Creek (880 T/y) and Ward Creek (855 T/y). Data from Second and Third Creeks may be somewhat misleading though because of a short period of data collection in the case of the former, and the fact that data collection occurred during major construction activities in these basins. In fact, analysis of suspended-sediment transport ratings with longer periods of record (17 to 20 years) show that sediment loads from the northeast streams have significantly decreased across the entire range of flows. Based on the historical data, the lowest contributors of suspended sediment from index stations, in increasing order are Logan House (3.0 T/y), Dollar (4.6 T/y), Quail Lake (6.4 T/y), Glenbrook (8.9 T/y), and Edgewood Creeks (21.3 T/y).

That the Upper Truckee River and Trout Creek are major sediment contributors is not surprising given their large drainage areas in relation to the other streams in the Lake Tahoe Basin. Per unit area, the western and northern streams produce the most sediment although for different reasons, and sediment yields from the northern streams have been decreasing since the early 1970's. Suspended-sediment yields from the Upper Truckee River are also decreasing with time but at a slower rate than in Third and Incline Creeks for example. In other parts of the watershed, temporal trends of decreasing loads per unit area and unit water were subtler. No statistically significant trend of increasing suspended-sediment loads or yields was identified as reported recently by other workers.

Fine-grained loads show a similar pattern as total loads with the greatest contributors being the Upper Truckee River (1010 T/y), Blackwood Creek (844 T/y), Trout Creek (462 T/y) and Ward Creek (412 T/y). The lowest contributors are Logan House Creek (2.3 T/y), Dollar Creek (2.6 T/y), Quail Lake Creek (3.2T/y) and Glenbrook Creek (7.0 T/y). In terms of fine-grained loadings per unit area, a slightly different picture emerges. Blackwood, Third, and Ward Creeks, all disturbed streams have the greatest fine-grained suspended-sediment yields at 21.5, 20.2, and 16.4 T/y/km^2. In comparison, the Upper Truckee River produces 7.1 T/y/km^2; General Creek, 2.8 T/y/km^2; and Logan House Creek, 0.4 T/y/km^2.

A first approximation of total, annual suspended-sediment loadings to Lake Tahoe is made by extrapolating average-annual and median-annual data from the index stations. Data from these stations encompass 54% of the total watershed area. Using this technique average-annual and median-annual loadings are 28,600 T/y and 18,300 T/y, respectively. About 6,300 T/y of fine-grained materials are delivered to the lake, based on median-annual data. A somewhat more refined estimate of total, annual suspended-sediment loads is made by extrapolating the sum of the average, median-annual values within each quadrant. In this case the annual loadings value to Lake Tahoe is about 25,500 T/y.

Sediment yields were also used to discriminate between loadings from disturbed and undisturbed watersheds. For example, although the western streams produce more sediment per unit area than eastern streams General Creek can be considered as a "reference" stream because of a lack of significant human intervention. Sediment yield from General Creek is about 9 T/y/km^2. In contrast, yields from Blackwood and Ward Creeks, streams disturbed to different degrees by human activities are about 66 and 34 t/y/km^2, respectively. On the eastern side of the lake, relatively undisturbed Logan House Creek produces 0.6 t/y/km^2 compared to the developed Edgewood Creek watershed that produces about 3 T/y/km^2. The effects of human disturbance on streams draining the northeast part of the Lake Tahoe watershed (Third, Second and Incline) are shown to have produced orders of magnitude more sediment in the 1970's (during construction and development) than at present.

The contribution of channel materials to sediment loads also varies widely. Undisturbed channels tend to have greater amounts of their sediment load emanating from upland areas. In the General Creek watershed, numerical modeling shows that about 78% of the fine materials passing the downstream-most gauge, originate from upland sources, with only 22% coming from channel sources. Simulations of the percentage of upland sediment contributions may be overestimated because of overestimates of runoff during the low-flow winter months. This results in simulations of erosion preferentially in upland areas rather than in channels because precipitation was simulated as rain instead of snow. Still, similar proportions of upland and channel materials were simulated on Ward Creek, suggesting that this may be typical of the wetter, western watersheds. This is not to say that General and Wards Creeks supply similar amounts of streambank materials. Per unit of channel length, Ward Creek supplies almost 5 times the amount of sediment and fine-grained material from streambanks than General Creek (Table 7-1).

Analysis of monumented cross sections shows that on average, 14.6 m^3/y/km of streambank materials (or 1.5 m^3/y/km of fine-grained materials) are eroded from the lower 8.5 km of General Creek. These values are within 27% of those simulated by CONCEPTS. The disturbed channels of Blackwood Creek provide about 217 m^3/y/km of sediment; 12.2 m^3/y/km of fines. This represents about 14 times the amount of streambank-derived sediment per km of channel than from General Creek, almost 4 times more than Ward Creek, but 66% less than from the Upper Truckee River (Table 7-1).

On the Upper Truckee River, channel contributions increase significantly with distance downstream from the most upstream stream gauge. These changes reflect the increasing disturbance to the Upper Truckee River in the vicinity of Washoe Meadows and downstream of the South Lake Tahoe airport as well as the decreasing influence of upland slopes. The apparent discrepancy between measured and simulated values along the Upper Truckee River (Table 7-1) is not an error but merely a function of different channel lengths. Measured data come from the Washoe Meadows reach which represents the most laterally active reach of the river. In contrast the simulated data are derived from the entire23.8 km simulated length extending to the gage upstream of Meyers, thereby moderating the resulting value obtained from simulation with CONCEPTS.

Edgewood and Logan House Creeks have been net sinks for sediment over the past 20 years. Of the streams where numerous bank-material samples were collected, relative proportions of fine-grained materials comprising the channel banks are greatest along Ward Creek and the Upper Truckee River (17% and 14%, respectively) and lowest along Edgewood and Incline Creeks.

Table 7-1. Average annual contributions of streambank materials expressed in m^3/y/km.

Stream	Total simulated	Total measured	Fines simulated	Fines measured
Blackwood	-	217	-	12.2
General	10.6	14.6	0.90	1.5
Upper Truckee[1]	54.5	645	9.5	90.3
Ward	45.6	-	4.4	-

[1] Rate reflects surveys over a short (2.9 km), unstable reach and, therefore are not indicative of the entire length of river.

The effect of the 1997 rain on snow event varied widely across the basin, from being a 60-year sediment event on Blackwood Creek to a 1.4-year sediment event along Third Creek. Based on magnitude-frequency analysis, western streams such as Ward, Blackwood, and General Creeks were impacted the greatest while the northeast streams were impacted the least. The January 1997 event represented only an 8-year sediment event on the Upper Truckee River near its mouth and served to flush sediment from this and other drainages. Post-1997 suspended-sediment loads are generally lower than previous because the flushing of stored sediment has made less sediment available for transport. However, in channels such as the Upper Truckee River and perhaps Trout Creek with broad, relatively flat, sinuous alluvial reaches, sediment contributions from streambank erosion have increased. This is due to extension and elongation of meanders with the ultimate development of cut-offs. Documented rates of meander migration of a reach of the Upper Truckee River have been quantified herein for the past 60 years and also show a decreasing rate of activity. It does not seem, therefore, that the runoff event rejuvenated stream channels throughout the basin. In fact, 1997 was not the peak sediment year in a number of watersheds.

Numerical simulations of suspended-sediment loadings from disturbed and undisturbed western streams, and the Upper Truckee River for the next 50 years shows a trend of decreasing sediment delivery to Lake Tahoe. This is particularly significant for the western streams because they currently produce some of the highest loadings to the lake and, over the past 20 years these high loads (per unit runoff) have remained relatively constant. That future loadings from the Upper Truckee River are simulated to decrease is significant because: (1) it is the largest contributor of suspended- and fine-grained sediment to the lake, (2) streambank erosion has increased recently, in part due to the effects of the January 1997 storm, and (3) notwithstanding the recent increase in bank erosion, loads (per unit runoff) over the longer term (past 24 years) have been shown to be decreasing. Results of simulations on the Upper Truckee River indicate that this longer-termed trend will continue and that the effects of 1997 event will be short-lived in the modeled watersheds. The accuracy and reliability of the numerical simulations is somewhat less than expected, however, because of a lack of detailed, high-quality climate data that could account for broad variations in precipitation and temperature between watersheds, and within a single watershed with elevation.

Being the largest sediment contributor to Lake Tahoe, results from the Upper Truckee River are summarized in greater detail. Streambanks are the major source of sediment based on simulation results at the mouth of the Upper Truckee River: 49% of the fine suspended load (clay and silt), 90% of the coarse suspended load (sands), and 79% of the total suspended load. The 50-year simulation of the Upper Truckee River predicts that on average, 770 T/y of sediment will be discharged to Lake Tahoe. Of this total, 690 T/y are clays and silts. The majority of sediment (60%) is generated in the first 25 years when channel erosion, particularly bank widening is most active. Almost two-thirds of the total suspended-sediment is simulated to come from streambank erosion. Of the total mass of fine-grained sediments delivered to the lake over the 50-year simulation period, 37% are from streambanks, with the balance from upland sources.

Results of the numerical simulations provide information as to where the fine sediments are being eroded. A summary of the relative contributions from upland and channel sources is shown reproduced from Section 5.5 (Table 5-18) in Table 7-2. Note that channel erosion dominates total suspended sediment loads but that the relative proportion of fine-grained loadings emanating from upland sources is greater in the two western streams. The Upper Truckee River still has the majority of its fine-grained loadings derived from its channel banks. This decreases to 37% over the 50-year simulation as a result of channel-adjustment processes.

Table 7-2. (Table 5-18) Upland versus channel sources of total and fine-grained suspended sediment for the three modeled watersheds during the validation periods. All data expressed as a percent.

	Source	General Creek	Ward Creek	Upper Truckee River
Total Suspended	Uplands	47	34	21
	Channel	53	66	79
Suspended Fines	Uplands	72	79	49
	Channel	28	21	51

Rapid geomorphic assessments (RGAs) at 300 stream sites and stream walks were used to calculate a semi-quantitative stability index based on diagnostic characteristics of the channel and adjacent side slopes. Greater values indicate a greater potential for erosion and sediment delivery. Values greater than 19 indicate an erosion problem that can be identified from individual basin maps for the seven intensely studied streams and on basinwide maps for all other sites. Values less than 11 indicate a relative stability of channel and little to no side slope contribution. Basinwide maps of the occurrence of bank erosion and the silt/clay content of those banks can be used to evaluate potentially critical stream reaches or specific locations. Streambank-erosion classes, taking into account the proportion of fine-grained sediment in the banks were assigned to almost 50 km of channels including Blackwood, Edgewood, General, Incline, Logan House and Ward Creeks, and the Upper Truckee River.

A similar analysis of the potential for upland contributions is based on GIS analysis of five parameters including slope steepness, surficial geology, precipitation, land use/landcover, and soil erodibility. The relative percentage of high upland-erosion potential within a drainage basin was positively correlated with median, annual suspended-sediment yields and can also be used to evaluate potentially critical areas.

In conclusion, the most significant findings of this research are that:

- Streambank erosion is an important contributor of suspended-sediment from disturbed streams,
- The Upper Truckee River is the greatest contributor of suspended-sediment and fine-grained sediment in the Lake Tahoe Basin,
- Sediment delivery from the Upper Truckee River could be significantly reduced by controlling streambank erosion in the reaches adjacent to the golf course and downstream from the airport,
- Blackwood Creek is a major contributor of both total and fine-grained sediment, particularly for the size of its drainage area and loads from disturbed western streams remain high.
- Loads from western streams are not increasing with time as reported by others,
- Median, long term suspended-sediment yields (per unit runoff) from northern streams are high, about the same as the wetter western streams but yields have shown significant decreases from the major development period in the 1960s and 1970s.

- Third Creek still produces a great deal of sediment for its size as a result of both upland and channel contributions.
- Disturbed watersheds contribute considerably more suspended sediment than their stable counterparts in each basin quadrant.
- Eastern streams produce the lowest sediment loads and those studied are net sinks for sediment.
- The major runoff event of January 1997 impacted western streams and the Upper Truckee River most severely, but did not seem to rejuvenate these fluvial systems. Effects were minor in the northern streams,
- The most significant effect of the January 1997 was to flush stored sediment from alluvial valleys resulting in generally lower transport rates in the years following the event,
- Numerical simulations of General and Ward Creeks and the Upper Truckee River show that suspended-sediment loads will continue to decrease from these streams over the next 50 years.

7.2 Future Research Needs

In light of the summary of results provided above and the knowledge gained during the course of this investigation, a number of research priorities have been identified. These include but are certainly not limited to:

- Determining the critical conditions for streambank failure and, therefore, streambank restoration based on a quantitative analysis of *in situ* conditions and the effects of bank-toe erosion, pore-water pressure, and the mechanical and hydrologic effects of riparian vegetation.
- A detailed, quantitative field study of Third Creek given its unusually high sediment yields (in comparison to Incline Creek) given its location and size.
- Perform detailed case-study analyses of some of the critical upland- and channel-erosion areas highlighted in this research as a means of designing appropriate erosion-control measures throughout the basin.
- Using geomorphic techniques, determine sediment-transport trends over the last 150 years to determine if trends over the past 40 years and current lake conditions represent the attenuation of conditions caused by the massive logging operations that took place in the mid- to late 1800s.
- Additional numerical simulations of upland and channel processes with improved climate data will further elucidate sediment source areas and management strategies.

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A Appendix A

Field Data Collected at Intensely Studied Streams

Table A-1. Summary of Blackwood Creek field data collected.

Site	River kilometer	2002 Survey	RGA	Samples	
			Form	Bed	Bank face
62-32	0.00	-	✓	-	-
62-31	0.32	✓	✓	PC	PS
62-30	0.32	✓	✓	PC	PS
62-29	0.33	✓	✓	PC	PS
62-28	1.22	-	-	-	-
62-27	1.22	-	-	-	-
62-26	1.23	-	-	-	-
62-25	1.77	-	✓	PC	PS
62-24	1.77	-	✓	PC	PS
62-23	1.78	-	✓	PC	PS
62-22a	1.97	-	✓	-	-
62-22	2.80	✓	✓	-	PS
62-21	2.80	✓	✓	-	PS
62-20	2.81	✓	✓	-	PS
62-19	3.95	-	✓	PC	PS
62-18	3.95	-	✓	PC	PS
62-17	3.95	-	✓	PC	PS
62-16	4.15	-	✓	PC	PS
62-15	4.15	✓	✓	PC	PS
62-14	4.15	✓	✓	PC	PS
62-13	5.07	✓	✓	PC	PS
62-12	5.08	-	✓	PC	PS
62-11	5.08	-	✓	PC	PS
62-10b	5.55	-	✓	-	-
62-10a	6.03	-	✓	-	-
62-10	6.50	-	✓	-	-
62-09	6.50	✓	✓	-	-
62-08	6.51	✓	✓	PC	PS
62-07a	6.84	-	✓	-	-
62-07	7.17	✓	✓	PC	PS
62-06	7.18	✓	✓	-	-
62-05	7.18	✓	✓	PS, PC	PS, PC
62-04a	7.69	-	✓	-	-
62-04	8.19	✓	✓	PC	-
62-03	8.19	✓	✓	PS	PS
62-02	8.29	-	-	-	-
62-01	8.29	-	✓	-	PS

PC = Particle Count
PS = Particle Size

Table A-2. Summary of Edgewood Creek field data collected.

Site	River kilometer	2002 Survey	RGA	Samples	
			Form	Bed	Bank face
40-28	0.00	-	-	-	-
40-27a	0.20	-	✓	PS	-
40-27	1.20	-	✓	PS	-
40-26	3.09	✓	✓	PS	PS
40-25	3.09	✓	✓	PS	PS
40-24	3.10	✓	✓	PS	PS
40-23	3.83	✓	✓	PS	PS
40-22	3.83	✓	✓	PS	PS
40-21	3.84	✓	✓	PS	PS
40-20	4.95	✓	✓	-	PS
40-19	4.96	✓	✓	-	PS
40-18	4.96	✓	✓	-	PS
40-17	5.22	-	-	-	-
40-16	5.22	-	-	-	-
40-15	5.23	-	-	-	-
40-14	5.62	✓	✓	PS	PS
40-13	5.62	✓	✓	PS	PS
40-12	5.63	✓	✓	PS	PS
40-11	6.40	✓	✓	PS	-
40-10	6.41	✓	✓	PS	-
40-09	6.41	✓	✓	PS	-
40-08	6.22	✓	✓	PS	-
40-07	6.22	✓	✓	PS	-
40-06	6.41	✓	✓	PS	-
40-05	6.42	✓	✓	PS	-
40-04	7.22	✓	-	PS	-
40-03	7.23	✓	✓	PS	-
40-02	7.21	✓	✓	PS	-
40-01	7.22	✓	✓	PS	-

PC = Particle Count
PS = Particle Size

Table A-3. Summary of General Creek field data collected.

Site	River kilometer	2002 Survey	RGA	Samples			BST	
			Form	Bed	Toe	Bank face	Test	Internal bank sample
56-38	0.00	-	-	-	-	-	-	-
56-37	0.01	✓	✓	PS, PC	-	PS	✓	PS
56-36	0.30	✓	✓	PC	-	PS	✓	PS
56-35	0.31	✓	-	-	-	-	-	-
56-34	0.57	✓	✓	PS	-	-	-	PS
56-33	0.70	✓	-	-	-	-	-	-
56-32	0.71	✓	✓	PC	-	-	-	PS
56-31	0.71	✓	-	-	-	PS, PC	-	-
56-30	0.89	✓	✓	PS, PC	-	PS	✓	PS
56-29	0.95	✓	✓	PC	PC	PS	✓	PS
56-28	1.17	✓	✓	PC	-	PS	-	PS
56-27	1.54	✓	✓	PS, PC	-	PS	-	PS
56-26	1.93	✓	✓	PS, PC	-	PC	✓	PS
56-25	1.94	✓	-	-	-	-	-	-
56-24	1.94	✓	✓	PS, PC	-	PS	-	PS
56-23	2.20	✓	✓	PC	-	PC	✓	PS
56-22	2.49	✓	✓	-	-	-	-	-
56-21	2.58	✓	✓	PS, PC	Boulders	Boulders	✓	-
56-20	2.97	✓	✓	PC	Boulders	PS, PC	-	PS
56-19	3.25	✓	✓	PC	PS	PS, PC	✓	PS
56-18	3.59	✓	✓	PC	PC	-	-	PS
56-17	3.60	✓	✓	PS, PC	PS, PC	PS	✓	PS
56-16	3.62	✓	✓	PS, PC	-	-	-	PS
56-14	4.21	✓	✓	PC	-	PS, PC	✓	PS
56-12	4.73	✓	✓	PC	-	PS	✓	PS
56-11	5.05	✓	✓	PS, PC	-	-	-	PS
56-10	5.24	✓	-	-	-	-	-	-
56-09	5.25	✓	✓	PC	-	PS, PC	-	-
56-08	5.33	✓	✓	PC	-	-	-	-
56-07	5.61	✓	✓	-	-	PS	-	-
56-06	5.90	✓	✓	PS, PC	-	PS	✓	PS
56-05	6.06	✓	✓	PC	-	PS	✓	PS
56-04	6.39	✓	-	-	-	-	-	-
56-03	6.50	✓	✓	PC	PS, PC	PC	✓	PS
56-02	6.66	✓	✓	PS, PC	PC	PS, PC	-	-
56-01	6.80	✓	✓	PC	PC	PS, PC	-	-
GC-45	8.08	✓	✓	PS, PC	-	-	-	-
GC-35	9.23	✓	-	-	-	-	-	-

PC = Particle Count
PS = Particle Size

Table A-4. Summary of Incline Creek field data collected.

Site	River kilometer	2002 Survey	RGA	Samples			BST	
			Form	Bed	Toe	Bank face	Test	Internal bank sample
19-40	0.00	-	-	-	-	-	-	-
19-39	0.05	✓	✓	-	-	PS	✓	PS
19-38	0.16	✓	✓	PS, PC	-	PS	-	PS
19-37	0.21	✓	✓	PS, PC	-	-	-	PS
19-36	0.26	✓	✓	PS	-	-	-	PS
19-35	0.40	✓	✓	PC	-	-	-	PS
19-34	0.57	✓	✓	PS, PC	-	-	-	PS
19-33	0.72	✓	✓	PS, PC	-	-	✓	PS
19-32	0.85	✓	✓	PS, PC	-	PS	✓	PS
19-31	1.08	✓	✓	PS, PC	-	PS	✓	PS
19-30	1.11	✓	-	-	-	-	-	-
19-29	1.22	✓	✓	PS, PC	Grass Covered	Grass Covered	-	Golf Course
19-28	1.32	✓	✓	PC	-	PS	-	-
19-27	1.55	✓	✓	PS, PC	No Toe	PS	-	PS
19-26	1.61	✓	✓	PS, PC	No Toe	No bank	-	No bank
19-25	1.77	✓	✓	PS, PC	-	PS, PC	-	PS
19-24	1.90	✓	✓	PS, PC	Boulders	Boulders	-	PS
19-23	2.06	✓	✓	PS, PC	-	PS	-	PS
19-22	2.17	✓	✓	PC	-	PS	-	PS
19-21	2.41	✓	✓	PS	Boulders	PS	-	PS
19-20	2.97	✓	-	-	-	-	-	-
19-19	3.05	✓	✓	PS, PC	-	PS	-	PS
19-18	3.40	✓	✓	PS	-	-	-	PS
19-17	3.42	✓	✓	PS, PC	-	-	-	PS
19-16	3.53	✓	✓	PS	-	-	-	-
19-15	3.54	✓	✓	Boulders	-	PS	-	PS
19-14	3.78	✓	✓	PS, PC	-	PS	-	PS
19-13	4.05	✓	✓	PC	-	PS	-	PS
19-12	4.22	✓	✓	PS, PC	-	PS	-	PS
19-11	4.34	✓	✓	PC	-	PS	-	PS
19-10	4.53	✓	✓	PC	Boulders	PS	✓	PS
19-09	4.64	✓	✓	PS, PC	-	PS	-	PS
19-08	4.81	✓	✓	PC	Boulders	PS	-	PS
19-07	4.97	✓	-	PS, PC	-	PS, PC	-	-
19-06	5.04	✓	✓	PS, PC	Boulders	PS, PC	-	PS
19-05	5.22	✓	✓	PC	Boulders	PS	✓	PS
19-04	5.39	✓	✓	PS, PC	Boulders	Boulders	-	PS
19-03	5.44	✓	✓	PS, PC	No Toe	Roots	-	Roots
19-02	5.61	✓	✓	PS, PC	No Toe	Grass covered	✓	PS
19-01	5.69	✓	✓	PS, PC	-	-	-	PS

PC = Particle Count
PS = Particle Size

Table A-5. Summary of Logan House Creek field data collected.

Site	River kilometer	2002 Survey	RGA	Samples
			Form	Bed
31-25	0.00	-	-	-
31-24	0.07	✓	-	-
31-23	0.23	✓	-	-
31-22	0.26	✓	-	-
31-21	0.41	✓	-	-
31-20	0.55	✓	-	-
31-19	0.66	-	-	-
31-18	0.66	✓	-	-
31-17	0.67	✓	-	-
31-16	0.92	-	-	-
31-15	0.97	✓	-	-
31-14	0.97	✓	-	-
31-13	0.98	✓	-	-
31-12	1.03	-	-	-
31-11	1.20	✓	✓	PS
31-10	1.21	✓	✓	PS
31-09	1.70	✓	✓	PS
31-08	1.71	✓	✓	PS
31-07	2.55	✓	✓	-
31-06	2.55	✓[1]	✓	-
31-05	3.02	✓[1]	✓	PS
31-04	3.03	✓	✓	PS
31-03	3.93	✓	✓	-
31-02	3.93	✓	✓	-
31-01	3.94	✓	✓	-

[1] Not exact match--actual historic pins missing
PC = Particle Count
PS = Particle Size

Table A-6. Summary of the Upper Truckee River field data collected.

Site	River kilometer	2002 Survey	RGA	Samples			Jet test			BST	
			Form	Bed	Toe	Bank face	Bed	Toe	Bank face	Test	Internal bank sample
44-119	0.00	-	-	-	-	-	-	-	-	-	-
44-110	1.558	-	✓	PS, PC	-	-	-	-	-	✓	PS
44-103	2.256	-	✓	PS, PC	-	PS	-	-	-	-	PS
44-92	2.941	-	✓	PS	PS	-	✓	✓	✓	✓	PS
44-87	4.511	-	✓	PS	Undercut	PS	-	-	-	✓	PS
44-85	5.055	-	✓	PS	-	PS	✓	✓	✓	✓	PS
44-82	5.837	-	✓	PS	PC	PC	-	-	-	-	-
44-78	7.137	-	✓	PS	PS	PS	-	-	-	✓	PS
44-75	8.455	-	✓	PS	PS	PS	-	✓	✓	✓	PS
44-72	10.037	-	✓	PS, PC	PS	PS	-	-	-	-	-
44-70	10.722	✓	-	-	-	-	-	-	-	-	-
44-69	10.751	✓	-	-	-	-	-	-	-	-	-
44-68	10.838	✓	✓	PS	PS	PS	-	✓	-	✓	PS
44-67	11.207	✓	✓	PC	PC	PS	-	-	-	-	-
44-62	11.674	✓	-	-	-	-	-	-	-	-	-
44-59	12.070	✓	✓	PS, PC	-	PS, PC	-	-	-	-	-
44-50	12.727	✓	-	-	-	-	-	-	-	-	-
44-43	13.146	✓	✓	PC	PS	PS	-	✓	✓	✓	PS
44-39	13.519	✓	✓	PC	PS	PS	-	✓	✓	✓	PS
44-30	14.071	✓	✓	PC	-	PS, PC	-	-	-	-	-
44-28	14.322	✓	-	-	-	-	-	-	-	-	-
44-27	14.753	✓	-	-	-	-	-	-	-	-	-
44-26	14.768	✓	✓	PC	PS	PS	-	-	✓	✓	PS
44-25	14.783	✓	-	-	-	-	-	-	-	-	-
44-24	15.277	✓	✓	PC	PC	PS	-	-	-	-	-
44-23	15.625	✓	-	-	-	-	-	-	-	-	-
44-22	15.870	✓	✓	PC	PS	PS	-	-	-	-	-
44-21a	16.40	-	✓	PS, PC	-	-	-	-	-	-	-
44-21	16.898	✓	✓	PC	-	PS	-	-	-	-	-
44-20	17.779	✓	✓	PC	PS	PS	-	✓	✓	✓	PS
44-19	17.999	✓	✓	PC	-	-	-	-	-	-	-
44-18	18.339	✓	-	-	-	-	-	-	-	-	-
44-17	18.573	✓	✓	PC	PC	PS	-	-	-	-	-
44-16	19.261	✓	✓	PC	PS	PS	-	-	-	-	-
44-15	19.940	✓	✓	PS, PC	-	PS	-	✓	-	✓	PS
44-14	20.136	✓	-	-	-	-	-	-	-	-	-
44-13	20.266	✓	-	-	-	-	-	-	-	-	-
44-12	20.749	✓	✓	PS, PC	PS, PC	PS	-	-	✓	✓	PS, PC
44-11	21.369	✓	✓	PS, PC	No Toe	PS	-	-	-	-	-
44-10	21.390	✓	-	-	-	-	-	-	-	-	-
44-09	21.639	✓	-	-	-	-	-	-	-	-	-
44-08	21.769	✓	✓	PC	No Toe	PS, PC	-	-	-	-	-
44-07	21.858	✓	-	-	-	-	-	-	-	-	-
44-06	22.538	✓	✓	PC	PS	PS	-	-	-	-	-
44-05	22.760	✓	-	-	-	-	-	-	-	-	-
44-04	23.009	✓	✓	PC	PS, PC	PS	-	✓	-	✓	PS
44-03	23.350	✓	-	-	-	-	-	-	-	-	-
44-02	23.711	✓	-	-	-	-	-	-	-	-	-
44-01	24.187	✓	✓	PC	No Toe	-	-	-	-	-	-

Table A-8. Summary of Ward Creek field data collected.

Site	River kilometer	2002 Survey	RGA	Samples			BST	
			Form	Bed	Toe	Bank face	Test	Internal bank sample
63-45	0.00	-	-	-	-	-	-	-
63-44	0.09	✓	✓	PC	-	PC	-	-
63-43	0.25	✓	✓	PC	-	-	✓	PS
63-42	0.44	✓	✓	-	-	-	-	-
63-41	0.51	✓	✓	PC	PC	PS, PC	-	-
63-40	0.63	✓	✓	PC	-	PC	-	PS
63-39	0.78	✓	✓	-	-	PC	✓	PS
63-38	0.99	✓	-	-	-	-	-	-
63-37	1.11	✓	✓	PC	-	-	✓	PS
63-36	1.12	✓	✓	Dam	Dam	Dam	-	-
63-35	1.14	✓	✓	PC	-	-	-	-
63-34	1.29	✓	✓	PC	PC	PS, PC	-	-
63-33	1.42	✓	✓	PC	PC	-	✓	PS
63-32	1.55	✓	✓	PC	-	PC	-	-
63-31	1.73	✓	-	-	-	-	-	-
63-30	1.97	✓	✓	PC	PC	Boulders	-	-
63-29	2.08	✓	✓	PC	PC	-	✓	PS
63-28	2.19	✓	-	-	-	-	-	-
63-27	2.28	✓	-	-	-	-	-	-
63-26	2.38	✓	✓	PC	PC	-	✓	PS
63-25	2.64	✓	✓	PC	PC	PC	-	-
63-24	3.01	✓	-	-	-	-	-	-
63-23	3.28	✓	✓	PC	Boulders	PC	-	-
63-22	3.51	✓	✓	PC	-	PC	-	-
63-21	3.64	✓	✓	PC	-	-	✓	PS
63-20	3.86	✓	-	-	-	-	-	-
63-19	4.06	✓	✓	PC	PC	-	✓	PS
63-18	4.25	✓	✓	PC	-	PS	-	-
63-17	4.36	✓	-	-	-	-	-	-
63-16	4.52	✓	✓	PC	Boulders	Boulders	-	-
63-15	4.74	✓	✓	PC	PC	PS	-	PS
63-14	5.12	✓	✓	PC	-	PS	✓	PS
63-13	5.36	✓	✓	PC	PC	PS	-	PS
63-12	5.53	✓	✓	PC	-	PS	✓	PS
63-11	5.80	✓	✓	-	-	PS	-	PS
63-10	5.81	✓	✓	PC	-	-	-	-
63-09	5.87	✓	✓	PC	-	PS, PC	-	-
63-08	5.94	✓	✓	-	PS	PS	-	PS
63-07	6.00	✓	-	-	-	-	-	-
63-06	6.10	✓	✓	PC	-	PC	-	-
63-05	6.17	✓	✓	PC	PS	PS	✓	PS
63-04	6.27	✓	✓	PC	PS	Vegetated	-	PS
63-03	6.42	✓	✓	PC	PC	-	-	PS
63-02	6.45	✓	✓	PC	PC	-	✓	PS
63-01	6.55	✓	✓	PC	PC	PS	✓	PS

B Appendix B

Particle-Size Distribution Tables

Table B-1. Internal bank material particle-size data for General, Incline and Ward Creeks and the Upper Truckee River (UTR).

Stream	Station number	River kilometer	Depth in meters	Bank left or right	Percent grain size in millimeters				Particle sizes in millimeters			
					Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Incline	19-01	5.69	0.40	L	0.00	30.8	66.3	2.84	0.15	0.68	3.50	6.80
Incline	19-02	5.61	0.38	L	0.00	3.8	93.3	2.89	0.12	0.28	0.73	1.80
Incline	19-04	5.39	0.40	L	0.00	11.3	79.9	8.74	0.08	0.21	1.20	4.00
Incline	19-05	5.22	0.45	R	0.00	19.2	78.0	2.74	0.15	0.41	2.20	4.30
Incline	19-06	5.04	0.50	L	0.00	28.1	65.6	6.22	0.14	0.80	3.90	8.50
Incline	19-08	4.81	0.28	R	0.00	36.2	56.7	7.16	0.11	0.78	6.30	13.0
Incline	19-09	4.64	0.30	L	0.00	49.2	50.2	0.51	0.30	1.80	10.5	14.0
Incline	19-10	4.53	0.34	L	0.00	14.8	80.9	4.35	0.12	0.37	1.80	7.80
Incline	19-11	4.34	0.40	R	0.00	42.4	57.4	0.19	0.41	1.10	40.0	57.0
Incline	19-12	4.22	0.37	R	0.00	39.9	55.8	4.29	0.10	1.10	6.60	17.0
Incline	19-13	4.05	0.38	R	0.00	21.0	72.2	6.77	0.10	0.34	2.80	7.00
Incline	19-15	3.54	0.30	L	0.00	22.0	73.3	4.71	0.12	0.42	3.00	6.60
Incline	19-17	3.42	0.37	L	0.00	10.5	82.1	7.43	0.10	0.22	0.92	4.10
Incline	19-18	3.40	0.40	R	0.00	4.93	91.5	3.59	0.13	0.31	0.79	2.00
Incline	19-19	3.05	0.46	R	0.00	21.6	74.7	3.76	0.12	0.40	3.30	7.80
Incline	19-21	2.41	0.30	R	0.00	29.7	66.0	4.32	0.15	0.61	7.00	17.0
Incline	19-22	2.17	0.45	L	0.00	10.9	70.5	18.62	0.05	0.22	1.10	3.80
Incline	19-23	2.06	0.33	R	0.00	32.6	60.1	7.32	0.12	0.60	7.20	18.0
Incline	19-24	1.90	0.30	R	0.00	46.6	48.6	4.77	0.13	1.30	7.70	14.0
Incline	19-25	1.77	0.20	L	0.00	93.0	6.52	0.50	3.60	31.0	51.0	64.0
Incline	19-27	1.55	0.25	R	0.00	28.8	66.0	5.24	0.15	0.72	3.20	7.10
Incline	19-31	1.08	0.35	L	0.00	23.9	74.8	1.30	0.25	0.68	3.40	9.30
Incline	19-32	0.85	0.41	L	0.00	18.6	72.3	9.10	0.09	0.38	2.60	10.0
Incline	19-33	0.72	0.34	L	0.00	11.9	77.4	10.7	0.08	0.21	1.10	5.90
Incline	19-34	0.57	0.20	L	0.00	2.95	93.8	3.29	0.13	0.40	1.10	1.80
Incline	19-35	0.40	0.76	R	0.00	26.6	68.4	5.00	0.15	0.67	3.30	7.20
Incline	19-35	0.40	0.25	L	0.00	40.7	55.9	3.43	0.18	1.00	11.0	50.0
Incline	19-36	0.26	0.20	R	0.00	18.2	78.5	3.32	0.15	0.37	2.40	15.0
Incline	19-36	0.26	0.25	L	0.00	34.9	63.3	1.80	0.24	0.81	6.10	15.0
Incline	19-37	0.21	0.36	L	0.00	36.4	58.5	5.09	0.11	0.69	21.0	33.0
Incline	19-38	0.16	0.25	R	0.00	4.87	79.7	15.5	0.06	0.19	0.78	2.00
Incline	19-38	0.16	0.50	L	0.00	20.9	71.3	7.75	0.10	0.35	2.60	6.00
Incline	19-39	0.05	0.38	L	0.00	11.9	86.1	2.08	0.29	0.70	1.70	3.70
UTR	44-04	23.0	0.30	R	0.00	11.6	76.3	12.1	0.078	0.39	1.7	3.7
UTR	44-04	23.0	0.50	R	1.00	84.0	15.0	0.00	3.00	15.0	35.0	51.0
UTR	44-04	23.0	0.70	R	0.00	19.3	74.3	6.33	0.13	0.40	2.80	22.0

Stream	Station number	River kilometer	Depth in meters	Bank left or right	Percent grain size in millimeters				Particle sizes in millimeters			
					Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
UTR	44-12	20.7	1.05	L	0.00	1.04	84.6	14.3	0.068	0.17	0.43	0.94
UTR	44-12	20.7	0.85	L	0.00	3.89	85.0	11.1	0.087	0.3	0.81	1.80
UTR	44-12	20.7	0.40	L	0.00	52.5	47.0	0.483	0.43	2.1	6.0	10.0
UTR	44-12	20.7	-	L	5.00	81.0	14.0	0.00	3.00	15.0	42.0	64.0
UTR	44-15	19.9	0.67	L	0.00	0.00	86.2	13.8	0.069	0.17	0.45	0.88
UTR	44-15	19.9	0.40	L	0.00	6.44	82.8	10.8	0.083	0.3	0.79	2.80
UTR	44-20	17.8	0.95	L	0.00	2.38	77.6	20.0	0.043	0.15	0.53	1.40
UTR	44-20	17.8	0.65	L	0.00	11.8	73.8	14.5	0.068	0.17	0.9	5.80
UTR	44-26	14.8	0.90	R	0.00	0.353	90.2	9.43	0.08	0.18	0.37	0.48
UTR	44-30	14.1	0.40	R	0.00	2.86	76.1	21.0	0.041	0.12	0.33	1.1
UTR	44-39	13.5	0.50	R	0.00	2.61	61.4	36.0	0.013	0.11	0.53	1.3
UTR	44-39	13.5	0.30	R	0.00	0.00	82.5	17.5	0.058	0.13	0.37	0.78
UTR	44-39	13.5	0.20	R	0.00	35.8	63.1	1.09	1.0	2.7	6.0	7.9
UTR	44-43	13.1	0.70	R	0.00	3.37	83.8	12.9	0.072	0.21	0.81	1.7
UTR	44-43	13.1	0.42	R	0.00	4.02	72.5	23.5	0.038	0.16	0.52	1.7
UTR	44-68	10.8	0.45	R	0.00	16.4	65.3	18.3	0.050	0.21	2.1	18
UTR	44-68	10.8	0.40	R	0.00	17.5	63.9	18.7	0.044	0.23	2.4	9.6
UTR	44-68	10.8	0.30	R	0.00	16.3	61.8	21.9	0.031	0.2	2.1	15
UTR	44-75	8.50	1.00	R	0.00	0.00	90.4	9.56	0.088	0.3	0.82	1.4
UTR	44-75	8.50	0.50	R	0.00	3.17	78.2	18.6	0.043	0.18	0.47	1.2
UTR	44-78	7.14	0.70	L	0.00	0.00	82.4	17.6	0.060	0.11	0.28	0.69
UTR	44-78	7.14	0.40	L	0.00	0.00	71.7	28.3	0.021	0.1	0.44	1
UTR	44-85	5.06	0.85	R	0.00	3.86	83.4	12.8	0.071	0.17	0.4	1
UTR	44-85	5.06	0.50	R	0.00	0.237	84.7	15.0	0.068	0.13	0.3	0.48
UTR	44-87	4.51	0.40	R	0.00	0.0	84.7	15.3	0.066	0.15	0.31	0.5
UTR	44-87	4.51	0.30	R	0.00	0.0	86.9	13.1	0.07	0.15	0.59	1.3
UTR	44-92	2.94	1.00	L	0.00	0.0	77.0	23.0	0.038	0.18	1.1	1.6
UTR	44-103	2.26	0.65	L	0.00	1.66	87.6	10.7	0.080	0.25	0.77	1.5
UTR	44-110	1.56	0.65	L	0.00	16.7	71.7	11.6	0.077	0.27	2.1	5.3
UTR	44-110	1.56	0.33	L	0.00	0.728	96.9	2.36	0.160	0.31	0.48	0.72
General	56-03	6.50	0.28	L	0.00	20.2	62.3	17.5	0.057	0.32	3.0	20.0
General	56-05	6.06	0.32	R	0.00	19.0	75.8	5.26	0.12	0.41	2.20	5.10
General	56-06	5.90	0.45	R	0.00	2.72	77.0	20.3	0.078	0.22	0.8	3.10
General	56-11	5.05	0.50	R	0.00	3.97	88.6	7.44	0.1	0.3	0.78	1.7
General	56-12	4.73	0.25	R	0.00	2.08	81.4	16.5	0.063	0.16	0.33	0.9
General	56-14	4.21	0.48	R	0.00	1.98	86.4	11.6	0.077	0.019	0.42	0.9
General	56-16	3.62	0.50	L	0.00	0.183	96.4	3.47	0.13	0.29	0.47	0.9

Stream	Station number	River kilometer	Depth in meters	Bank left or right	Percent grain size in millimeters				Particle sizes in millimeters			
					Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
General	56-17	3.60	0.50	R	0.00	20.9	65.4	13.7	0.07	0.35	3.1	9.1
General	56-18	3.59	0.40	L	0.00	41.0	54.7	4.28	0.26	1.1	11	28.0
General	56-19	3.25	0.45	R	0.00	35.9	55.2	8.88	0.12	0.82	10	22.0
General	56-20	2.90	0.40	R	0.00	41.3	51.4	7.21	0.13	0.91	21	44.0
General	56-23	2.20	0.60	R	0.00	12.6	65.1	22.4	0.043	0.19	1.3	5.9
General	56-23	2.20	0.40	R	0.00	21.8	63.7	14.5	0.07	0.3	3.4	16.0
General	56-24	1.94	2.00	R	0.00	0.00	87.9	12.1	0.07	0.25	0.7	0.9
General	56-24	1.94	0.50	R	0.00	26.8	62.3	10.9	0.079	0.37	4.1	9.8
General	56-26	1.93	0.35	R	0.00	5.81	75.4	18.8	0.051	0.2	0.71	2.3
General	56-27	1.54	0.40	R	0.00	37.6	52.4	10.0	0.095	0.68	25	51.0
General	56-28	1.17	0.70	R	0.00	1.14	87.0	11.8	0.072	0.18	0.42	0.9
General	56-29	0.95	0.30	R	0.00	20.4	69.0	10.6	0.087	0.4	3.1	28.0
General	56-30	0.89	0.38	R	0.00	20.2	66.6	13.2	0.071	0.29	3.1	18.0
General	56-32	0.71	0.45	R	0.00	2.26	88.7	9.01	0.082	0.2	0.46	1.1
General	56-32	0.71	0.30	R	0.00	5.28	94.7	0.0	0.31	0.65	1.3	2.0
General	56-34	0.57	0.50	R	0.00	4.75	91.4	3.85	0.13	0.32	0.82	2.0
General	56-36	0.30	0.50	R	0.00	34.7	64.9	0.438	0.1	0.26	1	3.2
General	56-37	0.01	0.20	R	0.00	10.4	83.3	6.32	0.79	7.1	21	28.0
Ward	63-01	6.55	0.65	R	0.00	11.9	63.7	24.4	0.031	0.170	1.00	7.8
Ward	63-02	6.45	0.55	L	0.00	3.22	69.0	27.7	0.020	0.120	0.450	1.4
Ward	63-03	6.42	0.20	L	0.00	28.9	53.6	17.5	0.052	0.250	8.9	39.0
Ward	63-04	6.27	0.60	R	0.00	3.77	69.2	27.1	0.030	0.160	0.840	1.9
Ward	63-05	6.17	0.60	L	0.00	29.6	57.4	13.1	0.078	0.400	9.9	21.0
Ward	63-08	5.94	0.30	L	0.00	1.24	79.6	19.2	0.043	0.130	0.270	0.470
Ward	63-10	5.81	0.80	L	0.00	42.4	57.4	0.193	0.410	1.10	40.0	57.0
Ward	63-12	5.53	0.80	R	0.00	4.00	75.0	21.0	0.040	0.120	0.480	1.8
Ward	63-13	5.36	0.20	R	0.00	1.15	65.9	33.0	0.021	0.100	0.170	0.7
Ward	63-14	5.12	1.50	R	0.00	12.0	69.5	18.5	0.049	0.220	1.3	8.3
Ward	63-15	4.74	1.05	L	0.00	2.66	64.4	32.9	0.015	0.110	0.800	1.6
Ward	63-15	4.74	0.70	L	0.00	45.1	42.1	12.9	0.080	1.00	13.0	22.0
Ward	63-19	4.06	0.40	L	0.00	21.9	68.0	10.2	0.080	0.3	8.1	20.0
Ward	63-21	3.64	0.70	L	0.00	9.38	86.0	4.64	0.110	0.3	1.1	3.6
Ward	63-21	3.64	0.40	L	0.00	19.9	73.1	7.04	0.110	0.33	3.0	10.0
Ward	63-26	2.38	0.37	L	0.00	21.1	72.5	6.39	0.120	0.520	2.9	6.8
Ward	63-29	2.08	0.37	L	0.00	2.68	77.6	19.7	0.042	0.150	0.5	1.2
Ward	63-33	1.42	0.35	L	0.00	5.49	80.1	14.4	0.07	0.25	0.82	2.1
Ward	63-37	1.11	0.40	L	0.00	3.5	81.5	15.0	0.070	0.220	0.680	1.7

Stream	Station number	River kilometer	Depth in meters	Bank left or right	Percent grain size in millimeters				Particle sizes in millimeters			
					Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Ward	63-39	0.78	0.40	R	0.00	0.845	76.7	22.5	0.010	0.100	0.220	0.47
Ward	63-40	0.63	0.60	R	0.00	46.0	42.5	11.5	0.100	1.5	13.0	23.0
Ward	63-43	0.25	0.70	R	0.00	1.27	73.5	25.2	0.0	0.12	0.41	0.9
Ward	63-43	0.25	0.40	L	0.00	49.0	43.1	7.91	0.12	1.8	20.0	38.0

Table B-2. Bank toe material particle-size data for General, Incline and Ward Creeks and the Upper Truckee River (UTR).

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Incline	19-04	5.39	-	100	0.00	0.00	0.00	-	-	-	-
Incline	19-05	5.22	-	100	0.00	0.00	0.00	-	-	-	-
Incline	19-06	5.04	-	100	0.00	0.00	0.00	-	-	-	-
Incline	19-07	4.97	0/100	0.00	64.7	32.5	2.75	0.82	8.00	11.00	14.0
Incline	19-07	4.97	0/100	6.00	68.0	26.0	0.00	0.36	8.00	25.0	189
Incline	19-08	4.81	-	100	0.00	0.00	0.00	-	-	-	-
Incline	19-09	4.64	100/0	0.00	31.1	62.5	6.39	0.13	0.82	4.30	13.0
Incline	19-09	4.64	100/0	0.00	5.69	91.8	2.56	0.12	0.27	0.68	2.30
Incline	19-10	4.53	-	100	0.00	0.00	0.00	-	-	-	-
Incline	19-11	4.34	100/0	0.00	12.4	83.2	4.40	0.10	0.27	1.00	4.30
Incline	19-11	4.34	100/0	0.00	20.5	73.5	6.01	0.12	0.48	2.30	5.00
Incline	19-19	3.05	100/0	0.00	4.98	89.1	5.96	0.09	0.20	0.73	2.00
Incline	19-21	2.41	-	100	0.00	0.00	0.00	-	-	-	-
Incline	19-22	2.17	0/100	75.0	14.6	10.4	0.00	5.00	125	380	568
Incline	19-24	1.90	-	100	0.00	0.00	0.00	-	-	-	-
Incline	19-25	1.77	60/40	40.0	11.7	45.5	2.79	0.23	2.10	3000[1]	3000[1]
Incline	19-28	1.32	100/0	0.00	27.2	70.7	2.01	0.22	0.80	4.10	12.0
Incline	19-32	0.85	100/0	0.00	11.5	77.1	11.4	0.07	0.21	1.10	7.20
UTR	44-04	23.0	100/0	0.00	1.01	91.5	7.51	0.100	0.230	0.480	0.880
UTR	44-04	23.0	100/0	0.00	0.00	80.2	19.8	0.042	0.110	0.340	0.730
UTR	44-04	23.0	0/100	20.0	74.0	6.00	0.00	9.00	25.0	72.0	111
UTR	44-06	22.5	100/0	0.00	26.40	69.8	3.76	0.140	0.400	5.20	13.0
UTR	44-12	20.7	22/78	33.9	43.1	21.7	1.33	0.470	45.0	95.0	155
UTR	44-15	19.9	100/0	0.00	1.68	74.3	24.0	0.033	0.130	0.530	1.20
UTR	44-16	19.3	100/0	0.00	23.3	71.8	4.96	0.130	0.520	3.50	8.60
UTR	44-17	18.6	0/100	5.00	83.0	12.0	0.0	5.00	26.0	52.0	62.0
UTR	44-20	17.8	100/0	0.00	0.394	74.0	25.6	0.037	0.120	0.380	1.00
UTR	44-21	16.9	100/0	0.00	2.56	92.3	5.13	0.090	0.200	0.410	0.770
UTR	44-22	15.9	100/0	0.00	6.36	87.2	6.39	0.110	0.240	0.510	1.40
UTR	44-24	15.3	0/100	27.0	57.0	7.00	9.00	0.350	21.0	73.0	107
UTR	44-26	14.8	100/0	0.00	0.966	77.5	21.5	0.040	0.120	0.330	0.700
UTR	44-30	14.1	16/84	1.04	83.0	15.7	0.274	1.80	11.0	31.0	42.0
UTR	44-39	13.5	100/0	0.00	4.01	78.2	17.8	0.052	0.1	0.540	1.80
UTR	44-43	13.1	100/0	0.00	0.00	76.5	23.5	0.024	0.200	1.00	1.50

Stream	**Station number**	**River kilometer**	**Percent particle size/percent particle count**	**Percent grain size in millimeters**				**Particle sizes in millimeters**			
				Boulder/ Cobble > 64	**Gravel 2 - 64**	**Sand 0.062 - 2**	**Silt and Clay < 0.062**	**D_{16}**	**D_{50}**	**D_{84}**	**D_{95}**
UTR	44-59	12.1	70/30	0.00	46.3	49.2	4.51	0.120	0.500	45.0	60.0
UTR	44-67	11.2	0/100	4.00	88.0	8.00	0.00	7.00	30.0	53.0	61.0
UTR	44-68	10.8	100/0	0.00	9.30	83.2	7.52	0.098	0.210	0.480	7.80
UTR	44-72	10.0	100/0	0.00	5.96	79.0	15.1	0.069	0.190	0.540	2.70
UTR	44-75	8.50	100/0	0.00	0.00	94.4	5.64	0.120	0.300	0.600	1.00
UTR	44-78	7.14	100/0	0.00	0.888	81.0	18.1	0.045	0.170	0.370	0.500
UTR	44-82	5.84	0/100	62.0	28.0	10.0	0.00	7.00	110	210	250
UTR	44-85	5.06	100/0	0.00	0.00	74.7	25.3	0.023	0.150	0.990	1.70
UTR	44-92	2.94	100/0	0.00	14.0	74.1	11.8	0.079	0.320	1.70	8.00
General	56-14	4.21	55/45	43.2	1.8	50.7	4.30	0.12	0.61	205	330
General	56-16	3.62	18/82	28.0	54.0	14.9	3.11	0.7	27.0	80.0	174
General	56-18	3.59	0/100	71.1	15.6	13.3	0.0	15.0	155	350	520
General	56-19	3.25	100/0	0.00	29.1	62.7	8.29	0.1	0.4	7.4	13.0
General	56-21	2.58	-	100	0.00	0.00	0.00	-	-	-	-
General	56-24	1.94	100/0	0.00	38.2	45.9	15.9	0.066	0.41	38.0	52.0
General	56-29	0.95	0/100	49.0	44.9	6.12	0.00	28.0	66.0	150	870
General	56-36	0.30	100/0	0.00	8.29	86.2	5.56	0.11	0.25	0.7	4.0
Ward	63-01	6.55	0/100	43.0	52.0	5.00	0.00	31.0	53.0	106	150
Ward	63-02	6.45	0/100	24.0	70.0	6.00	0.00	9.00	32.0	77	112
Ward	63-03	6.42	0/100	24.5	55.1	20.4	0.00	0.360	25.0	85.0	232
Ward	63-03	6.42	0/100	90.0	10.0	0.00	0.00	70.0	145	260	300
Ward	63-04	6.27	100/0	0.00	2.80	77.0	20.3	0.0	0.180	0.68	1.50
Ward	63-05	6.17	100/0	0.00	0.00	58.5	41.5	0.0	0.090	0.50	1.10
Ward	63-06	6.10	0/100	52.0	41.0	7.00	0.00	22.0	70.0	110	125
Ward	63-08	5.94	100/0	0.00	7.86	77.4	14.8	0.067	0.200	0.61	5.10
Ward	63-13	5.36	0/100	85.0	15.0	0.00	0.00	70.0	120	165	190
Ward	63-14	5.12	100/0	0.00	17.3	66.4	16.4	0.062	0.270	2.30	9.30
Ward	63-15	4.74	0/100	86.6	13.4	0.00	0.00	68.0	140	220	330
Ward	63-16	4.52	-	100	0.00	0.00	0.00	-	-	-	-
Ward	63-18	4.25	100/0	0.00	35.6	51.2	13.2	0.077	0.700	8.00	13.0
Ward	63-19	4.06	0/100	50.5	44.0	5.49	0.00	25.5	63.5	250	340
Ward	63-22	3.51	0/100	37.0	61.0	2.00	0.00	25.0	53.0	90.0	140
Ward	63-23	3.28	-	100	0.00	0.00	0.00	-	-	-	-
Ward	63-25	2.64	0/100	42.4	53.5	4.04	0.00	11.0	54.0	175	305
Ward	63-26	2.38	0/100	28.6	65.3	6.12	0.00	11.0	36.0	120	170
Ward	63-29	2.08	0/100	42.4	49.5	8.08	0.00	15.0	45.0	190	400
Ward	63-30	1.97	0/100	65.3	28.6	6.12	0.00	38.0	85.0	160	350

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Ward	63-32	1.55	0/100	76.1	18.5	5.43	0.00	30.0	235	385	525
Ward	63-33	1.42	0/100	40.0	53.0	7.00	0.00	22.0	47.0	110	170
Ward	63-34	1.29	0/100	50.5	34.7	14.7	0.00	19.0	76.0	195	350
Ward	63-35	1.14	0/100	46.5	49.5	4.04	0.00	11.0	60.0	113	225
Ward	63-37	1.11	0/100	73.2	25.8	1.03	0.00	38.0	167	310	400
Ward	63-41	0.51	0/100	69.1	26.8	4.12	0.00	28.0	100	243	395
Ward	63-43	0.25	0/100	69.7	28.3	2.02	0.00	37.0	120	212	295
Ward	63-44	0.09	0/100	34.0	55.0	8.00	3.00	7.00	41.0	99.0	180

Table B-3. Bed material particle-size data for all streams.

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Tahoe State Park	01-01	0.02	0/100	36.0	62.0	2.00	0.00	26.0	52.0	95.0	133
Tahoe State Park	01-02	0.90	50/50	22.0	38.7	35.4	3.87	0.19	51.0	104	118
Burton	02-01	0.26	0/100	16.0	84.0	0.00	0.00	18.0	40.0	63.0	91.0
Burton	02-02	0.85	0/100	52.0	48.0	0.00	0.00	37.0	65.0	157	186
Barton	03-01	0.41	100/0	0.00	31.8	67.9	0.23	0.55	1.25	3.1	4.9
Lake Forest	04-01	0.02	0/100	0.00	92.0	8.00	0.00	10.0	21.0	30.0	40.0
Dollar	05-01	0.31	0/100	24.0	74.0	2.00	0.00	19.0	43.0	81.0	133
Dollar	05-02	1.22	0/100	4.0	88.0	8.00	0.00	8.00	25.0	34.0	55.0
Watson	07-01	0.04	0/100	32.0	68.0	0.00	0.00	16.0	41.0	102	247
Watson	07-02	1.11	0/100	44.0	56.0	0.00	0.00	16.0	42.0	110	145
Carnelian Bay	08-01	0.11	0/100	22.0	78.0	0.00	0.00	28.0	39.0	71.0	85.0
Carnelian Canyon	09-01	0.03	0/100	0.00	100.0	0.00	0.00	7.0	19.0	32.0	37.0
Carnelian Canyon	09-02	1.30	0/100	0.00	100.0	0.00	0.00	5.0	13.0	22.0	29.0
Tahoe Vista	10-01a	0.11	0/100	8.0	92.0	0.00	0.00	12.0	29.0	41.0	72.0
Tahoe Vista	10-02	1.27	100/0	0.00	45.2	52.0	2.71	0.20	1.40	8.6	10.2
Griff	11-01	0.09	0/100	0.00	98.0	2.00	0.00	123	250	356	437
Griff	11-02	0.94	0/100	0.00	86.0	14.0	0.00	13.0	50.0	95	187
Griff	11-03	1.93	0/100	0.00	100.0	0.00	0.00	47.0	116	252	362
Griff	11-04	3.06	0/100	0.00	92.0	8.00	0.00	14.0	129	455	522
Griff	11-06	1.91	0/100	6.0	86.0	8.00	0.00	6.00	16.0	36.0	58.0
Kings Beach	12-01	0.08	26/74	26.0	48.0	25.9	0.09	0.31	16.0	66.0	136
First	14-02	0.25	16/84	-	-	-	-	-	50.0	310	425
First	14-04	0.78	24/76	-	-	-	-	-	161	331	400
First	14-06	1.92	0/100	92.0	4.0	4.00	0.00	130	202	330	418
Second	15-01	0.18	0/100	50.0	32.0	18.0	0.00	6.00	68.0	184	227
Second	15-02	1.19	40/60	-	-	-	-	-	22.0	372	547
Burnt	16-01	0.13	0/100	44.0	46.0	10.0	0.00	12.0	43.0	170	294
Burnt	16-03	2.17	100/0	0.00	6.0	91.2	2.86	0.140	0.43	1.20	2.10
Wood	17-01	0.06	0/100	86.0	4.0	10.0	0.00	65.0	141	288	404
Third	18-01	0.05	28/72	2.0	70.0	27.8	0.19	0.490	24.0	44.0	60.0
Third	18-02	0.59	0/100	12.0	84.0	4.00	0.00	25.0	35.0	60.0	91.0
Third	18-03	1.15	0/100	70.0	16.0	14.0	0.00	35.0	160	668	1094
Third	18-04	2.97	0/100	66.0	26.0	8.00	0.00	23.0	160	392	710
Third	18-08	7.61	28/72	-	-	-	-	-	62.0	200.0	410.0
Third	18-09	8.10	42/58	20.0	38.0	42.0	0.00	0.78	9.40	78.0	282
Third	18-10	2.31	20/80	2.00	70.0	27.5	0.47	0.41	24.00	44.0	60.0

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Incline	19-01	5.69	19/81	7.00	74.0	19.0	0.00	1.1	24.00	39.0	82.0
Incline	19-02	5.61	22/78	2.00	76.0	22.0	0.00	0.6	8.00	36.0	54.0
Incline	19-03	5.44	24/76	0.00	76.0	23.9	0.081	0.7	6.00	12.0	36.5
Incline	19-04	5.39	29/71	35.0	36.0	28.1	0.876	0.6	47.0	46.0	170
Incline	19-05	5.22	0/100	18.6	68.6	12.8	0.00	4.0	20.0	100	610
Incline	19-06	5.04	13/87	-	-	-	-	3.50	66.0	250	1635
Incline	19-07	4.97	24/76	24.4	51.6	23.7	0.328	0.70	10.4	3000[1]	3000[1]
Incline	19-08	4.81	0/100	47.9	37.2	14.9	0.00	3.00	70.0	290	3000[1]
Incline	19-09	4.64	17/83	24.0	59.0	16.9	0.058	1.60	11.0	85.0	126
Incline	19-10	4.53	0/100	18.2	71.7	9.09	1.01	4.00	26.0	76.0	130
Incline	19-11	4.34	0/100	5.0	80.0	15.0	0.00	3.00	20.0	50.0	64.0
Incline	19-12	4.22	15/85	38.3	46.8	14.9	0.05	3.0	51.00	112.0	1660.0
Incline	19-13	4.05	0/100	7.0	83.0	10.0	0.00	8.00	30.0	53	78
Incline	19-14	3.78	50/50	28.6	21.4	50.0	0.00	0.65	56.00	98.0	212.5
Incline	19-15	3.54	0/100	100	0.00	0.00	0.00	-	-	-	-
Incline	19-16	3.53	0/100	0.00	54.3	45.3	0.306	0.350	2.20	8.0	14.0
Incline	19-17	3.42	50/50	11.2	33.7	53.1	2.04	0.810	15.00	59.0	89.0
Incline	19-18	3.40	100/0	0.00	0.571	99.4	0.00	2.0	9.10	41.0	65.0
Incline	19-19	3.05	16/84	4.36	79.6	15.9	0.0541	1.90	8.10	42.0	61.0
Incline	19-21	2.41	0/100	100	-	-	-	-	3000[1]	3000[1]	3000[1]
Incline	19-22	2.17	0/100	75.0	14.6	10.4	0.00	5.00	125	380	568
Incline	19-23	2.06	54/46	25.0	21.0	52.9	1.09	0.200	1.10	146.0	290
Incline	19-24	1.90	25/75	75.0	6.4	18.6	0.00	1.50	3000[1]	3000[1]	3000[1]
Incline	19-25	1.77	40/60	60.0	7.0	33.0	0.00	0.88	3000[1]	3000[1]	3000[1]
Incline	19-26	1.61	22/78	16.0	62.0	20.3	1.68	0.450	8.00	64.0	129
Incline	19-27	1.55	75/25	4.8	20.2	75.0	0.00	0.540	1.00	20.0	64.0
Incline	19-28	1.32	0/100	37.8	49.0	13.3	0.00	3.00	26.0	160	230
Incline	19-29	1.22	18/82	-	-	-	-	-	6.00	8.0	10.0
Incline	19-31	1.08	39/61	42.7	18.3	33.8	5.19	0.220	20.0	180	300
Incline	19-32	0.85	16/84	57.0	27.0	15.8	0.163	2.00	73.0	150	210
Incline	19-33	0.72	44/56	31.0	25.0	43.9	0.149	0.550	19.0	110	215
Incline	19-34	0.57	28/72	39.0	39.0	21.3	0.664	1.00	60.0	120	204
Incline	19-35	0.40	0/100	62.0	24.0	14.0	0.00	9.0	84.0	115	186
Incline	19-36	0.26	100/0	0.00	24.1	75.7	0.255	0.410	0.890	10.0	23
Incline	19-37	0.21	20/80	38.0	42.0	19.9	0.137	1.20	49.5	215	629
Incline	19-38	0.16	18/82	48.0	34.0	18.0	0.00	1.30	54.0	153	206
Mill	20-01	0.01	100/0	0.00	16.6	82.5	0.9	0.4	1.0	2.0	3.2

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Tunnel	21-01	0.07	100/0	0.00	29.6	69.2	1.18	0.30	1.10	3.0	5.1
Tunnel	21-02	1.22	49/51	17.0	34.0	48.7	0.33	0.42	2.07	75.0	230
Bonpland	22-01	0.07	20/80	80.0	16.1	3.90	0.03	17.00	3000[1]	3000[1]	3000[1]
Marlette	24-01	0.01	22/78	55.0	23.0	22.0	0.00	1.20	74.0	145	220
Marlette	24-02	0.92	41/59	28.0	31.0	40.4	0.55	0.51	5.00	100	160
Marlette	24-03	1.28	100/0	0.00	19.6	79.6	0.82	0.22	0.70	2.1	4.0
Secret Harbor	25-01	0.20	100/0	0.00	79.0	21.0	0.00	1.40	9.60	39.0	44.0
Secret Harbor	25-02	0.55	100/0	0.00	53.1	44.7	2.23	0.21	2.04	5.1	7.0
Secret Harbor	25-05	0.04	100/0	0.00	29.6	67.7	2.64	0.25	0.90	3.8	45.0
Secret Harbor	25-06	1.27	100/0	0.00	12.7	85.8	1.48	0.30	0.82	1.8	3.7
Bliss	26-01	0.39	100/0	0.00	60.8	39.1	0.13	0.60	2.60	6.1	8.0
Bliss	26-02	1.20	100/0	0.00	44.2	55.8	0.00	0.49	1.50	5.0	7.1
Dead Mans Point	27-01	0.04	100/0	0.00	35.9	62.6	1.53	0.31	1.04	15.0	25.0
Dead Mans Point	27-02	0.59	100/0	0.00	21.6	77.4	1.06	0.25	0.87	2.6	5.5
Slaughterhouse	28-01	0.23	100/0	0.00	7.0	90.5	2.51	0.12	0.31	0.8	2.8
Slaughterhouse	28-02	2.25	100/0	0.00	67.7	32.2	0.11	0.90	4.10	10.5	17.0
Slaughterhouse	28-03	4.51	100/0	0.00	8.3	91.1	0.62	0.22	0.60	1.5	2.5
Glenbrook	29-02	0.76	100/0	0.00	64.6	35.2	0.24	0.52	5.00	15.0	26.0
Glenbrook	29-03	2.70	0/100	45.0	47.0	8.00	0.00	8.00	56.0	95.0	120
Glenbrook	29-06	3.35	16/84	41.1	42.9	15.7	0.27	2.00	28.0	60.0	100
North Logan House	30-02	0.48	35/65	19.0	46.0	34.3	0.71	0.39	19.0	66.0	240
Logan House	31-04	3.02	100/0	0.00	49.4	50.1	0.52	0.80	2.00	3.3	4.1
Logan House	31-08	1.71	100/0	0.00	87.9	12.1	0.04	2.50	10.03	21.0	30.0
Logan House	31-10	1.21	100/0	0.00	51.4	48.1	0.50	0.43	2.03	6.1	10.0
Cave Rock	32-02	0.09	100/0	0.00	37.8	62.2	0.00	0.30	1.10	4.3	11.0
Cave Rock	32-01	0.19	100/0	0.00	32.2	61.7	6.06	0.11	0.49	10.0	22.0
Cave Rock	32-04	0.89	100/0	0.00	50.6	49.4	0.00	0.32	2.01	10.0	15.0
Lincoln	33-01	0.22	100/0	0.00	28.2	69.1	2.70	0.20	0.82	3.2	6.6
Lincoln	33-02	1.19	8/92	47.0	45.0	7.92	0.08	4.00	56.0	280	490
North Zephyr	35-01	0.28	100/0	0.00	23.4	69.3	7.32	0.11	0.42	3.0	5.3
North Zephyr	35-02	1.26	100/0	0.00	35.2	64.1	0.652	0.26	0.90	4.2	8.0
Zephyr	37-02	0.99	100/0	0.00	39.4	58.4	2.22	0.24	1.06	3.2	5.8
McFaul	38-01	0.52	100/0	0.00	36.8	63.0	0.22	0.51	1.11	3.1	5.2
McFaul	38-02	1.69	0/100	50.0	0.00	50.0	0.00	0.36	160	680	1220
McFaul	38-04	3.23	100/0	0.00	18.2	75.1	6.65	0.41	1	3	4
Burke	39-01	0.13	100/0	0.00	19.1	80.9	0.00	0.60	1	2	3
Burke	39-02	1.58	85/15	3.8	11.3	83.6	1.42	0.20	0.60	2.0	45.0

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Burke	39-04	3.21	100/0	0.00	0.00	98.6	1.38	0.40	1.01	1.5	1.8
Burke	39-09	6.25	100/0	0.00	36.1	56.6	7.31	0.10	0.69	31.0	45.0
Edgewood	40-01	7.22	100/0	0.00	30.2	66.3	3.56	0.201	0.710	3.9	10.0
Edgewood	40-02	7.21	100/0	0.00	22.7	71.5	5.76	0.12	0.46	2.9	6.1
Edgewood	40-03	7.23	100/0	0.00	53.8	46.1	0.157	0.745	2.01	4.6	7.0
Edgewood	40-05	6.41	100/0	0.00	19.4	80.3	0.271	0.310	0.70	2.2	5.45
Edgewood	40-11	6.15	100/0	0.00	37.8	59.6	2.52	0.350	1.10	4.00	7.0
Edgewood	40-19	4.96	100/0	0.00	24.9	66.8	8.32	0.120	0.88	3.00	5.90
Edgewood	40-27	1.20	100/0	0.00	37.3	62.4	0.212	0.300	0.750	3.80	6.5
Edgewood	40-27a	0.20	100/0	0.00	82.9	17.0	0.0574	0.160	12.0	21.0	30.0
Edgewood[2]	-	-	100/0	0.00	35.6	63.7	0.650	0.130	0.89	3.00	5.9
Edgewood[2]	-	-	100/0	0.00	40.2	58.4	1.42	0.300	1.4	11.0	41.0
Bijou Park	41-01	1.32	100/0	0.00	23.7	75.8	0.516	0.103	0.7	3.0	6.0
Bijou Park	41-02	1.88	100/0	0.00	21.2	69.6	9.14	0.207	0.6	2.8	6.0
Bijou	42-01	0.54	100/0	0.00	23.4	74.3	2.33	0.18	0.50	3.0	5.2
Bijou	42-02	2.16	100/0	0.00	7.8	90.0	2.17	0.09	0.50	1.2	3.0
Bijou	42-03	3.44	100/0	0.00	33.1	62.2	4.75	0.10	1.01	6.4	13.0
Trout	43-01	1.45	75/25	0.00	0.00	100	0.00	0.30	0.59	360	470
Trout	43-02	2.49	100/0	0.00	60.1	39.9	0.00	0.48	2.40	5.4	7.1
Trout	43-03	4.71	25/75	-	-	-	-	-	11.0	20.0	26.0
Trout	43-04	7.05	100/0	0.00	50.9	49.1	0.00	0.21	2.00	4.0	6.1
Trout	43-06	7.47	100/0	0.00	76.4	23.4	0.16	0.70	4.20	7.3	11.0
Trout	43-07	8.13	40/60	60.0	21.0	19.0	0.0	1.3	22.0	65.0	180
Upper Truckee	44-01	24.2	0/100	40.0	45.0	15.0	0.00	6.00	45.0	95.0	130
Upper Truckee	44-04	23.0	0/100	11.0	81.0	8.00	0.00	8.00	30.0	59.0	77.0
Upper Truckee	44-06	22.5	0/100	28.0	72.0	0.00	0.00	40.0	56.0	77.0	91.0
Upper Truckee	44-08	21.8	0/100	50.0	40.5	9.52	0.00	9.00	55.0	545	1150
Upper Truckee	44-11	21.4	18/82	43.6	38.4	17.9	0.06	1.10	38.0	510	720
Upper Truckee	44-12	20.7	23/77	8.0	69.0	22.8	0.16	0.50	17.0	46.0	75.0
Upper Truckee	44-15	19.9	20/80	11.0	69.0	20.00	0.00	0.88	30.0	57.0	71.0
Upper Truckee	44-16	19.3	0/100	9.0	87.0	3.00	1.00	10.0	32.0	52.0	71.0
Upper Truckee	44-17	18.6	0/100	10.0	80.0	10.0	0.00	5.00	21.0	52.0	70.0
Upper Truckee	44-19	18.0	0/100	66.0	27.7	6.38	0.00	18.0	115	460	770
Upper Truckee	44-20	17.8	0/100	24.0	66.0	10.0	0.00	15.0	41.0	72.0	84.0
Upper Truckee	44-21	16.9	0/100	40.0	48.8	11.3	0.00	4.00	27.0	320	1400
Upper Truckee	44-22	15.9	0/100	27.0	58.0	15.0	0.00	3.00	30.0	85.0	108
Upper Truckee	44-24	15.3	0/100	27.0	70.0	3.00	0.00	10.00	37.0	80.0	121

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Upper Truckee	44-26	14.8	0/100	21.0	65.0	14.0	0.00	5.00	42.0	66.0	76.0
Upper Truckee	44-30	14.1	0/100	25.0	64.0	11.0	0.00	4.00	45.0	73.0	90.0
Upper Truckee	44-39	13.5	0/100	1.0	91.0	8.00	0.00	6.00	17.0	30.0	40.0
Upper Truckee	44-43	13.1	0/100	7.0	79.0	14.0	0.00	3.00	26.0	51.0	67.0
Upper Truckee	44-59	12.1	36/64	19.3	44.7	36.0	0.00	0.79	7.85	67.0	95.0
Upper Truckee	44-67	11.2	0/100	14.0	75.0	11.0	0.00	5.00	27.0	63.0	70.0
Upper Truckee	44-68	10.8	100/0	0.00	53.8	45.9	0.32	0.53	2.20	9.0	12.0
Upper Truckee	44-72	10.0	29/71	1.0	70.0	29.0	0.00	0.60	9.86	24.0	31.0
Upper Truckee	44-75	8.50	100/0	0.00	34.3	64.6	1.11	0.06	0.20	0.9	1.4
Upper Truckee	44-78	7.14	100/0	0.00	69.5	30.3	0.21	0.62	5.00	17.0	28.0
Upper Truckee	44-82	5.84	100/0	0.00	67.5	32.5	0.00	0.560	10.0	37.0	53.0
Upper Truckee	44-85	5.06	100/0	0.00	0.00	77.8	22.2	0.04	0.11	0.4	1.0
Upper Truckee	44-87	4.51	100/0	0.00	74.4	25.5	0.09	0.84	4.80	12.0	22.0
Upper Truckee	44-92	2.94	100/0	0.00	25.9	70.3	3.8	0.1	0.6	4.2	12.0
Taylor	46-01	0.90	0/100	44.0	50.0	6.0	0.0	15.0	52.0	120	185
Taylor	46-02	2.33	8/92	64.0	28.0	8.0	0.0	17.0	90.0	157	285
Tallac	47-01	1.37	0/100	22.0	77.0	1.00	0.00	20.0	40.0	72.0	122
Tallac	47-02	2.20	0/100	40.0	60.0	0.00	0.00	25.0	55.0	115	153
Tallac	47-03	2.55	20/80	8.5	71.5	19.9	0.07	0.81	14.0	52.0	64.0
Tallac	47-04	3.05	0/100	50.0	42.0	8.00	0.00	6.00	62.0	160	350
Tallac	47-05	2.95	50/50	2.0	48.0	47.3	2.69	0.51	4.00	52.0	62.0
Cascade	48-01	0.69	10/90	-	-	-	-	3000[1]	3000[1]	3000[1]	3000[1]
Eagle	49-01	0.58	0/100	42.0	58.0	0.00	0.00	21.0	54.0	88.0	121
Rubicon	51-01	0.92	25/75	0.00	75.0	24.81	0.19	0.67	7.00	19.0	31.0
Rubicon	51-02	1.27	100/0	0.00	12.5	87.2	0.3	0.1	0.2	0.6	2.9
Rubicon	51-03	1.60	100/0	0.00	62.1	37.9	0.00	1.04	2.30	5.0	7.0
Rubicon	51-04	1.71	50/50	50.0	13.2	36.7	0.13	0.61	16.0	3000[1]	3000[1]
Paradise Flat	52-01	0.62	100/0	0.00	34.7	65.3	0.00	0.80	1.50	3.45	6.2
Lonely Gulch	53-01	0.81	0/100	21.0	72.0	7.0	0.0	18.0	42.0	80.0	115
Lonely Gulch	53-02	1.24	0/100	35.0	62.0	3.0	0.00	18	52	91.0	161
Sierra	54-01	0.89	50/50	34.0	16.0	49	1.37	0.3	4.0	109	175
Meeks	55-01	1.23	0/100	0.00	100	0.00	0.00	20.0	30.0	41.0	47
Meeks	55-03	3.50	0/100	2.0	96.0	2.0	0.0	17.0	32.0	40.0	45.5
Meeks	55-04	3.50	30/70	4.2	65.8	29.7	0.30	0.8	21.5	39.0	50.0
General	56-01	6.80	0/100	58.0	39.0	3.00	0.00	18.0	80.0	180	480
General	56-02	6.66	5/95	61.2	33.9	5.00	0.00	11.0	3000[1]	3000[1]	3000[1]
General	56-03	6.50	0/100	70.8	29.2	0.00	0.00	0.36	91.0	251	532

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
General	56-05	6.06	0/100	22.0	73.0	5.00	0.00	18.0	35.0	70.0	95.0
General	56-06	5.90	17/83	14.0	69.0	17.0	0.00	1.80	26.0	60.0	77.0
General	56-08	5.33	0/100	74.0	24.0	2.00	0.00	40.0	99.0	218	335
General	56-09	5.25	0/100	46.0	54.0	0.00	0.00	17.0	56.0	150	220
General	56-12	4.73	0/100	2.00	89.0	9.00	0.00	8.00	21.0	38.0	54.0
General	56-14	4.21	0/100	40.0	56.0	4.00	0.00	27.0	50.0	142	177
General	56-16	3.62	18/82	0.00	82.0	18.0	0.00	1.30	9.10	21.0	26.0
General	56-17	3.60	16/84	38.0	46.0	14.7	1.32	0.70	27.0	80.0	174
General	56-18	3.59	0/100	71.8	20.51	7.69	0.00	39.0	107	323	531
General	56-19	3.25	0/100	44.0	49.5	6.59	0.00	14.0	55.0	142	395
General	56-20	2.90	0/100	40.0	52.0	8.00	0.00	10.0	31.0	230	290
General	56-21	2.58	50/50	36.7	13.3	49.8	0.17	0.60	2.00	310	495
General	56-24	1.94	20/80	11.0	69.0	19.9	0.07	0.79	10.0	41.0	67.0
General	56-23	2.20	0/100	57.0	39.0	4.00	0.00	32.0	72.0	125	210
General	56-26	1.93	34/66	50.0	15.0	35.0	0.00	0.60	64.0	115	155
General	56-27	1.54	16/84	56.0	28.0	16.0	0.00	1.90	47.0	125	165
General	56-28	1.17	0/100	68.0	24.0	8.00	0.00	4.00	97.0	128	160
General	56-29	0.95	0/100	49.0	44.9	6.12	0.00	28.0	66.0	150	870
General	56-30	0.89	23/77	4.00	73.0	18.0	5.02	0.34	15.0	41.0	61.0
General	56-32	0.71	0/100	30.6	61.2	8.12	0.00	8.30	30.4	147	467
General	56-34	0.57	100/0	0.00	0.41	98.6	1.02	0.17	0.34	0.7	0.9
General	56-36	0.30	0/100	37.0	60.0	3.00	0.00	31.0	52.0	86.0	113
General	56-37	0.01	21/79	7.00	72.0	21.0	0.00	0.82	20.0	50.0	70
McKinney	57-01	0.28	0/100	36.0	64.0	0.00	0.00	25.0	58.0	87.0	134
McKinney	57-02	1.25	0/100	80.0	20.0	0.00	0.00	62.0	121	190	265
Quail Lane	58-01	0.02	0/100	60.0	40.0	0.00	0.00	32.0	74.0	119	147
Quail Lane	58-02	0.21	0/100	32.0	66.0	2.0	0.00	25.0	50.0	80.0	111
Homewood	59-01	0.09	0/100	30.0	66.0	4.0	0.00	25.0	39.0	91.0	104
Homewood	59-02	0.41	0/100	48.0	50.0	2.0	0.00	26.0	60.0	155	255
Madden	60-1	0.10	0/100	88.0	12.0	0.00	0.00	71.0	149	245	264
Blackwood	62-04	8.19	0/100	65.2	31.9	2.90	0.00	27.0	120	200	3000[1]
Blackwood	62-05	7.18	28/72	46.0	26.0	26.8	1.22	0.44	41.0	255	340
Blackwood	62-07	7.17	0/100	47.1	42.9	10.0	0.00	5.00	62.0	170	305
Blackwood	62-08	6.51	0/100	50.5	42.3	7.22	0.00	11.0	65.0	115	160
Blackwood	62-12	5.08	0/100	52.0	42.0	6.00	0.00	6.00	70.0	160	220
Blackwood	62-15	4.15	0/100	40.0	52.0	8.00	0.00	16.0	51.0	96.0	132
Blackwood	62-18	3.95	0/100	14.3	79.6	6.12	0.00	9.00	26.0	60.0	115

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Blackwood	62-24	1.77	0/100	14.3	84.4	1.30	0.00	15.0	40.0	63.0	86.0
Blackwood	62-30	0.32	0/100	8.42	75.8	15.8	0.00	2.00	28.0	55.0	69.0
Blackwood	62-32	0.00	0/100	7.00	92.0	1.00	0.00	21.0	35.0	52.0	65.0
Ward	63-01	6.55	0/100	63.0	36.0	1.00	0.00	32	80	145	170
Ward	63-02	6.45	0/100	67.0	30.0	3.00	0.00	20	96	170	210
Ward	63-03	6.42	0/100	51.0	36.0	13.0	0.00	9	65	142	190
Ward	63-04	6.27	0/100	51.0	40.0	9.00	0.00	8	67	130	160
Ward	63-05	6.17	0/100	53.0	44.0	3.00	0.00	35	65	122	135
Ward	63-09	5.87	0/100	50.0	40.0	10.0	0.00	8	63	115	147
Ward	63-06	6.10	0/100	38.0	57.0	5.00	0.00	13	48	130	180
Ward	63-10	5.81	0/100	19.6	76.3	4.12	0.00	11.0	35.0	74.0	105
Ward	63-12	5.53	0/100	16.0	76.0	8.00	0.00	5.00	32.0	61.0	81.0
Ward	63-13	5.36	0/100	81.8	17.2	1.01	0.00	55.0	120	220	300
Ward	63-14	5.12	0/100	59.6	30.9	9.57	0.00	12.0	85.0	165	225
Ward	63-15	4.74	0/100	86.9	11.1	2.02	0.00	69.0	120	205	270
Ward	63-16	4.52	0/100	73.0	26.0	1.00	0.00	46.0	105	240	300
Ward	63-18	4.25	0/100	56.8	33.7	9.47	0.00	15.0	81.0	300	430
Ward	63-19	4.06	0/100	53.7	41.1	5.26	0.00	14.0	75.0	248	410
Ward	63-21	3.64	0/100	40.0	58.0	2.00	0.00	26.0	55.0	110	170
Ward	63-22	3.51	0/100	37.0	61.0	2.00	0.00	25.0	53.0	90.0	140
Ward	63-23	3.28	0/100	35.0	62.0	3.00	0.00	25.0	52.0	110	145
Ward	63-25	2.64	0/100	49.0	46.9	4.08	0.00	11.0	53.0	235	340
Ward	63-26	2.38	0/100	58.3	41.7	0.00	0.00	26.5	90.0	260	425
Ward	63-29	2.08	0/100	51.6	46.2	2.20	0.00	12.5	65.0	315	650
Ward	63-30	1.97	0/100	52.3	40.7	6.98	0.00	11.0	84.0	340	3000[1]
Ward	63-32	1.55	0/100	54.7	41.9	3.49	0.00	21.0	90.0	385	595
Ward	63-33	1.42	0/100	53.8	38.5	7.69	0.00	31.0	91.0	328	465
Ward	63-34	1.29	0/100	68.9	28.9	2.22	0.00	36.0	86.0	245	500
Ward	63-35	1.14	0/100	46.5	49.5	4.04	0.00	11.0	60.0	113	225
Ward	63-37	1.11	0/100	73.2	25.8	1.03	0.00	38.0	167	310	400
Ward	63-40	0.63	0/100	59.4	39.6	1.04	0.00	21.0	117	250	457
Ward	63-41	0.51	0/100	42.9	51.0	6.12	0.00	9.00	53.0	160	310
Ward	63-43	0.25	0/100	69.7	28.3	2.02	0.00	37.0	120	212	295
Ward	63-44	0.09	0/100	48.0	43.0	9.00	0.00	17.0	62.0	115	160

[1] A Value of 3000 mm was given to boulders over 2 m that were not measured and to bedrock.

[2] Particle size labels partially destroyed in transit and site name unknown.

Table B-4. Bank face material particle-size data for all streams.

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Burton	02-01	0.26	100/0	0.00	39.0	52.3	8.68	0.140	1.04	5.50	10.0
Burton	02-02	0.85	50/50	50.0	28.7	19.3	2.07	0.900	31.0	3000[1]	3000[1]
Barton	03-02	1.06	100/0	0.00	69.5	28.6	1.93	0.600	4.80	11.5	20.5
Lake Forest	04-01	0.02	100/0	0.00	63.0	33.8	3.19	0.400	4.10	10.3	24.0
Dollar	05-02	1.22	100/0	0.00	78.0	21.2	0.84	0.780	8.08	20.8	28.0
Cedar Flats	06-01	0.06	20/80	80.0	10.3	8.8	0.85	10.7	3000[1]	3000[1]	3000[1]
Cedar Flats	06-02	0.67	50/50	50.0	28.9	20.0	1.10	0.910	32.0	3000[1]	3000[1]
Carnelian Bay	08-01	0.11	100/0	0.00	25.6	71.4	3.05	0.245	0.99	4.00	10.0
Carnelian Canyon	09-01	0.03	100/0	0.00	41.9	55.2	2.82	0.300	1.45	5.50	10.0
Tahoe Vista	10-01b	0.02	100/0	0.00	5.47	92.9	1.59	0.12	0.20	0.40	2.10
Griff	11-06	1.91	100/0	0.00	67.2	30.0	2.77	0.29	0.50	11.0	16.0
Kings Beach	12-01	0.08	100/0	0.00	10.2	86.4	3.39	0.15	0.30	0.80	5.00
First	14-05	1.92	100/0	0.00	8.13	89.7	2.19	0.30	0.90	1.60	2.50
First	14-06	1.92	100/0	0.00	62.5	35.5	2.06	0.50	3.80	10.3	24.0
Second	15-01	0.18	100/0	0.00	37.0	61.7	1.28	0.480	1.50	7.00	20.0
Burnt	16-01	0.13	100/0	0.00	23.9	73.2	2.84	0.285	1.00	3.00	5.8
Burnt	16-02	1.25	100/0	0.00	33.3	62.4	4.24	0.20	0.80	5.50	10.1
Burnt	16-03	2.17	100/0	0.00	35.6	57.0	7.43	0.11	0.61	4.00	8.20
Wood	17-01	0.06	100/0	0.00	14.0	77.7	8.21	0.11	0.49	1.80	5.00
Third	18-01	0.05	100/0	0.00	6.14	92.9	0.95	0.300	0.60	1.10	2.2
Third	18-01	0.05	100/0	0.00	11.1	86.1	2.73	0.240	0.70	1.60	3.4
Third	18-02	0.59	100/0	0.00	21.3	76.1	2.65	0.10	0.81	3.20	10.9
Third	18-03	1.15	100/0	0.00	46.5	51.9	1.63	0.500	1.70	12.0	23.0
Third	18-05	4.87	100/0	0.00	30.9	66.3	2.78	0.20	0.80	3.50	7.80
Third	18-08	7.61	100/0	0.00	29.8	67.3	2.83	0.20	0.80	3.50	7.50
Third	18-09	8.10	100/0	0.00	27.3	70.0	2.71	0.17	0.65	3.75	11.0
Third	18-10	2.31	100/0	0.00	21.6	76.2	2.14	0.30	0.91	2.50	6.00
Incline	19-04	5.39	-	100	0.00	0.00	0.00	-	-	-	-
Incline	19-05	5.22	100/0	0.00	2.95	85.2	11.8	0.08	0.26	0.80	1.70
Incline	19-06	5.04	19/81	23.9	59.1	15.0	2.03	1.40	15.0	101	925
Incline	19-07	4.97	100/0	0.00	64.7	32.5	2.75	0.42	4.00	6.80	7.90
Incline	19-07	4.97	26/74	6.00	68.0	23.6	2.36	0.61	8.00	25.0	189
Incline	19-08	4.81	100/0	0.00	35.8	59.9	4.32	0.20	1.10	5.90	11.0
Incline	19-08	4.81	100/0	0.00	30.7	63.9	5.40	0.15	0.78	4.10	9.90
Incline	19-09	4.64	100/0	0.00	31.1	62.5	6.39	0.13	0.82	4.30	13.0

Stream	**Station number**	**River kilometer**	**Percent particle size/percent particle count**	**Percent grain size in millimeters**				**Particle sizes in millimeters**			
				Boulder/ Cobble > 64	**Gravel 2 - 64**	**Sand 0.062 - 2**	**Silt and Clay < 0.062**	**D_{16}**	**D_{50}**	**D_{84}**	**D_{95}**
Incline	19-09	4.64	100/0	0.00	5.69	91.8	2.56	0.12	0.27	0.68	2.30
Incline	19-10	4.53	100/0	0.00	29.8	64.0	6.20	0.12	0.71	4.00	7.70
Incline	19-10	4.53	100/0	0.00	16.7	74.4	8.98	0.09	0.28	2.10	6.50
Incline	19-11	4.34	100/0	0.00	12.4	83.2	4.40	0.10	0.27	1.00	4.30
Incline	19-11	4.34	100/0	0.00	20.5	73.5	6.01	0.12	0.48	2.30	5.00
Incline	19-12	4.22	100/0	0.00	0.00	91.2	8.81	0.09	0.30	0.79	1.20
Incline	19-13	4.05	100/0	0.00	8.90	82.1	9.01	0.09	0.31	1.20	3.80
Incline	19-14	3.78	100/0	0.00	21.1	71.0	7.95	0.10	0.41	2.70	6.80
Incline	19-15	3.54	100/0	0.00	29.3	63.3	7.43	0.11	0.62	4.00	8.70
Incline	19-19	3.05	100/0	0.00	4.98	89.1	5.96	0.09	0.20	0.73	2.00
Incline	19-21	2.41	100/0	0.00	11.3	74.9	13.8	0.07	0.20	1.20	3.30
Incline	19-22	2.17	100/0	0.00	8.40	86.6	5.00	0.13	0.37	1.20	3.10
Incline	19-23	2.06	100/0	0.00	42.4	57.4	0.19	0.41	1.10	40.0	57.0
Incline	19-24	1.90	-	100	0.00	0.00	0.00	-	-	-	-
Incline	19-25	1.77	60/40	40.0	11.7	45.5	2.79	0.23	2.10	3000[1]	3000[1]
Incline	19-28	1.32	100/0	0.00	27.2	70.7	2.01	0.22	0.80	4.10	12.0
Incline	19-31	1.08	100/0	0.00	11.0	82.3	6.66	0.09	0.25	1.00	7.10
Incline	19-31	1.08	100/0	0.00	20.5	76.3	3.25	0.20	0.70	3.00	20.0
Incline	19-32	0.85	100/0	0.00	11.5	77.1	11.4	0.07	0.21	1.10	7.20
Incline	19-38	0.16	100/0	0.00	5.31	82.4	12.3	0.07	0.22	0.81	2.10
Incline	19-39	0.05	100/0	0.00	8.21	82.8	8.99	0.08	0.25	1.00	3.00
Mill	20-01	0.01	100/0	0.00	10.0	80.2	9.79	0.081	3.00	1.20	3.40
Mill	20-02	0.89	100/0	0.00	2.1	91.9	5.97	0.110	0.280	0.500	1.00
Mill	20-03	1.90	100/0	0.00	28.8	67.3	3.83	0.200	0.76	3.65	6.10
Secret Harbor	25-01	0.20	100/0	0.00	0.0	95.3	4.68	0.107	0.230	0.490	0.800
Slaughterhouse	28-02	2.25	100/0	0.00	18.2	75.1	6.70	0.120	0.600	2.20	4.80
Glenbrook	29-01	0.03	100/0	0.00	43.6	55.9	0.572	0.345	1.50	5.10	7.00
Glenbrook	29-03	2.70	100/0	0.00	38.2	59.1	2.71	0.350	1.40	11.0	23.0
Glenbrook	29-04	3.22	100/0	0.00	52.4	47.1	0.485	0.510	2.10	10.0	22.0
Glenbrook	29-06	3.35	100/0	0.00	65.0	33.6	1.40	0.600	5.00	24.0	40.0
Cave Rock	32-04	0.89	0/100	96.0	4.00	0.0	0.00	130	235	520	1155
Lincoln	33-02	1.19	24/76	0.00	0.0	94.2	5.78	0.700	11.0	54.0	250
North Zephyr	35-03	1.59	100/0	0.00	29.7	66.3	4.02	0.245	0.10	4.00	7.2
McFaul	38-04	3.23	100/0	0.00	24.8	75.2	0.00	0.111	0.475	2.10	3.50
Burke	39-02	1.58	100/0	0.00	15.3	80.1	4.61	0.120	0.508	2.00	5.10
Burke	39-05	3.58	100/0	0.00	0.0	91.9	8.08	0.075	0.150	0.310	0.550
Edgewood	40-13	5.62	100/0	0.00	28.0	67.1	4.83	0.16	0.76	3.10	6.8

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
Edgewood	40-19	4.96	100/0	0.00	0.00	97.6	2.40	1.99	0.41	0.95	1.5
Edgewood	40-22	3.83	100/0	0.00	7.5	84.9	7.57	0.10	0.37	1.08	3.2
Edgewood	40-25	3.09	100/0	0.00	7.9	87.1	4.98	0.11	0.28	1.04	2.9
Bijou Park	41-01	1.32	100/0	0.00	17.2	78.6	4.20	0.190	0.710	2.05	4.00
Trout	43-03	4.71	100/0	0.00	40.8	55.6	3.60	0.320	1.40	3.80	6.00
Trout	43-04	7.05	100/0	0.00	19.6	71.8	8.67	0.980	0.640	2.50	9.85
Trout	43-05	6.52	100/0	0.00	9.53	78.9	11.6	0.080	0.250	0.990	3.10
Trout	43-06	7.47	100/0	0.00	2.16	94.5	3.31	0.130	0.300	5.10	1.00
Trout	43-07	8.13	8/92	18.0	74.0	7.4	0.59	4.00	22.0	65.0	180
UTR	44-04	23.0	100/0	0.00	19.3	74.3	6.33	0.13	0.41	2.80	21.0
UTR	44-06	22.5	100/0	0.00	0.79	91.7	7.47	0.09	0.22	0.48	0.89
UTR	44-08	21.8	5/95	95.0	0.14	4.68	0.18	3000[1]	3000[1]	3000[1]	3000[1]
UTR	44-11	21.4	100/0	0.00	0.21	85.7	14.1	0.069	0.15	0.33	0.50
UTR	44-12	20.7	100/0	0.00	3.26	85.6	11.1	0.077	0.21	0.53	1.40
UTR	44-15	19.9	100/0	0.00	1.68	74.3	24.0	0.033	0.13	0.53	1.20
UTR	44-16	19.3	100/0	0.00	14.0	79.8	6.21	0.13	0.52	3.50	8.60
UTR	44-17	18.6	100/0	0.00	0.00	87.0	13.0	0.072	0.23	1.00	1.60
UTR	44-19	18.0	100/0	0.00	0.16	84.1	15.7	0.063	0.13	0.34	0.63
UTR	44-20	17.8	100/0	0.00	2.56	92.3	5.13	0.090	0.20	0.41	0.77
UTR	44-21	16.9	100/0	0.00	3.81	85.1	11.1	0.078	0.10	0.47	1.30
UTR	44-24	15.3	100/0	0.00	12.5	85.7	1.77	0.32	0.80	1.80	3.40
UTR	44-26	14.8	100/0	0.00	0.00	89.7	10.3	0.072	0.16	0.24	0.42
UTR	44-30	14.1	16/84	1.04	83.0	15.7	0.27	1.80	11.0	31.0	42.0
UTR	44-39	13.5	100/0	0.00	2.43	86.7	10.9	0.076	0.18	0.42	1.30
UTR	44-43	13.1	100/0	0.00	7.60	80.9	11.5	0.078	0.22	0.89	3.20
UTR	44-59	12.1	70/30	0.00	46.3	49.2	4.51	0.12	0.50	45.0	60.0
UTR	44-67	11.2	100/0	0.00	28.9	63.0	8.03	0.10	0.41	4.80	11.0
UTR	44-68	10.8	100/0	0.00	14.1	69.7	16.2	0.060	0.22	1.50	11.0
UTR	44-72	10.0	100/0	0.00	0.24	88.5	11.2	0.071	0.13	0.38	0.78
UTR	44-75	8.50	100/0	0.00	0.00	84.4	15.6	0.064	0.20	0.90	1.40
UTR	44-78	7.14	100/0	0.00	0.00	93.2	6.83	0.090	0.18	0.32	0.47
UTR	44-82	5.84	0/100	62.0	28.0	10.0	0.00	7.00	110	210	250
UTR	44-85	5.06	100/0	0.00	1.23	81.6	17.1	0.060	0.21	0.96	1.70
UTR	44-87	4.51	100/0	0.00	0.52	83.1	16.4	0.062	0.13	0.23	0.47
UTR	44-92	2.94	100/0	0.00	5.31	87.5	7.18	0.11	0.30	1.10	2.10

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
UTR	44-103	2.26	100/0	0.00	5.03	92.4	2.56	0.13	0.30	0.51	2.00
Taylor	46-01	0.90	100/0	0.00	36.6	54.1	9.24	0.100	0.630	12.0	42.0
Taylor	46-02	2.33	100/0	0.00	19.7	64.5	15.8	0.062	0.300	3.09	15.0
Tallac	47-01	1.37	100/0	0.00	6.16	89.9	3.90	0.170	0.340	0.725	3.17
Tallac	47-02	2.20	100/0	0.00	35.4	54.1	10.4	0.087	0.345	17.0	26.0
Tallac	47-03	2.55	100/0	0.00	4.14	89.7	6.15	0.120	0.430	1.20	1.90
Tallac	47-04	3.05	100/0	0.00	21.3	67.6	11.1	0.082	0.330	3.30	14.0
Cascade	48-01	0.69	30/70	70.0	10.9	18.7	0.39	1.10	3000[1]	3000[1]	3000[1]
Eagle	49-01	0.58	100/0	0.00	35.3	64.7	0.00	0.70	1.40	3.10	5.60
Rubicon	51-01	0.92	100/0	0.00	2.68	73.3	24.0	0.09	0.210	0.620	2.90
Rubicon	51-02	1.27	100/0	0.00	3.20	91.2	5.56	0.101	0.250	0.700	1.50
Rubicon	51-03	1.60	100/0	0.00	23.1	75.3	1.56	0.210	0.700	2.70	4.90
Paradise Flat	52-01	0.62	100/0	0.00	8.05	81.1	10.9	0.08	0.320	1.10	2.85
Lonely Gulch	53-02	1.24	-	0.00	19.9	79.6	0.541	0.41	1.00	2.25	4.10
Sierra	54-01	0.89	100/0	0.00	5.53	84.1	10.4	0.09	0.490	1.20	2.08
General	56-01	6.80	5/95	95.0	1.3	3.4	0.31	3000[1]	3000[1]	3000[1]	3000[1]
General	56-02	6.66	10/90	90.0	1.7	7.8	0.45	3000[1]	3000[1]	3000[1]	3000[1]
General	56-02	6.66	10/90	90.0	4.2	5.7	0.02	3000[1]	3000[1]	3000[1]	3000[1]
General	56-03	6.50	100/0	0.00	16.6	66.4	17.0	0.06	0.36	2.10	5.0
General	56-05	6.06	100/0	0.00	23.1	74.7	2.20	0.20	0.63	3.00	6.8
General	56-06	5.90	100/0	0.00	7.9	81.1	11.0	0.08	0.23	0.85	3.1
General	56-07	5.61	100/0	0.00	7.1	79.7	13.2	0.07	0.20	0.50	4.0
General	56-09	5.25	75/25	18.9	6.1	65.7	9.28	0.08	0.22	240	530
General	56-12	4.73	100/0	0.00	1.0	87.4	11.6	0.08	0.20	0.48	0.9
General	56-14	4.21	55/45	43.2	1.8	50.7	4.30	0.12	0.61	205	330
General	56-17	3.60	100/0	0.00	27.0	59.6	13.43	0.07	0.41	4.50	10.0
General	56-19	3.25	32/68	22.0	46.0	28.2	3.82	0.39	20.0	71.0	150
General	56-20	2.90	35/65	65.0	16.5	17.0	1.51	1.00	31.0	230	290
General	56-21	2.58	-	100	0.00	0.00	0.00	-	-	-	-
General	56-23	2.20	0/100	19.0	63.0	18.0	0.00	0.36	36.0	70.0	100
General	56-24	1.94	100/0	0.00	38.2	45.9	15.9	0.07	0.41	38.0	52.0
General	56-26	1.93	0/100	17.0	70.0	13.0	0.00	5.00	33.0	72.0	110
General	56-27	1.54	100/0	0.00	30.5	63.4	6.17	0.12	62.0	5.20	19.0
General	56-28	1.17	100/0	0.00	2.0	90.0	7.97	0.08	0.17	0.37	0.5
General	56-29	0.95	100/0	0.00	12.0	81.7	6.31	0.13	0.43	1.50	10.5
General	56-30	0.89	100/0	0.00	0.3	94.7	5.02	0.08	0.17	0.35	0.5

Stream	Station number	River kilometer	Percent particle size/percent particle count	Percent grain size in millimeters				Particle sizes in millimeters			
				Boulder/ Cobble > 64	Gravel 2 - 64	Sand 0.062 - 2	Silt and Clay < 0.062	D_{16}	D_{50}	D_{84}	D_{95}
General	56-32	0.71	90/10	10.0	32.6	51.7	5.68	0.13	0.64	24.0	80.0
General	56-36	0.30	100/0	0.00	8.3	86.2	5.56	0.11	0.25	0.70	4.0
General	56-37	0.01	100/0	0.00	66.8	33.1	0.11	0.32	0.81	17.0	27.0
McKinney	57-01	0.28	100/0	0.00	15.5	68.9	15.6	0.063	0.230	1.90	7.00
Homewood	59-01	0.09	100/0	0.00	13.5	77.1	9.38	0.102	0.40	1.60	4.00
Homewood	59-02	0.41	100/0	0.00	29.7	61.4	8.87	0.091	0.40	14.0	46.0
Blackwood	62-02	8.29	100/0	17.9	68.9	0.11	1.22	2.50	30.8	68.0	87.0
Blackwood	62-04	8.19	100/0	0.00	53.5	1.25	12.4	0.091	2.70	24.0	41.0
Blackwood	62-05	7.18	27/73	17.2	55.8	0.17	6.03	0.300	8.50	70.0	210
Blackwood	62-07	7.17	100/0	0.00	47.1	0.00	1.25	0.400	1.60	8.10	10.5
Blackwood	62-08	6.51	100/0	0.00	9.97	1.87	12.1	0.0720	0.230	0.93	4.70
Blackwood	62-12	5.08	100/0	0.00	26.1	0.00	3.86	0.07	0.34	4.80	12.5
Blackwood	62-15	4.15	100/0	0.00	32.7	1.31	8.18	0.090	0.305	34.0	51.0
Blackwood	62-18	3.95	100/0	0.00	9.97	1.87	12.1	0.075	0.240	0.95	4.90
Blackwood	62-21	2.80	100/0	0.00	51.2	0.00	4.02	0.20	2.10	24.0	40.0
Blackwood	62-22a	1.97	100/0	0.00	50.9	0.00	1.00	0.290	2.01	10.6	21.0
Blackwood	62-24	1.77	100/0	0.00	26.1	0.00	3.86	0.270	1.01	4.30	13.0
Blackwood	62-30	0.32	100/0	23.4	46.6	0.67	6.84	0.200	31.0	80.0	100
Ward	63-01	6.55	100/0	0.00	31.0	51.0	17.9	0.050	0.300	12.0	24.0
Ward	63-02	6.45	0/100	24.0	70.0	6.00	0.00	9.00	32.0	77.0	112
Ward	63-05	6.17	100/0	0.00	3.79	84.1	12.1	0.079	0.230	0.600	1.40
Ward	63-06	6.10	0/100	52.0	41.0	7.00	0.00	22.0	70.0	110	125
Ward	63-08	5.94	100/0	0.00	8.95	74.9	16.10	0.062	0.170	0.510	6.20
Ward	63-09	5.87	50/50	40.0	9.50	44.6	5.87	0.140	18.0	88.0	127
Ward	63-10	5.81	100/0	0.00	0.73	85.3	14.0	0.067	0.170	0.400	0.690
Ward	63-12	5.53	100/0	0.00	0.00	88.4	11.6	0.071	0.160	0.600	1.20
Ward	63-13	5.36	100/0	0.00	13.8	64.4	21.8	0.041	0.140	1.00	20.0
Ward	63-14	5.12	100/0	0.00	17.3	66.4	16.4	0.062	0.270	2.30	9.30
Ward	63-15	4.74	100/0	0.00	9.09	74.4	16.5	0.060	0.260	1.20	3.30
Ward	63-16	4.52	-	100	0.00	0.00	0.00	-	-	-	-
Ward	63-18	4.25	100/0	0.00	35.6	51.2	13.2	0.077	0.700	8.0	13.0
Ward	63-22	3.51	0/100	4.04	81.8	14.1	0.00	3.00	9.00	32.0	61.0
Ward	63-23	3.28	0/100	67.0	28.0	5.00	0.00	40.0	120	290	650
Ward	63-25	2.64	0/100	12.0	79.0	9.0	0.00	4.00	24.0	49.0	97.0
Ward	63-30	1.97	-	100	0.00	0.00	0.00	-	-	-	-
Ward	63-32	1.55	0/100	76.1	18.5	5.43	0.00	30.0	235	385	525

Stream	**Station number**	**River kilometer**	**Percent particle size/percent particle count**	**Percent grain size in millimeters**				**Particle sizes in millimeters**			
				Boulder/ Cobble > 64	**Gravel 2 - 64**	**Sand 0.062 - 2**	**Silt and Clay < 0.062**	**D_{16}**	**D_{50}**	**D_{84}**	**D_{95}**
Ward	63-33	1.42	100/0	0.00	15.1	74.9	9.91	0.093	0.310	1.90	10.0
Ward	63-34	1.29	0/100	41.4	50.5	7.07	1.01	9.00	45	170	220
Ward	63-35	1.14	0/100	46.5	49.5	4.04	0.00	11.0	60.0	113	225
Ward	63-39	0.78	0/100	57.6	27.3	13.1	2.02	4.00	70.0	206	296
Ward	63-40	0.63	0/100	18.0	41.0	29.0	12.0	0.400	10.0	69.0	124
Ward	63-41	0.51	30/70	34.5	35.5	24.5	5.49	0.220	32.0	108	187
Ward	63-44	0.09	0/100	34.0	55.0	8.00	3.00	7.00	41.0	99.0	180

[1] A Value of 3000 mm was given to boulders over 2 m that were not measured and to bedrock.

C Appendix C

Suspended-Sediment Rating Scattergraphs with Regression Equations

Data on CD

D Appendix D

Percent of Suspended Sediment Finer than 0.062mm Scattergraphs and Equations

Data on CD

E Appendix E

Annual Suspended-Sediment Load Tables

Data on CD

F Appendix F

Rapid Geomorphic Assessments (RGA) - Sites

Table F-1. Summary of rapid geomorphic assessment indices for all streams.

Stream	Station number	River kilometer	Combined stability index	Channel stability index	Side-slope erosion
Tahoe State Park	01-01	0.02	8.5	8.5	0
Tahoe State Park	01-02	0.90	11.5	11.5	0
Burton	02-01	0.26	13.5	13.5	0
Burton	02-02	0.85	12.5	12.5	0
Barton	03-02	0.41	6	6	0
Barton	03-01	1.06	7	7	0
Lake Forest	04-02	0.02	0	0	0
Lake Forest	04-03	1.04	5.5	5.5	0
Lake Forest	04-01	1.85	7	7	0
Dollar	05-01	0.31	8	6.5	1.5
Dollar	05-02	1.22	7	7	0
Cedar Flats	06-01	0.06	5.5	5.5	0
Cedar Flats	06-02	0.67	11	11	0
Watson	07-01	0.04	6	6	0
Watson	07-02	1.11	6	6	0
Carnelian Bay	08-01	0.11	7	7	0
Carnelian Canyon	09-01	0.03	8.5	8.5	0
Carnelian Canyon	09-02	1.30	7	7	0
Carnelian Canyon	09-04	1.90	7	7	0
Tahoe Vista	10-01a	0.11	13.5	13.5	0
Tahoe Vista	10-01b	0.02	25	18	7
Tahoe Vista	10-02	1.27	11	11	0
Tahoe Vista	10-05	2.88	30	18	12
Tahoe Vista	10-06	2.32	16.25	11	5.25
Griff	11-01	0.09	11.5	11.5	0
Griff	11-02	0.94	15	11	4
Griff	11-03	1.93	19.25	11.5	7.75
Griff	11-04	3.06	14.5	9	5.5
Griff	11-06	1.91	7.5	7.5	0
Kings Beach	12-01	0.08	14.5	14.5	0
First	14-01	0.03	4	4	0
First	14-02	0.25	20	8	12
First	14-04	0.78	22	10	12
First	14-05	1.92	11	11	0
First	14-06	1.92	22.75	17.5	5.25
Second	15-01	0.18	29.5	22	7.5
Second	15-02	1.19	20.5	8.5	12
Burnt	16-01	0.13	14.75	11	3.75
Burnt	16-02	1.25	17	13	4
Burnt	16-03	2.17	12	12	0
Wood	17-01	0.06	13	11	2
Third	18-01	0.05	23.25	18	5.25
Third	18-02	0.59	12	10	2
Third	18-03	1.15	12	10	2
Third	18-04	2.97	16	14	2
Third	18-05	4.87	16.5	14.5	2
Third	18-08	7.61	12	10	2
Third	18-09	8.10	15	12	3
Third	18-10	2.31	17.5	12.5	5

Stream	Station number	River kilometer	Combined stability index	Channel stability index	Side-slope erosion
Incline	19-01	5.69	15.5	11.5	4
Incline	19-02	5.61	14.75	9.5	5.25
Incline	19-03	5.44	17.5	11.5	6
Incline	19-04	5.39	13.75	9.5	4.25
Incline	19-05	5.22	17.75	13.5	4.25
Incline	19-06	5.04	18.75	12	6.75
Incline	19-08	4.81	22	18	4
Incline	19-09	4.64	19	12	7
Incline	19-10	4.53	19	11.5	7.5
Incline	19-11	4.34	17.5	11.5	6
Incline	19-12	4.22	16.5	11.5	5
Incline	19-13	4.05	10.5	10.5	0
Incline	19-14	3.78	14.5	11	3.5
Incline	19-15	3.54	13	11	2
Incline	19-16	3.53	16	11.5	4.5
Incline	19-17	3.42	17	13.5	3.5
Incline	19-18	3.40	13.5	10	3.5
Incline	19-19	3.05	18	14	4
Incline	19-21	2.41	18.5	14.5	4
Incline	19-22	2.17	21.5	17.5	4
Incline	19-23	2.06	20	16	4
Incline	19-24	1.90	18.5	14.5	4
Incline	19-25	1.77	19.5	15.5	4
Incline	19-26	1.61	9.5	5.5	4
Incline	19-27	1.55	18.25	13	5.25
Incline	19-28	1.32	17	12.5	4.5
Incline	19-29	1.22	21	17	4
Incline	19-31	1.08	26	16	10
Incline	19-32	0.85	21	13.5	7.5
Incline	19-33	0.72	22.5	16.5	6
Incline	19-34	0.57	14.5	11.5	3
Incline	19-35	0.40	13	10	3
Incline	19-36	0.26	16.5	13.5	3
Incline	19-37	0.21	12	10	2
Incline	19-38	0.16	25.25	19.5	5.75
Incline	19-39	0.05	20.5	16.5	4
Mill	20-01	0.01	25.5	21.5	4
Mill	20-02	0.89	14.5	10.5	4
Mill Creek	20-03	1.90	12	10	2
Tunnel	21-01	0.07	16.5	12.5	4
Tunnel	21-02	1.22	11.75	9	2.75
Bonpland	22-01	0.07	9	7	2
Marlette	24-01	0.01	16.75	13	3.75
Marlette	24-02	0.92	21	15	6
Marlette	24-03	1.28	27.5	24.5	3
Secret Harbor	25-01	0.20	10	7.5	2.5
Secret Harbor	25-02	0.55	12.5	8.5	4
Secret Harbor	25-05	0.04	10.25	7	3.25
Secret Harbor	25-06	1.27	16	12.5	3.5
Bliss	26-01	0.39	17.5	14.5	3

Stream	Station number	River kilometer	Combined stability index	Channel stability index	Side-slope erosion
Bliss	26-02	1.20	10.5	7.5	3
Dead Mans Point	27-01	0.04	12	9	3
Dead Mans Point	27-02	0.59	15	12	3
Slaughterhouse	28-01	0.23	11	7.5	3.5
Slaughterhouse	28-02	2.25	19.5	16.5	3
Slaughterhouse	28-03	4.51	15.5	11.5	4
Glenbrook	29-01	0.03	20	17	3
Glenbrook	29-02	0.76	12.5	9.5	3
Glenbrook	29-03	2.70	18	14.5	3.5
Glenbrook	29-04	3.22	28.5	24.5	4
Glenbrook	29-06	3.35	19.5	15.5	4
North Logan House	30-02	0.48	15	12	3
Logan House	31-01	3.94	11	7	4
Logan House	31-04	3.02	12	8	4
Logan House	31-06	2.55	14	10	4
Logan House	31-08	1.71	14	10	4
Logan House	31-10	1.21	13.5	9.5	4
Cave Rock	32-01	0.19	15	12	3
Cave Rock	32-02	0.09	20	16	4
Cave Rock	32-04	0.89	23	19.5	3.5
Lincoln	33-01	0.22	23	19.5	3.5
Lincoln	33-02	1.19	21.5	18	3.5
North Zephyr	35-01	0.28	24.5	20.5	4
North Zephyr	35-02	1.26	20	16	4
North Zephyr	35-03	1.59	25	21	4
Zephyr	37-01	0.13	21	17	4
Zephyr	37-02	0.99	24.5	18.5	6
McFaul	38-01	0.52	29	22.5	6.5
McFaul	38-02	1.69	21.5	19.5	2
McFaul	38-04	3.23	33.5	27.5	6
Burke	39-01	0.13	13.5	13.5	0
Burke	39-02	1.58	17	14	3
Burke	39-03	3.20	6.5	6.5	0
Burke	39-04	3.21	10.5	10.5	0
Burke	39-05	3.58	15.5	12	3.5
Burke	39-06	4.13	9	6	3
Burke	39-09	6.25	9.75	6.5	3.25
Edgewood	40-01	7.22	14	9.5	4.5
Edgewood	40-02	7.21	24	19.5	4.5
Edgewood	40-03	7.23	30.5	19.5	11
Edgewood	40-05	6.41	12.25	9	3.25
Edgewood	40-07	6.22	8.75	5.5	3.25
Edgewood	40-11	6.15	17	12.5	4.5
Edgewood	40-13	5.62	30	19	11
Edgewood	40-19	4.96	12.25	8.5	3.75
Edgewood	40-22	3.83	17.25	13.5	3.75
Edgewood	40-25	3.09	20	16.5	3.5
Edgewood	40-27	1.20	12.5	8.5	4
Edgewood	40-27a	0.20	15	11	4
Bijou Park	41-01	1.32	23	20	3

Stream	Station number	River kilometer	Combined stability index	Channel stability index	Side-slope erosion
Bijou Park	41-02	1.88	22.5	19.5	3
Bijou	42-01	0.54	18	14.5	3.5
Bijou	42-02	2.16	19	16	3
Bijou	42-03	3.44	16	16	0
Trout	43-01	1.45	10	10	0
Trout	43-02	2.49	16.5	13	3.5
Trout	43-03	4.71	18	18	0
Trout	43-04	7.05	21.5	18.5	3
Trout	43-05	6.52	21.5	18.5	3
Trout	43-06	7.47	22	19	3
Trout	43-07	8.13	17.75	14	3.75
Upper Truckee	44-01	24.2	15	15	0
Upper Truckee	44-04	23.0	14.5	14.5	0
Upper Truckee	44-06	22.5	15.5	15.5	0
Upper Truckee	44-08	21.8	13.25	11	2.25
Upper Truckee	44-11	21.4	15.75	12.5	3.25
Upper Truckee	44-12	20.7	19.5	19.5	0
Upper Truckee	44-15	19.9	19.75	16	3.75
Upper Truckee	44-16	19.3	23.75	20	3.75
Upper Truckee	44-17	18.6	15	15	0
Upper Truckee	44-19	18.0	14.75	12.5	2.25
Upper Truckee	44-20	17.8	17	17	0
Upper Truckee	44-21	16.9	14.5	11	3.5
Upper Truckee	44-21a	16.4	12.5	12.5	0
Upper Truckee	44-22	15.9	9.5	9.5	0
Upper Truckee	44-24	15.3	14	14	0
Upper Truckee	44-26	14.8	15.5	15.5	0
Upper Truckee	44-30	14.1	8.5	8.5	0
Upper Truckee	44-39	13.5	16.5	16.5	0
Upper Truckee	44-43	13.1	21.5	21.5	0
Upper Truckee	44-59	12.1	15	15	0
Upper Truckee	44-67	11.2	19	19	0
Upper Truckee	44-68	10.8	18	18	0
Upper Truckee	44-72	10.0	15.5	15.5	0
Upper Truckee	44-75	8.50	18	18	0
Upper Truckee	44-78	7.14	19	19	0
Upper Truckee	44-82	5.84	18.75	15	3.75
Upper Truckee	44-85	5.06	21	21	0
Upper Truckee	44-87	4.51	20.25	16.5	3.75
Upper Truckee	44-92	2.94	21.25	17.5	3.75
Taylor	46-01	0.90	8	8	0
Taylor	46-02	2.33	8	8	0
Tallac	47-01	1.37	8.5	8.5	0
Tallac	47-02	2.20	9	9	0
Tallac	47-03	2.55	9	9	0
Tallac	47-04	3.05	8.5	8.5	0
Tallac	47-05	2.95	7	7	0
Cascade	48-01	0.69	12	10	2
Eagle	49-01	0.58	7	5.5	1.5
Bliss State Park	50-01	0.41	5.5	5.5	0

Stream	Station number	River kilometer	Combined stability index	Channel stability index	Side-slope erosion
Rubicon	51-01	0.92	11	11	0
Rubicon	51-02	1.27	8	6	2
Rubicon	51-03	1.60	13.5	13.5	0
Rubicon	51-04	1.71	8	8	0
Rubicon	51-05	2.11	5.5	5.5	0
Paradise Flat	52-01	0.62	18	18	0
Lonely Gulch	53-01	0.81	6.5	6.5	0
Lonely Gulch	53-02	1.24	10	10	0
Sierra	54-01	0.89	6	6	0
Meeks	55-01	1.23	12.5	12.5	0
Meeks	55-02	3.15	13	13	0
Meeks	55-03	3.50	12.5	12.5	0
Meeks	55-04	3.50	14	14	0
General	56-01	6.80	10	8	2
General	56-02	6.66	11	8	3
General	56-03	6.50	23.5	17.5	6
General	56-05	6.06	15.5	10.5	5
General	56-06	5.90	19.5	13.5	6
General	56-08	5.33	16.5	11.5	5
General	56-09	5.25	14.5	11.5	3
General	56-11	5.05	8.5	8.5	0
General	56-12	4.73	21.5	16.5	5
General	56-14	4.21	13	13	0
General	56-16	3.62	16	16	0
General	56-17	3.60	16.5	16.5	0
General	56-18	3.59	11.5	11.5	0
General	56-19	3.25	15	15	0
General	56-20	2.97	11.75	8.5	3.25
General	56-21	2.58	21.5	17.5	4
General	56-23	2.20	20	20	0
General	56-24	1.94	18.5	14	4.5
General	56-26	1.93	8.5	8.5	0
General	56-27	1.54	21.5	15	6.5
General	56-28	1.17	19	15	4
General	56-29	0.95	28.5	20.5	8
General	56-30	0.89	22	17.5	4.5
General	56-32	0.71	13.5	13.5	0
General	56-34	0.57	8	8	0
General	56-36	0.30	14.5	8.5	6
General	56-37	0.01	20.75	17.5	3.25
General	GC45	8.08	10.5	7.5	3
McKinney	57-01	0.28	10	10	0
McKinney	57-02	1.25	9	9	0
Quail Lane	58-01	0.02	6	6	0
Quail Lane	58-02	0.21	7	7	0
Homewood	59-01	0.09	18	18	0
Homewood	59-02	0.41	16	16	0
Madden	60-1	0.10	11	11	0
Blackwood	62-02	8.29	11.5	9	2.5
Blackwood	62-04	8.19	18.75	13	5.75

Stream	Station number	River kilometer	Combined stability index	Channel stability index	Side-slope erosion
Blackwood	62-04a	7.69	14	10.5	3.5
Blackwood	62-05	7.18	14	11	3
Blackwood	62-07	7.17	28	21	7
Blackwood	62-07a	6.84	14	11	3
Blackwood	62-08	6.51	21.5	15	6.5
Blackwood	62-10a	5.55	13	9.5	3.5
Blackwood	62-10b	6.03	18.5	14.5	4
Blackwood	62-12	5.08	23.5	17	6.5
Blackwood	62-15	4.15	16.5	16.5	0
Blackwood	62-18	3.95	27	19.5	7.5
Blackwood	62-21	2.80	21.5	15	6.5
Blackwood	62-22a	1.97	17	17	0
Blackwood	62-24	1.77	22	17	5
Blackwood	62-30	0.32	21	15	6
Blackwood	62-32	0.00	17	17	0
Ward	63-01	6.55	11.5	11.5	0
Ward	63-02	6.45	14	14	0
Ward	63-03	6.42	5.5	5.5	0
Ward	63-04	6.27	13	13	0
Ward	63-05	6.17	13	13	0
Ward	63-06	6.10	12.5	12.5	0
Ward	63-08	5.94	16	16	0
Ward	63-09	5.87	12	12	0
Ward	63-10	5.81	11	11	0
Ward	63-12	5.53	14.5	14.5	0
Ward	63-13	5.36	12	12	0
Ward	63-14	5.12	14	14	0
Ward	63-15	4.74	16.5	16.5	0
Ward	63-16	4.52	12.5	12.5	0
Ward	63-18	4.25	15.5	15.5	0
Ward	63-19	4.06	17	15	2
Ward	63-21	3.64	18.5	18.5	0
Ward	63-22	3.51	19.5	14.5	5
Ward	63-23	3.28	13	13	0
Ward	63-25	2.64	11.5	8.5	3
Ward	63-26	2.38	20.5	18	2.5
Ward	63-29	2.08	13	11	2
Ward	63-30	1.97	14	10.5	3.5
Ward	63-32	1.55	10	10	0
Ward	63-33	1.42	13.5	13.5	0
Ward	63-34	1.29	13.5	13.5	0
Ward	63-35	1.14	7.5	7.5	0
Ward	63-36	1.12	12.5	12.5	0
Ward	63-37	1.11	15	15	0
Ward	63-39	0.78	17.5	17.5	0
Ward	63-40	0.63	20.5	17	3.5
Ward	63-41	0.51	12.5	12.5	0
Ward	63-42	0.44	19.5	19.5	0
Ward	63-43	0.25	17.5	17.5	0
Ward	63-44	0.09	5.5	5.5	0

Table F-2. Detailed summary of rapid geomorphic assessments for all streams.

Stream	Station number	River kilometer	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Stream bank erosion		Stream bank instability		Woody vegetative cover		Bank accretion		Channel stability index	Percent sediment contribution from side-slopes		Side-slope erosion	Combined stability index
								Left	Right	Left	Right	Left	Right	Left	Right		Left	Right		
Tahoe State Park	01-01	0.02	I	Cobble/Gravel	No	11-25%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	11-25%	11-25%	8.5	0	0	0	8.5
Tahoe State Park	01-02	0.90	I	Gravel/Sand	No	0-10%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	11.5	0	0	0	11.5
Burton	02-01	0.26	V	Boulder/Cobble	No	0-10%	0-10%	Fluvial	None	26-50%	0-10%	26-50%	76-100%	26-50%	51-75%	12.5	0	0	0	12.5
	02-02	0.85	V	Bedrock/Cobble	No	0-10%	0-10%	Fluvial	None	26-50%	0-10%	26-50%	26-50%	0-10%	0-10%	13.5	0	0	0	13.5
	03-01	0.41	I	Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	11-25%	11-25%	6	0	0	0	6
Barton	03-02	1.06	I	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	7	0	0	0	7
Lake Forest	04-01	0.02	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	0	0	0	0	0
Lake Forest	04-02	1.04	II	Bedrock	Bed and Banks	-	-	-	-	-	-	-	-	-	-	5.5	0	0	0	5.5
Lake Forest	04-03	1.85	I	Bedrock/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	7	0	0	0	7
Dollar	05-01	0.31	I	Cobble/Gravel	No	51-75%	0-10%	Fluvial	None	11-25%	0-10%	51-75%	76-100%	51-75%	51-75%	6.5	0	0	1.5	8
Dollar	05-02	1.22	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	7	0	0	0	7
Cedar Flats	06-01	0.06	I	Bedrock/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	5.5	0	0	0	5.5
Cedar Flats	06-02	0.67	IV	Boulder/Cobble	No	76-100%	0-10%	Fluvial	Fluvial	11-25%	11-25%	76-100%	76-100%	26-50%	26-50%	11	0	0	0	11
Watson	07-01	0.04	I	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	6	0	0	0	6
Watson	07-02	1.11	I	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	6	0	0	0	6
Carnelian Bay	08-01	0.11	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	7	0	0	0	7
Carnelian Canyon	09-01	0.03	I	Gravel	No	76-100%	0-10%	None	Fluvial	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	8.5	0	0	0	8.5
Carnelian Canyon	09-02	1.30	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	7	0	0	0	7
Carnelian Canyon	09-04	1.90	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	7	0	0	0	7
Tahoe Vista	10-01a	0.11	I	Boulder/Cobble	No	76-100%	76-100%	None	None	0-10%	0-10%	26-50%	11-25%	0-10%	0-10%	11	0	0	0	11
Tahoe Vista	10-01b	0.02	V	Sand	No	26-50%	0-10%	Fluvial	Fluvial	26-50%	11-25%	26-50%	11-25%	26-50%	0-10%	11	0	100	7	16.25
Tahoe Vista	10-02	1.27	I	Silt Clay	No	51-75%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	0-10%	0-10%	13.5	0	0	0	13.5
Tahoe Vista	10-05	2.88	V	Boulder/Cobble	No	0-10%	0-10%	Mass Wasting	Mass Wasting	76-100%	51-75%	76-100%	76-100%	26-50%	51-75%	18	100	100	12	25
Tahoe Vista	10-06	2.32	I	Boulder/Cobble	No	0-10%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	51-75%	26-50%	26-50%	18	50	60	5.25	30
Griff	11-01	0.09	III	Boulder/Cobble	No	26-50%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	76-100%	0-10%	0-10%	11.5	0	0	0	11.5
Griff	11-02	0.94	I	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Fluvial	11-25%	11-25%	51-75%	51-75%	11-25%	11-25%	11	0	0	4	15
Griff	11-03	1.93	I	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Fluvial	26-50%	26-50%	76-100%	76-100%	11-25%	26-50%	11.5	75	50	7.75	19.25
Griff	11-04	3.06	I	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	11-25%	11-25%	9	40	80	5.5	14.5
Griff	11-06	1.91	I	Gravel	No	76-100%	0-10%	None	Fluvial	0-10%	0-10%	51-75%	51-75%	26-50%	11-25%	7.5	0	0	0	7.5

Stream	**Station number**	**River kilometer**	**Stage of channel evolution**	**Bed material**	**Bed or bank protection**	**Incision**	**Constriction**	**Stream bank erosion**		**Stream bank instability**		**Woody vegetative cover**		**Bank accretion**		**Channel stability index**	**Percent sediment contribution from side-slopes**		**Side-slope erosion**	**Combined stability index**
								Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**		**Left**	**Right**		
Kings Beach	12-01	0.08	I	Boulder/Cobble	No	0-10%	0-10%	Fluvial	Fluvial	0-10%	0-10%	0-10%	11-25%	11-25%	11-25%	14.5	0	0	0	14.5
First	14-01	0.03	I	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	26-50%	26-50%	76-100%	76-100%	4	0	0	0	4
First	14-02	0.25	I	Boulder/Cobble	No	51-75%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	11-25%	11-25%	8	100	100	12	20
First	14-04	0.78	I	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	0-10%	0-10%	26-50%	26-50%	26-50%	26-50%	10	85	100	12	22
First	14-05	1.92	I	Boulder/Cobble	No	0-10%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	0-10%	0-10%	11	0	0	0	11
First	14-06	1.92	V	Boulder/Cobble	No	0-10%	0-10%	Fluvial	Mass Wasting	11-25%	51-75%	76-100%	76-100%	11-25%	0-10%	17.5	50	70	5.25	22.75
Second	15-01	0.18	V	Boulder/Cobble	No	0-10%	0-10%	Mass Wasting	Mass Wasting	51-75%	51-75%	11-25%	11-25%	11-25%	11-25%	22	70	75	7.5	29.5
Second	15-02	1.19	I	Boulder/Cobble	No	51-75%	0-10%	Fluvial	None	0-10%	0-10%	11-25%	51-75%	11-25%	26-50%	8.5	100	100	12	20.5
Burnt	16-01	0.13	I	Boulder/Cobble	No	26-50%	0-10%	Mass Wasting	Fluvial	26-50%	11-25%	51-75%	76-100%	26-50%	26-50%	11	40	20	3.75	14.75
Burnt	16-02	1.25	I	Sand	No	11-25%	0-10%	Fluvial	Fluvial	11-25%	26-50%	76-100%	76-100%	26-50%	11-25%	13	25	40	4	17
Burnt	16-03	2.17	I	Sand	No	26-50%	0-10%	Fluvial	Fluvial	11-25%	26-50%	76-100%	76-100%	26-50%	11-25%	12	0	0	0	12
Wood	17-01	0.06	I	Boulder/Cobble	No	0-10%	0-10%	None	None	0-10%	0-10%	26-50%	51-75%	0-10%	11-25%	11	0	0	2	13
Third	18-01	0.05	V	Gravel	No	11-25%	11-25%	Mass Wasting	Fluvial	51-75%	26-50%	51-75%	51-75%	26-50%	51-75%	18	65	50	5.25	23.25
Third	18-02	0.59	I	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Fluvial	11-25%	11-25%	76-100%	76-100%	26-50%	26-50%	10	20	15	2	12
Third	18-03	1.15	I	Boulder/Cobble	No	11-25%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	51-75%	11-25%	11-25%	10	10	5	2	12
Third	18-04	2.97	I	Boulder/Cobble	One Bank	26-50%	0-10%	Fluvial	Fluvial	11-25%	26-50%	11-25%	11-25%	11-25%	26-50%	14	25	0	2	16
Third	18-05	4.87	III	Boulder/Cobble	No	11-25%	0-10%	Fluvial	None	11-25%	0-10%	26-50%	26-50%	0-10%	0-10%	14.5	20	0	2	16.5
Third	18-08	7.61	I	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	11-25%	11-25%	76-100%	76-100%	11-25%	11-25%	10	75	80	2	12
Third	18-09	8.10	I	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Fluvial	51-75%	26-50%	76-100%	76-100%	26-50%	11-25%	12	60	50	3	15
Third	18-10	2.31	I	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Fluvial	51-75%	26-50%	51-75%	76-100%	11-25%	26-50%	12.5	35	40	5	17.5
Incline	19-01	5.69	I	Boulder/Cobble	No	11-25%	11-25%	None	None	0-10%	0-10%	26-50%	26-50%	0-10%	11-25%	11.5	25	70	4	15.5
Incline	19-02	5.61	I	Gravel	No	0-10%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	26-50%	11-25%	9.5	75	80	5.25	14.75
Incline	19-03	5.44	I	Gravel	No	0-10%	0-10%	None	None	11-25%	11-25%	76-100%	76-100%	0-10%	11-25%	11.5	85	95	6	17.5
Incline	19-04	5.39	I	Boulder/Cobble	No	0-10%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	11-25%	9.5	60	40	4.25	13.75
Incline	19-05	5.22	I	Gravel	No	0-10%	11-25%	None	Fluvial	11-25%	0-10%	76-100%	76-100%	0-10%	0-10%	13.5	65	85	4.25	17.75
Incline	19-06	5.04	I	Boulder/Cobble	Both Banks	11-25%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	0-10%	0-10%	12	20	80	6.75	18.75
Incline	19-08	4.81	I	Boulder/Cobble	No	0-10%	0-10%	Mass Wasting	Mass Wasting	76-100%	76-100%	76-100%	76-100%	0-10%	0-10%	18	80	80	4	22
Incline	19-09	4.64	I	Gravel	No	0-10%	0-10%	Fluvial	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	12	95	100	7	19
Incline	19-10	4.53	I	Gravel	No	11-25%	11-25%	Fluvial	None	0-10%	0-10%	76-100%	76-100%	0-10%	11-25%	11.5	95	100	7.5	19
Incline	19-11	4.34	I	Gravel	No	11-25%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	0-10%	11-25%	11.5	85	80	6	17.5

Stream	Station number	River kilometer	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Stream bank erosion		Stream bank instability		Woody vegetative cover		Bank accretion		Channel stability index	Percent sediment contribution from side-slopes		Side-slope erosion	Combined stability index
								Left	Right	Left	Right	Left	Right	Left	Right		Left	Right		
Incline	19-12	4.22	I	Gravel	No	0-10%	0-10%	Fluvial	None	0-10%	0-10%	76-100%	76-100%	0-10%	11-25%	11.5	95	30	5	16.5
Incline	19-13	4.05	I	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	11-25%	0-10%	10.5	0	0	0	10.5
Incline	19-14	3.78	I	Boulder/Cobble	One Bank	26-50%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	11	20	15	3.5	14.5
Incline	19-15	3.54	I	Boulder/Cobble	One Bank	0-10%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	11	0	0	2	13
Incline	19-16	3.53	I	Sand	No	11-25%	0-10%	None	None	11-25%	11-25%	0-10%	11-25%	76-100%	76-100%	11.5	50	20	4.5	16
Incline	19-17	3.42	I	Gravel	No	11-25%	26-50%	None	Fluvial	0-10%	11-25%	51-75%	11-25%	26-50%	26-50%	13.5	0	40	3.5	17
Incline	19-18	3.40	I	Sand	No	11-25%	0-10%	None	Fluvial	0-10%	11-25%	51-75%	26-50%	76-100%	76-100%	10	20	20	3.5	13.5
Incline	19-19	3.05	I	Gravel	No	11-25%	0-10%	Fluvial	Fluvial	0-10%	0-10%	26-50%	26-50%	0-10%	0-10%	14	0	0	4	18
Incline	19-21	2.41	III	Boulder/Cobble	No	0-10%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	76-100%	0-10%	0-10%	14.5	95	80	4	18.5
Incline	19-22	2.17	III	Boulder/Cobble	Bed and Banks	0-10%	0-10%	Fluvial	Fluvial	11-25%	0-10%	26-50%	26-50%	0-10%	0-10%	17.5	20	60	4	21.5
Incline	19-23	2.06	III	Boulder/Cobble	No	0-10%	0-10%	None	Fluvial	0-10%	11-25%	11-25%	11-25%	11-25%	0-10%	16	80	10	4	20
Incline	19-24	1.90	III	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	51-75%	11-25%	51-75%	51-75%	0-10%	11-25%	14.5	75	25	4	18.5
Incline	19-25	1.77	III	Boulder/Cobble	One Bank	26-50%	0-10%	Fluvial	Fluvial	0-10%	0-10%	11-25%	26-50%	0-10%	0-10%	15.5	15	70	4	19.5
Incline	19-26	1.61	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	11-25%	26-50%	5.5	0	0	4	9.5
Incline	19-27	1.55	I	Gravel	No	51-75%	0-10%	Fluvial	Fluvial	0-10%	0-10%	26-50%	0-10%	0-10%	0-10%	13	50	60	5.25	18.25
Incline	19-28	1.32	I	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Fluvial	0-10%	11-25%	51-75%	51-75%	0-10%	0-10%	12.5	0	45	4.5	17
Incline	19-29	1.22	II	Gravel	One Bank	0-10%	0-10%	None	None	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	17	0	0	4	21
Incline	19-31	1.08	V	Sand	No	11-25%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	16	100	100	10	26
Incline	19-32	0.85	V	Boulder/Cobble	No	0-10%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	11-25%	26-50%	13.5	80	75	7.5	21
Incline	19-33	0.72	V	Boulder/Cobble	No	11-25%	26-50%	Fluvial	Fluvial	0-10%	0-10%	11-25%	26-50%	26-50%	26-50%	16.5	85	80	6	22.5
Incline	19-34	0.57	I	Boulder/Cobble	Both Banks	26-50%	0-10%	None	Fluvial	0-10%	11-25%	26-50%	26-50%	26-50%	0-10%	11.5	0	30	3	14.5
Incline	19-35	0.40	I	Boulder/Cobble	No	11-25%	0-10%	Fluvial	None	26-50%	0-10%	51-75%	51-75%	11-25%	51-75%	10	30	5	3	13
Incline	19-36	0.26	I	Sand	No	51-75%	0-10%	Fluvial	Fluvial	51-75%	11-25%	51-75%	51-75%	0-10%	11-25%	13.5	50	20	3	16.5
Incline	19-37	0.21	I	Boulder/Cobble	No	11-25%	0-10%	None	Fluvial	0-10%	51-75%	51-75%	51-75%	51-75%	26-50%	10	10	55	2	12
Incline	19-38	0.16	V	Boulder/Cobble	No	11-25%	26-50%	Mass Wasting	Fluvial	76-100%	11-25%	26-50%	76-100%	0-10%	26-50%	19.5	80	55	5.75	25.25
Incline	19-39	0.05	V	Gravel	One Bank	11-25%	0-10%	Fluvial	None	0-10%	0-10%	26-50%	11-25%	0-10%	26-50%	16.5	95	0	4	20.5
Mill Creek	20-01	0.01	IV	Sand	No	51-75%	0-10%	Fluvial	Fluvial	51-75%	51-75%	0-10%	11-25%	0-10%	0-10%	21.5	0	0	4	25.5
Mill	20-02	0.89	V	Gravel/Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	0-10%	0-10%	76-100%	76-100%	10.5	0	0	4	14.5
Mill	20-03	1.90	I	Silt Clay	No	76-100%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	0-10%	0-10%	10	0	0	2	12
Tunnel	21-01	0.07	VI	Sand	No	76-100%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	12.5	0	0	4	16.5

Stream	**Station number**	**River kilometer**	**Stage of channel evolution**	**Bed material**	**Bed or bank protection**	**Incision**	**Constriction**	**Stream bank erosion**		**Stream bank instability**		**Woody vegetative cover**		**Bank accretion**		**Channel stability index**	**Percent sediment contribution from side-slopes**		**Side-slope erosion**	**Combined stability index**
								Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**		**Left**	**Right**		
Tunnel	21-02	1.22	I	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	11-25%	11-25%	0-10%	0-10%	9	10	20	2.75	11.75
Bonpland	22-01	0.07	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	7	0	0	2	9
Marlette	24-01	0.01	V	Gravel	No	51-75%	0-10%	Fluvial	Fluvial	11-25%	11-25%	51-75%	51-75%	26-50%	26-50%	13	20	40	3.75	16.75
Marlette	24-02	0.92	VI	Gravel/Sand	No	51-75%	0-10%	Fluvial	Fluvial	11-25%	26-50%	11-25%	11-25%	26-50%	11-25%	15	50	50	6	21
Marlette	24-03	1.28	III	Sand	No	0-10%	0-10%	Mass Wasting	Mass Wasting	76-100%	76-100%	26-50%	11-25%	0-10%	0-10%	24.5	0	0	3	27.5
Secret Harbour	25-01	0.20	I	Gravel	No	51-75%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	11-25%	0-10%	7.5	5	5	2.5	10
Secret Harbour	25-02	0.55	VI	Gravel	No	76-100%	0-10%	Fluvial	Fluvial	0-10%	11-25%	51-75%	76-100%	51-75%	51-75%	8.5	0	0	4	12.5
Secret Harbour	25-05	0.04	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	0-10%	0-10%	76-100%	76-100%	7	0	20	3.25	10.25
Secret Harbour	25-06	1.27	I	Sand/Silt Clay	No	76-100%	76-100%	None	None	0-10%	0-10%	11-25%	11-25%	51-75%	51-75%	12.5	0	0	3.5	16
Bliss	26-01	0.39	I	Sand	No	26-50%	0-10%	Fluvial	Fluvial	11-25%	11-25%	26-50%	26-50%	0-10%	0-10%	14.5	0	0	3	17.5
Bliss	26-02	1.20	I	Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	26-50%	26-50%	7.5	0	0	3	10.5
Dead Mans Point	27-01	0.04	I	Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	0-10%	0-10%	9	0	0	3	12
Dead Mans Point	27-02	0.59	I	Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	12	0	0	3	15
Slaughterhouse	28-01	0.23	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	0-10%	0-10%	7.5	0	0	3.5	11
Slaughterhouse	28-02	2.25	VI	Sand	No	51-75%	0-10%	Fluvial	Fluvial	11-25%	11-25%	11-25%	11-25%	0-10%	0-10%	16.5	0	0	3	19.5
Slaughterhouse	28-03	4.51	I	Sand/Silt Clay	No	76-100%	0-10%	None	None	0-10%	0-10%	11-25%	11-25%	0-10%	0-10%	11.5	0	0	4	15.5
Glenbrook	29-01	0.03	V	Gravel/Sand	No	26-50%	51-75%	None	Fluvial	11-25%	0-10%	76-100%	51-75%	0-10%	11-25%	17	0	0	3	20
Glenbrook	29-02	0.76	I	Gravel	No	76-100%	0-10%	None	Fluvial	0-10%	11-25%	26-50%	26-50%	0-10%	26-50%	9.5	10	0	3	12.5
Glenbrook	29-03	2.70	VI	Gravel	No	26-50%	0-10%	Fluvial	Fluvial	11-25%	11-25%	51-75%	51-75%	0-10%	0-10%	14.5	5	5	3.5	18
Glenbrook	29-04	3.22	IV	Gravel/Sand	No	0-10%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	11-25%	11-25%	0-10%	0-10%	24.5	10	10	4	28.5
Glenbrook	29-06	3.35	I	Gravel/Sand	No	11-25%	11-25%	Fluvial	Fluvial	0-10%	0-10%	26-50%	26-50%	0-10%	0-10%	15.5	50	50	4	19.5
North Logan House	30-02	0.48	I	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	11-25%	11-25%	51-75%	51-75%	0-10%	0-10%	12	0	0	3	15
Logan House	31-01	3.94	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	7	0	0	4	11
Logan House	31-04	3.02	I	Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	8	50	0	4	12
Logan House	31-06	2.55	I	Sand	No	26-50%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	10	0	0	4	14
Logan House	31-08	1.71	I	Sand	No	26-50%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	10	0	0	4	14
Logan House	31-10	1.21	I	Gravel/Sand	No	26-50%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	9.5	75	75	4	13.5
Cave Rock	32-01	0.19	I	Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	12	0	0	3	15
Cave Rock	32-02	0.09	I	Sand	No	0-10%	0-10%	None	None	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	16	20	20	4	20
Cave Rock	32-04	0.89	VI	Sand	No	0-10%	0-10%	Fluvial	Fluvial	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	19.5	50	50	3.5	23

Stream	Station number	River kilometer	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Stream bank erosion		Stream bank instability		Woody vegetative cover		Bank accretion		Channel stability index	Percent sediment contribution from side-slopes		Side-slope erosion	Combined stability index
								Left	Right	Left	Right	Left	Right	Left	Right		Left	Right		
Lincoln	33-01	0.22	VI	Sand	No	0-10%	11-25%	Fluvial	Fluvial	0-10%	0-10%	11-25%	11-25%	0-10%	0-10%	19.5	50	50	3.5	23
Lincoln	33-02	1.19	III	Gravel	No	0-10%	0-10%	Fluvial	Fluvial	11-25%	11-25%	11-25%	11-25%	0-10%	0-10%	18	50	50	3.5	21.5
North Zephyr	35-01	0.28	VI	Sand	No	0-10%	51-75%	Fluvial	Fluvial	0-10%	0-10%	26-50%	26-50%	0-10%	0-10%	20.5	50	50	4	24.5
North Zephyr	35-02	1.26	VI	Sand	No	51-75%	11-25%	Mass Wasting	Fluvial	0-10%	11-25%	51-75%	51-75%	0-10%	0-10%	16	50	50	4	20
North Zephyr	35-03	1.59	V	Sand	No	11-25%	0-10%	Mass Wasting	Fluvial	26-50%	11-25%	11-25%	26-50%	0-10%	0-10%	21	50	50	4	25
Zephyr	37-01	0.13	VI	Sand/Silt Clay	No	0-10%	26-50%	Fluvial	Fluvial	0-10%	0-10%	51-75%	26-50%	26-50%	51-75%	17	70	30	4	21
Zephyr	37-02	0.99	II	Sand	Both Banks	51-75%	0-10%	Fluvial	Mass Wasting	11-25%	26-50%	26-50%	26-50%	26-50%	26-50%	18.5	50	50	6	24.5
McFaul	38-01	0.52	IV	Sand	No	26-50%	0-10%	Mass Wasting	Fluvial	26-50%	11-25%	0-10%	0-10%	0-10%	0-10%	22.5	50	50	6.5	29
McFaul	38-02	1.69	VI	Boulder/Cobble	Both Banks	0-10%	0-10%	Fluvial	Fluvial	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	19.5	60	40	2	21.5
McFaul	38-04	3.23	IV	Sand	No	11-25%	26-50%	Mass Wasting	Mass Wasting	51-75%	51-75%	0-10%	11-25%	0-10%	0-10%	27.5	50	50	6	33.5
Burke	39-01	0.13	I	Gravel/Sand	No	0-10%	0-10%	Fluvial	Fluvial	0-10%	0-10%	0-10%	0-10%	76-100%	76-100%	13.5	0	0	0	13.5
Burke	39-02	1.58	I	Gravel/Sand	No	11-25%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	26-50%	0-10%	0-10%	14	0	100	3	17
Burke	39-03	3.20	I	Gravel/Sand	Bed and Banks	51-75%	0-10%	None	None	0-10%	0-10%	26-50%	26-50%	51-75%	51-75%	6.5	0	0	0	6.5
Burke	39-04	3.21	I	Silt Clay	No	51-75%	0-10%	Fluvial	None	0-10%	0-10%	26-50%	51-75%	26-50%	26-50%	10.5	0	0	0	10.5
Burke	39-05	3.58	III	Gravel	No	26-50%	0-10%	Fluvial	Fluvial	11-25%	11-25%	51-75%	51-75%	51-75%	51-75%	12	50	0	3.5	15.5
Burke	39-06	4.13	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	26-50%	26-50%	51-75%	51-75%	6	50	0	3	9
Burke	39-09	6.25	I	Sand/Silt Clay	No	76-100%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	51-75%	51-75%	6.5	20	50	3.25	9.75
Edgewood	40-01	7.22	I	Gravel/Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	11-25%	11-25%	11-25%	11-25%	9.5	0	50	4.5	14
Edgewood	40-02	7.21	III	Gravel/Sand	No	11-25%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	11-25%	11-25%	11-25%	11-25%	19.5	0	50	4.5	24
Edgewood	40-03	7.23	III	Sand	No	0-10%	0-10%	Fluvial	Fluvial	0-10%	0-10%	0-10%	11-25%	0-10%	0-10%	19.5	100	100	11	30.5
Edgewood	40-05	6.41	VI	Gravel/Sand	No	51-75%	0-10%	None	Fluvial	0-10%	0-10%	51-75%	51-75%	51-75%	51-75%	9	0	25	3.25	12.25
Edgewood	40-07	6.22	I	Gravel/Sand	No	51-75%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	51-75%	51-75%	5.5	25	10	3.25	8.75
Edgewood	40-11	6.15	I	Sand/Silt Clay	Bed and Banks	26-50%	0-10%	Fluvial	Fluvial	11-25%	11-25%	26-50%	26-50%	26-50%	26-50%	12.5	0	50	4.5	17
Edgewood	40-13	5.62	VI	Sand	Bed and Banks	0-10%	0-10%	Fluvial	Fluvial	26-50%	11-25%	0-10%	0-10%	11-25%	11-25%	19	80	100	11	30
Edgewood	40-19	4.96	I	Gravel/Sand	No	26-50%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	51-75%	51-75%	51-75%	8.5	0	75	3.75	12.25
Edgewood	40-22	3.83	III	Gravel/Sand	Bed	26-50%	0-10%	Fluvial	Fluvial	11-25%	11-25%	51-75%	51-75%	26-50%	26-50%	13.5	65	0	3.75	17.25
Edgewood	40-25	3.09	III	Gravel/Sand	No	26-50%	0-10%	Mass Wasting	Fluvial	26-50%	11-25%	11-25%	26-50%	26-50%	26-50%	16.5	30	70	3.5	20
Edgewood	40-27	1.20	VI	Silt Clay	No	76-100%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	76-100%	76-100%	8.5	0	0	4	12.5
Edgewood	40-27a	0.20	II	Gravel	Bed and Banks	76-100%	0-10%	None	None	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	11	0	0	4	15
Bijou Park	41-01	1.32	III	Sand	No	11-25%	11-25%	Fluvial	Fluvial	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	20	0	0	3	23

Stream	Station number	River kilometer	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Stream bank erosion		Stream bank instability		Woody vegetative cover		Bank accretion		Channel stability index	Percent sediment contribution from side-slopes		Side-slope erosion	Combined stability index
								Left	Right	Left	Right	Left	Right	Left	Right		Left	Right		
Bijou Park	41-02	1.88	I	Sand	Both Banks	11-25%	0-10%	Fluvial	Fluvial	11-25%	0-10%	0-10%	0-10%	0-10%	0-10%	19.5	0	0	3	22.5
Bijou	42-01	0.54	VI	Sand	No	51-75%	0-10%	Fluvial	None	0-10%	0-10%	0-10%	26-50%	0-10%	0-10%	14.5	0	0	3.5	18
Bijou	42-02	2.16	I	Sand	No	0-10%	0-10%	None	None	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	16	0	0	3	19
Bijou	42-03	3.44	I	Sand	No	0-10%	0-10%	None	None	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	16	0	0	0	16
Trout	43-01	1.45	I	Sand	One Bank	51-75%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	10	0	0	0	10
Trout	43-02	2.49	I	Gravel/Sand	No	11-25%	0-10%	Fluvial	Fluvial	11-25%	0-10%	51-75%	51-75%	26-50%	0-10%	13	40	60	3.5	16.5
Trout	43-03	4.71	VI	Gravel/Sand	No	0-10%	0-10%	Fluvial	Fluvial	11-25%	11-25%	0-10%	11-25%	0-10%	0-10%	18	0	0	0	18
Trout	43-04	7.05	VI	Gravel/Sand	No	11-25%	11-25%	Mass Wasting	Fluvial	26-50%	0-10%	11-25%	11-25%	11-25%	26-50%	18.5	60	40	3	21.5
Trout	43-05	6.52	II	Gravel/Sand	One Bank	26-50%	0-10%	Fluvial	Mass Wasting	11-25%	26-50%	11-25%	11-25%	11-25%	0-10%	18.5	0	0	3	21.5
Trout	43-06	7.47	VI	Gravel/Sand	No	11-25%	11-25%	Fluvial	Mass Wasting	0-10%	11-25%	11-25%	11-25%	11-25%	0-10%	19	0	0	3	22
Trout	43-07	8.13	VI	Gravel	No	11-25%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	51-75%	11-25%	0-10%	14	60	40	3.75	17.75
Upper Truckee	44-01	24.2	III	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Fluvial	0-10%	0-10%	26-50%	26-50%	0-10%	0-10%	15	0	0	0	15
Upper Truckee	44-04	23.0	V	Boulder/Cobble	No	26-50%	0-10%	None	Fluvial	0-10%	11-25%	0-10%	0-10%	76-100%	0-10%	14.5	0	0	0	14.5
Upper Truckee	44-06	22.5	V	Boulder/Cobble	No	26-50%	0-10%	None	Mass Wasting	0-10%	76-100%	51-75%	0-10%	76-100%	0-10%	15.5	0	0	0	15.5
Upper Truckee	44-08	21.8	I	Boulder/Cobble	No	26-50%	0-10%	Mass Wasting	None	0-10%	0-10%	51-75%	51-75%	0-10%	0-10%	11	25	0	2.25	13.25
Upper Truckee	44-11	21.4	VI	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	51-75%	0-10%	0-10%	12.5	25	0	3.25	15.75
Upper Truckee	44-12	20.7	V	Boulder/Cobble	No	26-50%	0-10%	Mass Wasting	Mass Wasting	51-75%	11-25%	11-25%	11-25%	0-10%	11-25%	19.5	0	0	0	19.5
Upper Truckee	44-15	19.9	V	Gravel	No	51-75%	0-10%	Mass Wasting	Fluvial	51-75%	0-10%	11-25%	26-50%	0-10%	76-100%	16	15	0	3.75	19.75
Upper Truckee	44-16	19.3	IV	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Mass Wasting	11-25%	51-75%	11-25%	11-25%	0-10%	0-10%	20	0	15	3.75	23.75
Upper Truckee	44-17	18.6	V	Boulder/Cobble	No	26-50%	0-10%	None	Mass Wasting	0-10%	76-100%	51-75%	11-25%	76-100%	0-10%	15	0	0	0	15
Upper Truckee	44-19	18.0	VI	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	26-50%	11-25%	0-10%	12.5	5	15	2.25	14.75
Upper Truckee	44-20	17.8	V	Boulder/Cobble	No	26-50%	11-25%	None	Mass Wasting	0-10%	76-100%	11-25%	11-25%	76-100%	0-10%	17	0	0	0	17
Upper Truckee	44-21	16.9	VI	Boulder/Cobble	No	51-75%	0-10%	Fluvial	Fluvial	11-25%	0-10%	26-50%	26-50%	26-50%	26-50%	11	0	40	3.5	14.5
Upper Truckee	44-21a	16.4	VI	Boulder/Cobble	Bed and Banks	26-75%	26-50%	Fluvial	Fluvial	11-25%	11-25%	26-50%	26-50%	51-75%	51-75%	12.5	0	0	0	12.5
Upper Truckee	44-22	15.9	VI	Gravel	No	51-75%	26-50%	None	None	0-10%	0-10%	11-25%	51-75%	76-100%	76-100%	9.5	0	0	0	9.5
Upper Truckee	44-24	15.3	V	Boulder/Cobble	One Bank	26-50%	0-10%	None	Fluvial	0-10%	26-50%	51-75%	11-25%	76-100%	0-10%	14	0	0	0	14
Upper Truckee	44-26	14.8	V	Boulder/Cobble	No	26-50%	0-10%	None	Mass Wasting	0-10%	76-100%	51-75%	0-10%	76-100%	0-10%	15.5	0	0	0	15.5
Upper Truckee	44-30	14.1	VI	Boulder/Cobble	No	26-50%	0-10%	Fluvial	None	0-10%	0-10%	76-100%	76-100%	0-10%	76-100%	8.5	0	0	0	8.5
Upper Truckee	44-39	13.5	V	Boulder/Cobble	No	26-50%	0-10%	None	Mass Wasting	0-10%	76-100%	11-25%	0-10%	76-100%	0-10%	16.5	0	0	0	16.5
Upper Truckee	44-43	13.1	V	Boulder/Cobble	One Bank	11-25%	0-10%	Mass Wasting	Mass Wasting	51-75%	26-50%	0-10%	0-10%	26-50%	26-50%	21.5	0	0	0	21.5

Stream	Station number	River kilometer	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Stream bank erosion		Stream bank instability		Woody vegetative cover		Bank accretion		Channel stability index	Percent sediment contribution from side-slopes		Side-slope erosion	Combined stability index
								Left	Right	Left	Right	Left	Right	Left	Right		Left	Right		
Upper Truckee	44-59	12.1	V	Boulder/Cobble	No	26-50%	0-10%	None	Mass Wasting	0-10%	0-10%	26-50%	26-50%	0-10%	0-10%	15	0	0	0	15
Upper Truckee	44-67	11.2	V	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Mass Wasting	26-50%	51-75%	11-25%	0-10%	26-50%	26-50%	19	0	0	0	19
Upper Truckee	44-68	10.8	V	Gravel	One Bank	51-75%	11-25%	Mass Wasting	Fluvial	51-75%	0-10%	26-50%	11-25%	0-10%	76-100%	18	0	0	0	18
Upper Truckee	44-72	10.0	V	Gravel	No	26-50%	0-10%	None	Fluvial	0-10%	11-25%	0-10%	0-10%	76-100%	0-10%	15.5	0	0	0	15.5
Upper Truckee	44-75	8.50	V	Gravel	No	26-50%	0-10%	None	Mass Wasting	0-10%	76-100%	0-10%	0-10%	76-100%	0-10%	18	0	0	0	18
Upper Truckee	44-78	7.14	V	Sand	No	26-50%	0-10%	None	Mass Wasting	0-10%	76-100%	0-10%	0-10%	76-100%	0-10%	19	0	0	0	19
Upper Truckee	44-82	5.84	II	Sand	Both Banks	26-50%	0-10%	None	None	0-10%	0-10%	26-50%	26-50%	0-10%	0-10%	15	0	60	3.75	18.75
Upper Truckee	44-85	5.06	V	Sand	No	26-50%	0-10%	Fluvial	Mass Wasting	26-50%	26-50%	0-10%	0-10%	26-50%	0-10%	21	0	0	0	21
Upper Truckee	44-87	4.51	VI	Sand	No	51-75%	0-10%	Fluvial	Fluvial	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%	16.5	0	15	3.75	20.25
Upper Truckee	44-92	2.94	V	Gravel/Sand	One Bank	26-50%	0-10%	Mass Wasting	None	51-75%	11-25%	0-10%	51-75%	11-25%	76-100%	17.5	0	15	3.75	21.25
Taylor	46-01	0.90	I	Boulder/Cobble	No	26-50%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	8	0	0	0	8
Taylor	46-02	2.33	I	Boulder/Cobble	No	26-50%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	8	0	0	0	8
Tallac	47-01	1.37	I	Cobble/Gravel	No	76-100%	26-50%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	8.5	0	0	0	8.5
Tallac	47-02	2.20	I	Boulder/Cobble	No	11-25%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	9	0	0	0	9
Tallac	47-03	2.55	I	Gravel	No	26-50%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	9	0	0	0	9
Tallac	47-04	3.05	I	Boulder/Cobble	No	11-50%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	8.5	0	0	0	8.5
Tallac	47-05	2.95	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	7	0	0	0	7
Cascade	48-01	0.69	I	Boulder/Cobble	No	0-10%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	10	0	0	2	12
Eagle	49-01	0.58	I	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	11-25%	0-10%	5.5	0	0	1.5	7
Bliss State Park	50-01	0.41	I	Bedrock/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	5.5	0	0	0	5.5
Rubicon	51-01	0.92	I	Gravel	No	0-10%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	11	0	0	0	11
Rubicon	51-02	1.27	I	Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	26-50%	26-50%	6	0	0	2	8
Rubicon	51-03	1.60	I	Gravel/Sand	No	0-10%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	13.5	0	0	0	13.5
Rubicon	51-04	1.71	I	Bedrock/Gravel	No	26-50%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	8	0	0	0	8
Rubicon	51-05	2.11	I	Bedrock/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	5.5	0	0	0	5.5
Paradise Flat	52-01	0.62	V	Sand	No	0-10%	0-10%	Fluvial	Fluvial	11-25%	11-25%	76-100%	76-100%	0-10%	0-10%	18	0	0	0	18
Lonely Gulch	53-01	0.81	I	Cobble/Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	6.5	0	0	0	6.5
Lonely Gulch	53-02	1.24	I	Boulder/Cobble	No	0-10%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	10	0	0	0	10
Sierra	54-01	0.89	I	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	11-25%	11-25%	6	0	0	0	6
Meeks	55-01	1.23	I	Sand/Silt Clay	No	0-10%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	12.5	0	0	0	12.5

Stream	Station number	River kilometer	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Stream bank erosion		Stream bank instability		Woody vegetative cover		Bank accretion		Channel stability index	Percent sediment contribution from side-slopes		Side-slope erosion	Combined stability index
								Left	Right	Left	Right	Left	Right	Left	Right		Left	Right		
Meeks	55-02	3.15	V	Gravel	No	26-50%	0-10%	Fluvial	None	11-25%	0-10%	26-50%	51-75%	11-25%	51-75%	13	0	0	0	13
Meeks	55-03	3.50	V	Gravel	No	26-50%	0-10%	None	Fluvial	0-10%	11-25%	76-100%	76-100%	26-50%	0-10%	12.5	0	0	0	12.5
Meeks	55-04	3.50	V	Gravel	No	11-25%	0-10%	Fluvial	None	11-25%	0-10%	51-75%	76-100%	0-10%	26-50%	14	0	0	0	14
General	56-01	6.80	I	Boulder/Cobble	One Bank	76-100%	11-25%	None	Fluvial	0-10%	0-10%	11-25%	11-25%	76-100%	76-100%	8	0	0	2	10
General	56-02	6.66	I	Boulder/Cobble	No	0-10%	0-10%	None	Fluvial	0-10%	0-10%	51-75%	51-75%	76-100%	76-100%	8	0	0	3	11
General	56-03	6.50	V	Boulder/Cobble	No	0-10%	0-10%	Mass Wasting	Fluvial	76-100%	11-25%	51-75%	76-100%	0-10%	51-75%	17.5	60	20	6	23.5
General	56-05	6.06	I	Boulder/Cobble	No	0-10%	0-10%	None	Fluvial	0-10%	11-25%	76-100%	26-50%	76-100%	0-10%	10.5	0	85	5	15.5
General	56-06	5.90	V	Boulder/Cobble	No	0-10%	0-10%	None	Fluvial	0-10%	26-50%	76-100%	51-75%	76-100%	0-10%	13.5	0	95	6	19.5
General	56-08	5.33	I	Boulder/Cobble	No	0-10%	0-10%	Fluvial	Fluvial	11-25%	11-25%	76-100%	76-100%	11-25%	26-50%	11.5	20	60	5	16.5
General	56-09	5.25	III	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	11-25%	11-25%	51-75%	51-75%	26-50%	51-75%	11.5	0	0	3	14.5
General	56-11	5.05	I	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	0-10%	11-25%	76-100%	76-100%	26-50%	26-50%	8.5	0	0	0	8.5
General	56-12	4.73	V	Gravel	Bed and Banks	0-10%	11-25%	None	Mass Wasting	0-10%	76-100%	76-100%	76-100%	51-75%	0-10%	16.5	0	100	5	21.5
General	56-14	4.21	I	Boulder/Cobble	Both Banks	0-10%	0-10%	None	Fluvial	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	13	0	0	0	13
General	56-16	3.62	V	Gravel	One Bank	0-10%	0-10%	Fluvial	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	16	0	0	0	16
General	56-17	3.60	V	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Mass Wasting	0-10%	26-50%	76-100%	11-25%	26-50%	0-10%	16.5	0	0	0	16.5
General	56-18	3.59	VI	Boulder/Cobble	Bed and Banks	11-25%	0-10%	Fluvial	Fluvial	0-10%	11-25%	51-75%	51-75%	26-50%	11-25%	11.5	0	0	0	11.5
General	56-19	3.25	V	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Mass Wasting	0-10%	76-100%	76-100%	26-50%	76-100%	0-10%	15	0	0	0	15
General	56-20	2.97	I	Boulder/Cobble	No	11-25%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	11-25%	0-10%	8.5	0	15	3.25	11.75
General	56-21	2.58	IV	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Mass Wasting	0-10%	51-75%	51-75%	51-75%	0-10%	0-10%	17.5	15	60	4	21.5
General	56-23	2.20	V	Boulder/Cobble	No	0-10%	26-50%	None	Mass Wasting	0-10%	76-100%	11-25%	11-25%	76-100%	0-10%	20	0	0	0	20
General	56-24	1.94	V	Gravel	No	26-50%	0-10%	None	Fluvial	0-10%	26-50%	0-10%	76-100%	76-100%	0-10%	14	0	25	4.5	18.5
General	56-26	1.93	VI	Boulder/Cobble	No	51-75%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	51-75%	51-75%	51-75%	8.5	0	0	0	8.5
General	56-27	1.54	V	Boulder/Cobble	No	11-25%	0-10%	None	Mass Wasting	0-10%	51-75%	76-100%	76-100%	11-25%	0-10%	15	95	80	6.5	21.5
General	56-28	1.17	V	Boulder/Cobble	No	0-10%	0-10%	None	Mass Wasting	0-10%	11-25%	76-100%	76-100%	11-25%	0-10%	15	0	0	4	19
General	56-29	0.95	V	Boulder/Cobble	No	0-10%	11-25%	Fluvial	Mass Wasting	11-25%	76-100%	76-100%	0-10%	26-50%	0-10%	20.5	10	100	8	28.5
General	56-30	0.89	V	Gravel/Cobble	No	0-10%	0-10%	Fluvial	Mass Wasting	0-10%	11-25%	51-75%	26-50%	26-50%	0-10%	17.5	10	50	4.5	22
General	56-32	0.71	V	Gravel/Cobble	No	11-25%	0-10%	None	Fluvial	0-10%	11-25%	76-100%	51-75%	11-25%	11-25%	13.5	0	0	0	13.5
General	56-34	0.57	I	Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	8	0	0	0	8
General	56-36	0.30	I	Boulder/Cobble	No	11-25%	11-25%	None	Fluvial	0-10%	0-10%	76-100%	76-100%	26-50%	51-75%	8.5	85	95	6	14.5
General	56-37	0.01	V	Gravel	No	0-10%	0-10%	Mass Wasting	None	26-50%	0-10%	0-10%	0-10%	51-75%	76-100%	17.5	20	0	3.25	20.75

Stream	Station number	River kilometer	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Stream bank erosion		Stream bank instability		Woody vegetative cover		Bank accretion		Channel stability index	Percent sediment contribution from side-slopes		Side-slope erosion	Combined stability index
								Left	Right	Left	Right	Left	Right	Left	Right		Left	Right		
General	GC45	8.08	I	Boulder/Cobble	Bed and Banks	0-10%	0-10%	None	None	0-10%	0-10%	26-50%	11-25%	76-100%	76-100%	7.5	0	0	3	10.5
McKinney	57-01	0.28	VI	Cobble/Gravel	No	26-50%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	10	0	0	0	10
McKinney	57-02	1.25	I	Boulder/Cobble	No	11-25%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	9	0	0	0	9
Quail Lane	58-01	0.02	I	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	6	0	0	0	6
Quail Lane	58-02	0.21	I	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	0-10%	0-10%	7	0	0	0	7
Homewood	59-01	0.09	V	Gravel	No	0-10%	0-10%	Fluvial	Fluvial	26-50%	26-50%	26-50%	26-50%	26-50%	26-50%	18	0	0	0	18
Homewood	59-02	0.41	V	Boulder/Cobble	No	11-25%	26-50%	Fluvial	Fluvial	11-25%	11-25%	51-75%	76-100%	11-25%	26-50%	16	0	0	0	16
Madden	60-1	0.10	II	Boulder/Cobble	No	11-25%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	0-10%	0-10%	11	10	10	0	11
Blackwood	62-02	8.29	III	Bedrock/Cobble	Bed and Banks	11-25%	0-10%	None	None	0-10%	0-10%	76-100%	51-75%	11-25%	11-25%	9	0	75	2.5	11.5
Blackwood	62-04	8.19	III	Boulder/Cobble	Bed	11-25%	0-10%	Fluvial	None	0-10%	26-50%	26-50%	76-100%	11-25%	11-25%	13	20	20	5.75	18.75
Blackwood	62-04a	7.69	VI	Boulder/Cobble	No	51-75%	0-10%	Fluvial	Fluvial	11-25%	11-25%	26-50%	26-50%	76-100%	26-50%	10.5	10	40	3.5	14
Blackwood	62-05	7.18	VI	Boulder/Cobble	Bed	26-50%	0-10%	Fluvial	Fluvial	11-25%	11-25%	51-75%	26-50%	26-50%	26-50%	11	0	90	3	14
Blackwood	62-07	7.17	V	Boulder/Cobble	No	0-10%	11-25%	Fluvial	Mass Wasting	11-25%	76-100%	11-25%	0-10%	26-50%	26-50%	21	10	10	7	28
Blackwood	62-07a	6.84	V	Boulder/Cobble	No	51-75%	0-10%	None	Mass Wasting	0-10%	11-25%	51-75%	26-50%	76-100%	26-50%	11	0	80	3	14
Blackwood	62-08	6.51	V	Cobble/Gravel	No	11-25%	0-10%	None	Mass Wasting	0-10%	51-75%	76-100%	11-25%	76-100%	11-25%	15	20	20	6.5	21.5
Blackwood	62-10a	5.55	VI	Boulder/Cobble	No	51-75%	0-10%	None	Fluvial	0-10%	26-50%	51-75%	51-75%	76-100%	11-25%	9.5	50	50	3.5	13
Blackwood	62-10b	6.03	V	Cobble/Gravel	No	26-50%	0-10%	None	Mass Wasting	0-10%	26-50%	26-50%	11-25%	76-100%	11-25%	14.5	0	80	4	18.5
Blackwood	62-12	5.08	V	Boulder/Cobble	No	11-25%	0-10%	None	Mass Wasting	0-10%	51-75%	26-50%	11-25%	26-50%	0-10%	17	0	0	6.5	23.5
Blackwood	62-15	4.15	V	Cobble/Gravel	No	26-50%	0-10%	Fluvial	Fluvial	26-50%	11-25%	11-25%	26-50%	11-25%	11-25%	16.5	0	100	0	16.5
Blackwood	62-18	3.95	V	Cobble/Gravel	No	11-25%	26-50%	None	Mass Wasting	0-10%	76-100%	26-50%	0-10%	0-10%	76-100%	19.5	80	0	7.5	27
Blackwood	62-21	2.80	V	Cobble/Gravel	No	26-50%	0-10%	Mass Wasting	None	51-75%	0-10%	11-25%	51-75%	11-25%	51-75%	15	40	0	6.5	21.5
Blackwood	62-22a	1.97	V	Gravel	No	51-75%	0-10%	Fluvial	Mass Wasting	26-50%	11-25%	11-25%	11-25%	51-75%	0-10%	17	90	0	0	17
Blackwood	62-24	1.77	V	Gravel	No	26-50%	0-10%	Fluvial	Mass Wasting	11-25%	51-75%	26-50%	11-25%	76-100%	11-25%	17	0	0	5	22
Blackwood	62-30	0.32	V	Cobble/Gravel	Bed	11-25%	0-10%	Mass Wasting	None	51-75%	0-10%	11-25%	76-100%	11-25%	76-100%	15	0	0	6	21
Blackwood	62-32	0.00	II	Gravel	Both Banks	11-25%	0-10%	None	None	26-50%	26-50%	0-10%	0-10%	26-50%	26-50%	17	0	0	0	17
Ward	63-01	6.55	V	Boulder/Cobble	No	26-50%	0-10%	None	Fluvial	0-10%	26-50%	76-100%	26-50%	26-50%	51-75%	11.5	0	0	0	11.5
Ward	63-02	6.45	III	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	0-10%	11-25%	26-50%	51-75%	0-10%	0-10%	14	0	0	0	14
Ward	63-03	6.42	I	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	51-75%	26-50%	11-25%	51-75%	5.5	0	0	0	5.5
Ward	63-04	6.27	VI	Boulder/Cobble	No	26-50%	26-50%	None	Fluvial	0-10%	11-25%	51-75%	26-50%	51-75%	0-10%	13	0	0	0	13
Ward	63-05	6.17	III	Boulder/Cobble	No	26-50%	0-10%	Fluvial	None	11-25%	0-10%	26-50%	51-75%	0-10%	0-10%	13	0	0	0	13

Stream	Station number	River kilometer	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Stream bank erosion		Stream bank instability		Woody vegetative cover		Bank accretion		Channel stability index	Percent sediment contribution from side-slopes		Side-slope erosion	Combined stability index
								Left	Right	Left	Right	Left	Right	Left	Right		Left	Right		
Ward	63-06	6.10	V	Boulder/Cobble	No	51-75%	0-10%	Fluvial	None	11-25%	0-10%	51-75%	26-50%	11-25%	0-10%	12.5	0	0	0	12.5
Ward	63-08	5.94	V	Boulder/Cobble	No	26-50%	0-10%	None	Mass Wasting	0-10%	76-100%	26-50%	0-10%	76-100%	0-10%	16	0	0	0	16
Ward	63-09	5.87	VI	Boulder/Cobble	No	26-50%	0-10%	None	Fluvial	0-10%	0-10%	26-50%	26-50%	11-25%	0-10%	12	0	0	0	12
Ward	63-10	5.81	V	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	0-10%	11-25%	76-100%	51-75%	51-75%	51-75%	11	0	0	0	11
Ward	63-12	5.53	V	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	11-25%	0-10%	11-25%	51-75%	0-10%	26-50%	14.5	0	0	0	14.5
Ward	63-13	5.36	V	Boulder/Cobble	No	26-50%	0-10%	None	Fluvial	0-10%	26-50%	51-75%	11-25%	76-100%	26-50%	12	0	0	0	12
Ward	63-14	5.12	V	Boulder/Cobble	No	51-75%	0-10%	Fluvial	Mass Wasting	0-10%	26-50%	76-100%	11-25%	51-75%	0-10%	14	0	0	0	14
Ward	63-15	4.74	V	Boulder/Cobble	One Bank	26-50%	0-10%	None	Mass Wasting	0-10%	76-100%	51-75%	0-10%	76-100%	0-10%	16.5	0	0	0	16.5
Ward	63-16	4.52	VI	Boulder/Cobble	No	51-75%	0-10%	Fluvial	Fluvial	11-25%	11-25%	51-75%	51-75%	0-10%	0-10%	12.5	0	0	0	12.5
Ward	63-18	4.25	V	Boulder/Cobble	No	26-50%	0-10%	Mass Wasting	None	26-50%	0-10%	11-25%	26-50%	0-10%	26-50%	15.5	0	0	0	15.5
Ward	63-19	4.06	VI	Boulder/Cobble	Bed and Banks	11-25%	0-10%	Fluvial	Fluvial	11-25%	11-25%	76-100%	76-100%	76-100%	76-100%	8.5	0	0	0	8.5
Ward	63-21	3.64	V	Boulder/Cobble	No	11-25%	0-10%	Mass Wasting	Fluvial	51-75%	26-50%	11-25%	26-50%	11-25%	26-50%	18.5	0	0	0	18.5
Ward	63-22	3.51	V	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Mass Wasting	11-25%	51-75%	51-75%	51-75%	76-100%	11-25%	14.5	0	50	5	19.5
Ward	63-23	3.28	VI	Boulder/Cobble	No	11-25%	0-10%	None	Mass Wasting	0-10%	0-10%	11-25%	26-50%	11-25%	51-75%	13	0	0	0	13
Ward	63-25	2.64	VI	Boulder/Cobble	No	26-50%	0-10%	None	Fluvial	0-10%	0-10%	26-50%	51-75%	76-100%	51-75%	8.5	0	30	3	11.5
Ward	63-26	2.38	V	Boulder/Cobble	No	26-50%	26-50%	Fluvial	Mass Wasting	11-25%	51-75%	26-50%	51-75%	51-75%	0-10%	18	0	30	2.5	20.5
Ward	63-29	2.08	VI	Boulder/Cobble	No	11-25%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	26-50%	11-25%	11	0	80	2	13
Ward	63-30	1.97	VI	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	51-75%	26-50%	11-25%	10.5	0	30	3.5	14
Ward	63-32	1.55	VI	Boulder/Cobble	No	26-50%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	76-100%	26-50%	26-50%	10	0	0	0	10
Ward	63-33	1.42	V	Boulder/Cobble	No	11-25%	0-10%	Mass Wasting	Fluvial	26-50%	0-10%	51-75%	51-75%	26-50%	51-75%	13.5	0	0	0	13.5
Ward	63-34	1.29	V	Boulder/Cobble	No	11-25%	0-10%	None	Mass Wasting	0-10%	51-75%	76-100%	76-100%	76-100%	0-10%	13.5	0	0	0	13.5
Ward	63-35	1.14	VI	Boulder/Cobble	No	51-75%	0-10%	None	Fluvial	0-10%	11-25%	76-100%	76-100%	26-50%	51-75%	7.5	0	0	0	7.5
Ward	63-36	1.12	VI	Boulder/Cobble	Bed and Banks	26-50%	26-50%	Mass Wasting	Fluvial	26-50%	0-10%	76-100%	76-100%	26-50%	26-50%	12.5	0	0	0	12.5
Ward	63-37	1.11	VI	Boulder/Cobble	One Bank	11-25%	0-10%	Fluvial	Fluvial	26-50%	0-10%	26-50%	76-100%	11-25%	0-10%	15	0	0	0	15
Ward	63-39	0.78	V	Boulder/Cobble	No	11-25%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	11-25%	26-50%	0-10%	76-100%	17.5	0	0	0	17.5
Ward	63-40	0.63	V	Boulder/Cobble	One Bank	11-25%	0-10%	Fluvial	Mass Wasting	0-10%	26-50%	26-50%	26-50%	26-50%	26-50%	17	0	30	3.5	20.5
Ward	63-41	0.51	VI	Boulder/Cobble	No	11-25%	11-25%	None	Fluvial	0-10%	11-25%	26-50%	51-75%	26-50%	26-50%	12.5	0	0	0	12.5
Ward	63-42	0.44	V	Boulder/Cobble	No	11-25%	11-25%	Mass Wasting	Mass Wasting	76-100%	11-25%	11-25%	51-75%	0-10%	76-100%	19.5	0	0	0	19.5
Ward	63-43	0.25	V	Boulder/Cobble	No	11-25%	0-10%	Mass Wasting	Fluvial	26-50%	26-50%	26-50%	51-75%	11-25%	11-25%	17.5	0	0	0	17.5
Ward	63-44	0.09	VI	Boulder/Cobble	No	26-50%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	76-100%	76-100%	5.5	0	0	0	5.5

G Appendix G

CONCEPTS Model Cross-Section Data

Table G-1. Table of CONCEPTS values used in the General Creek simulation.

CONCEPTS cross-section	New name	River kilometer	Bed roughness	Bank			Floodplain roughness
				Critical shear stress (Pa)		Roughness	
				Left	Right		
1	1	6.80	0.15	53	53	0.15	0.2
2	4	6.39	0.15	5	4	0.15	0.2
3	6	5.90	0.15	4	4	0.15	0.2
4	9	5.25	0.15	4	5	0.15	0.2
5	12	4.73	0.15	4	4	0.15	0.2
6	13	4.21	0.15	7	7	0.15	0.2
7	15	3.62	0.10	4	5	0.10	0.2
8	18b	3.12	0.10	8	8	0.10	0.2
9	20	2.58	0.10	53	53	0.10	0.2
10	23	1.95	0.10	2	2	0.10	0.2
11	26	1.54	0.10	20	20	0.10	0.2
12	27	1.17	0.10	20	20	0.10	0.2
13	30	0.71	0.10	6	4	0.10	0.2
14	35	0.30	0.10	4	4	0.10	0.2
15	36	0.01	0.10	2	2	0.10	0.2

Table G-2. Table of CONCEPTS values used in the Upper Truckee River simulation.

CONCEPTS cross-section	New name	River kilometer	Bed roughness	Bank			Floodplain roughness
				Critical shear stress (Pa)		Roughness	
				Left	Right		
1	1	24.19	0.10	2.5	2.5	0.08	0.15
2	2	23.71	0.10	9	7	0.08	0.15
3	4	23.01	0.10	4	4	0.08	0.15
4	6	22.54	0.10	7	7	0.08	0.15
5	7	21.86	0.10	8	8	0.08	0.15
6	11	21.37	0.10	8	9	0.08	0.15
7	12	20.75	0.10	6	6	0.08	0.15
8	14	20.14	0.10	6	6	0.08	0.15
9	SYN	19.54	0.10	6	6	0.08	0.15
10	SYN	18.94	0.10	6	6	0.08	0.15
11	18	18.34	0.10	6	6	0.08	0.15
12	20	17.78	0.10	9	6	0.08	0.15
13	SYN	17.14	0.10	6	6	0.08	0.15
14	SYN	16.51	0.10	6	7	0.08	0.15
15	22	15.87	0.08	6	7	0.08	0.15
16	24	15.28	0.06	6	6	0.08	0.15
17	26	14.77	0.05	100	100	0.08	0.15
18	30	14.07	0.05	5	5	0.08	0.15
19	36	13.70	0.05	0.5	3	0.06	0.15
20	39	13.52	0.05	0.5	0.5	0.06	0.15
21	42	13.16	0.05	0.25	0.25	0.05	0.15
22	47	12.87	0.05	0.25	0.25	0.05	0.15
23	50	12.73	0.05	0.5	0.5	0.06	0.15
24	53	12.47	0.05	0.5	0.5	0.05	0.15
25	57	12.20	0.05	6	9	0.06	0.15
26	61	11.68	0.05	0.5	0.5	0.05	0.15
27	67	11.21	0.05	4	4	0.05	0.15
28	68	10.84	0.05	4	4	0.05	0.15
29	71	10.56	0.05	4	4	0.05	0.15
30	72	10.04	0.05	4	4	0.05	0.15
31	73	9.41	0.05	4	4	0.05	0.15
32	74	8.81	0.05	4	4	0.05	0.10
33	SYN	8.12	0.05	4	4	0.05	0.10
34	77	7.59	0.05	6	6	0.05	0.10
35	79	6.91	0.05	4	4	0.05	0.10
36	81	6.28	0.05	4	4	0.05	0.10
37	83	5.58	0.05	4	4	0.05	0.10
38	85	5.06	0.05	4	4	0.05	0.10
39	87	4.51	0.08	6	6	0.05	0.10
40	SYN	3.94	0.05	4	4	0.05	0.10
41	90	3.37	0.05	4	4	0.05	0.10
42	96	2.77	0.05	4	4	0.05	0.10
43	103	2.26	0.05	6	6	0.05	0.10
44	109	1.62	0.05	6	6	0.05	0.10
45	114	1.04	0.05	4	4	0.05	0.10
46	117	0.38	0.05	4	4	0.05	0.10

Table G-3. Table of CONCEPTS values used in the Ward Creek simulation.

CONCEPTS cross-section	New name	River kilometer	Bed roughness	Bank			Floodplain roughness
				Critical shear stress (Pa)		Roughness	
				Left	Right		
1	11	5.80	0.10	6	4	0.10	0.2
2	12	5.53	0.10	6	1	0.08	0.2
3	14	5.12	0.08	2.5	6	0.10	0.2
4	15	4.74	0.10	1.5	25	0.08	0.15
5	17	4.36	0.10	1.5	6	0.08	0.2
6	19	4.06	0.10	8	8	0.08	0.2
7	21	3.64	0.08	10	0.5	0.06	0.15
8	23	3.28	0.10	15	0.5	0.08	0.2
9	24	3.01	0.10	25	0.5	0.08	0.15
10	25	2.64	0.12	10	2	0.10	0.15
11	27	2.28	0.10	15	4	0.08	0.2
12	30	1.97	0.12	15	15	0.10	0.2
13	32	1.55	0.12	15	15	0.10	0.2
14	35	1.14	0.15	20	20	0.10	0.2
15	39	0.78	0.12	12	12	0.08	0.2
16	42	0.44	0.10	10	12	0.08	0.2
17	44	0.09	0.08	15	15	0.06	0.15

H Appendix H

Response to Comments

Subject: **Response to Comments – Lake Tahoe Basin Framework Implementation Study: Sediment Loadings and Channel Erosion**

This document provides the response to comments received for the Lake Tahoe Basin Framework Implementation Study: Sediment Loadings and Channel Erosion. Comments were received from:

Tahoe Regional Planning Agency (TRPA)	July 15, 2003
Hydroikos Associates	July 22, 2003
Nevada Division of Environmental Protection	August 26, 2003
UC Davis Tahoe Research Group (TRG)	September 1, 2003
US Geological Survey (Nevada District)	October 2, 2003

Each comment is presented below for reference and is followed by a response in italics. Some comments were omitted if the comment regarded punctuation and/or grammatical corrections. These comments were incorporated into the document.

A. Tahoe Regional Planning Agency (TRPA), July 15, 2003

Comment 1: pg 1-8, the reference to the watershed map should cite TRPA as the source, there is another watershed map we frequently use by Jorgensen that was an HA by the survey that has 109 sheds.

Response: *Source of the map has been changed to "TRPA".*

Comment 2: Pg 2-16, on Table 2-8, it would be nice to have a column or even a separate table with the station site id and the name of the site. I know the site id's pretty well but especially for the multiple stations, to reference Martin Av Trout Creek compared to the upper USFS site.

Response: *Because different agencies use different names and numbers we thought it better to retain one numbering convention throughout the report, that being USGS station numbers.*

Comment 3: Pg 3-6, as per Kip's comment on Second Creek, a mention of the debris flow is probably needed to clarify the cause of the high numbers, here's the reference to Pat's report on that, prior to the 1988 Glancy paper;

Response: *Although we had included a statement describing flash floods and changes in channel characteristics, we added a statement about the debris flow on Second Creek.*

Comment 4: Pg 3-23, although the delivery of sands and gravels is not as critical to the lake itself, we are concerned with the erosion of these that get onto a roadway and become ground up to the finer particles, which could then get to the lake.

Response: *OK*

Comment 5: Pg 3-28, regarding disturbances are not only related to the upper Third Creek watershed (avalanche), there is a tributary to Third called Rosewood that has had a significant contribution to Third over time, notable a failed erosion control in the spring of 1997, unrelated to the flood.

Response: *OK, noted.*

Comment 6: Also on this page, there is no small lake between the two stations on Trout Creek, you could be thinking of Lake Baron just downstream of the Meyers Upper Truckee station, or Lake Christopher which was on Cold Creek below Pioneer Trail.

Response: *Our mistake, text changed accordingly.*

Comment 7: Pg. 3-42, although I agree the link to clarity can be used at Ward because of the long term data collection link, Ward still has about the highest precip levels in the basin (USGS WRI 99-4110), which makes it difficult to apply to the rest of the basin.

Response: *It is for the reason that you mention that we feel that Ward would be a good long-term monitoring station. Data from this watershed would then be able to provide a conservative estimate of changes in lake clarity.*

Comment 8: Section 4.6, starting on pg. 4-17: in all the tables of RGA's and streamwalks it would be helpful to have an inset of where in the walk the stream gages are, or a reference to the Hwy. On Upper Truckee we generally call the gages not Hwy 50 bridges since they are all close to a Hwy 50 bridge, but the Meyers gage, the Elks Club bridge, the Carrows site, and for Trout, the Pioneer gage, Martin gage, ect. My comment above on naming the sites could be referenced here.

Response: *Names will not be added because agencies may use different naming conventions. However, as per your suggestion, stream-gage locations have been added to the tables.*

Comment 9: Also the tables of the recon work starting with Upper Truckee went from the lake upstream, until 4.6.4 on page 4-42. At General it looks like the survey starts from the headwaters down to the lake, then switches back to the lake to upstream at Edgewood, pg 4-62.

Response: *Concur. We have changed the arrangement of the General Creek Table and write-up to be consistent with the other streams.*

Comment 10: Pg. 5-21, it sounds like you did Not use Echo Creek data at all, because of diversions, it is a problem because the diversions are not consistent, still it is a significant tributary to Upper Truckee and should probably be labeled as such.

Response: *Since the flows from Echo Creek were diverted out of the Upper Truckee watershed it was not considered for the simulations. Only the portions of the watershed contributing to flow to Lake Tahoe during the simulation period were considered as part of the watershed.*

Comment 11: There's a period typo on 5-79.

Response: *OK, fixed.*

B. Hydroikos Associates, July 22, 2003

Comment 1: P. 2-12 (methods). When you do a regression of log Load vs. log Discharge, you get a spurious correlation, since L = C x Q. The final load estimates are exactly the same if you regress log Ci vs log Qi. The r2 just looks better with log L vs. log Q.

Response: *Concur. The following statement has been added: "Regressions equations of load (L) versus discharge (Q) (like eq. 7) have spuriously high coefficients of determination (r^2) because Q is included on both sides of the equation. This, however, does not effect calculations of load if the alternative (discharge versus concentration) is used."*

Comment 2: A correction for retransformation bias is usually applied to estimates of daily load; this is necessary because of the bias introduced when you go from log space back to arithmetic space. Did you apply such a factor, and if so, which one?

Response: *We are well aware that transformations are often applied to sediment transport data emanating from regression analysis. In this study we decided against using a transformation after initial trials. The following has been added to the manuscript to address this issue: "In this study, a decision was made not to apply a correction factor, following some preliminary trials using Lake Tahoe gaging-station data which showed inconsistent results. A standard approach to transform this type of data does not exist. Loads were first estimated using the regression equation directly, and second with application of several different correction factors: Quasi Maximum Likelihood Estimator, Smearing Estimator, and Minimum Variance Unbiased Estimator (Ferguson, 1986, USGS, 2003). The various correction factors generated differing results. In an example published by the USGS (2003), the three transformation techniques listed above provided results different in both magnitude and direction. The USGS (2003) also emphasize other factors may be more important than correcting any bias: "the misspecification of the appropriate regression model in a particular situation can yield sizable errors and render any care taken in correcting for bias as a useless exercise". Because of the care taken in this study to assure that the regression models used were appropriate, and the uncertainty and lack of consistency in transformation results, no correction factor was applied to the sediment load data reported here."*

Comment 3: P. 2-15, Sec. 2.7.3. It is important to express yields on a per area basis, as you have done. But much of the later discussion is framed in terms of total load for each watershed, not yield. (e.g. p. 7-4).

Response: *Concur. We start with loads and then go back to yields (per unit area) when we discuss differences between sites and/or watersheds because it helps to understand dominant* *controls and processes. Still, loads are important in terms of the total volume of material being delivered to the lake.*

Comment 4: P. 3-4, Table 3-1. It would be useful to have the total yield of each watershed for the same time interval (1993-2001 should work for 18-20 watersheds). This is especially important since the interannual variation is so high; comparisons between watershed yield rates could be biased if the time period is not consistent. Appendix E (annual totals) seems to be missing. The totals for fine sediment for a common time period would also be important, perhaps more so than for SS. I also have a set of independent variables for the watersheds, and I would like to test your fine sediment yield data against my watershed variables using PCA or multiple regression**.**

Response: *Although the suggestion is a good one the problem with comparing data from the same time interval is that it greatly restricts the length of record, number of samples and, therefore, the reliability of the results. Our approach was to use the longest period of record available and then to use median values so as to reduce the effects of outlier data. Appendix E is on the CD contained in the report. We are happy to make all of our data available to you.*

Comment 5: P. 3-13 (and p. 7-3) How good are the SS data for all streams during the Jan '97 storm? Do the data actually support estimates of recurrence intervals? What method did you use to calculate the curve?

Response: *Given that the flow and sediment data are from the U.S. Geological Survey, we assume that the data is first rate. Estimates of recurrence intervals come from the peak-flow data from the USGS using the standard Log-Pearson III technique as described in the text.*

Comment 6: P. 3-17, Table 3-7. These are very interesting and useful data. Since some the watersheds have both upstream (secondary)and downstream (primary) stations (e.g. Ward Cr.), it would be useful to subtract out the upstream from the downstream load (where you have common time periods), and show the yield for the area that contributes runoff between the stations. That should help sort out land use impacts in some cases.

Response: *We have done this later in the chapter by comparing upstream and downstream stations within several watersheds where sufficient data were available.*

Comment 7: P. 5-79, para. 2, line 5. Seems to be a phrase missing.

Response: *Concur; fixed.*

Comment 8: P. 6-6, Sec. 6.2.4, 2nd paragraph. I agree that the volcanic breccia "badlands" of Ward and Blackwood should be rated as highly erodible (a no-brainer). But you can't support that on the basis of high suspended sediment yields, and then use suspended sediment data to test the erosion potential map. It sounds a little circular to me. I think a wording change would take care of the problem.

Response: *That's not quite what we did. Surficial geology was ranked as were the other indicies used in the erosion-potential index as objectively as possible. This empirical technique relies on the sum of the various factors. This area ranked high due to a combination of those factors (geology, slope precipitation etc.). The sediment data is then used to test this.*

Comment 9: P. 6-8. Did you coordinate with Matt Luck, who did a lot of GIS work for TRG? He developed mean ann. precipitation estimates (at 4 km grid size) for me from: PRISM (Parameter-elevation Regressions on Independent Slopes Model; Daly et al., 1994 [Daly, C., R.P. Neilson, and D.L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology, 33, 140-158.])

Response: *The short answer to this question is no, we were not aware of this person or his work. The long answer is that we spent considerable time hunting for additional/better precipitation data in the literature, from data bases on the Web and through our contacts in the region. Nobody made us aware of these data.*

Comment 10: P. 6-13, Sec. 6.3.3. I would like more detail on the regression of the different SS variables vs. the upland erosion potential index. Which gaging stations/watersheds did you use? Did you subtract out the upstream loads from the downstream loads, and calculate the index for the contributing area between stations? If you don't do that, you have to throw out the downstream stations, since they do not represent independent observations; the effects at upstream station are nested within the effects at downstream stations. It would be very interesting to try a step-wise multiple regression with the different erodibility indices. You might find that just 3 of them will give you an $r^2 = 0.60$, and the rest don't help all that much. You could also try interaction terms, e.g. (soil erodibility (k) index) x (precipitation index). That might bring Ward and Blackwood into line. (Land cover/land use) x (precip) might also be useful.5-79, para. 2, line 5. Seems to be a phrase missing.

Response: *All good points. Sediment-transport data from 24 gaging stations were used. A table (Table 6-9) has been added listing which stations were used in the analysis. We did attempt a number of interaction terms without much success. We did not subtract out the upland loads from the downstream loads and re-calculate the contributing drainage areas as you suggest. This could be fruitful but did not have sufficient time to re-do the analysis.*

Comment 11: P. 7-4. "Loads from western streams are not increasing with time as reported by others"—who are the others (USGS Water Resour. Inv. Rep. 02-4030, perhaps)? Should cite them here.

Response: *You are correct in that we are referring to the Rowe et al., (2002) report. It is customary not to use citations in abstracts or conclusions so we have left it out here. We have cited that report and the fact that our results disagree in the body of the manuscript.*

C. Nevada Division of Environmental Protection, August 26, 2003

- **Comment 1:** Page 2-3: what is phi superscript b stated in number 3? Is this the friction angle?

Response: *Definition of* ϕ^b *has been added to the text.*

Comments 2-4: Section 2-6: it does not appear that any bias correction method was applied when regression models were retransformed into log space. This is a concern as calculated loads may grossly over or underestimate the actual load.

- Taken form USGS website: "Estimates of suspended sediment loads are often derived from periodic data using regression models. Many of the regression models involve transformation into logarithmic space, but final results are often required to be in original engineering units; therefore, retransformation of load data is needed. This retransformation involves a bias correction problem" that has received much attention." The entire report, including methods commonly used to overcome this problem is available at: http://co.water.usgs.gov/sediment/bias.frame.html
- It is recommended that the question of bias correction be addressed in one manner or another for this study: either one method should be applied to calculated loads, or it should be justified why no bias correction method was utilized.

Response: *The issue of bias correction is now addressed in the text in considerably more detail. In this study we decided against using a transformation after initial trials. The following has been added to the manuscript to address this issue: "In this study, a decision was made not to apply a correction factor, following some preliminary trials using Lake Tahoe gaging-station data which showed inconsistent results. A standard approach to transform this type of data does not exist. Loads were first estimated using the regression equation directly, and second with application of several different correction factors: Quasi Maximum Likelihood Estimator, Smearing Estimator, and Minimum Variance Unbiased Estimator (Ferguson, 1986, USGS, 2003). The various correction factors generated differing results. In an example published by the USGS (2003), the three transformation techniques listed above provided results different in both magnitude and direction. The USGS (2003) also emphasize other factors may be more important than correcting any bias: "the misspecification of the appropriate regression model in a particular situation can yield sizable errors and render any care taken in correcting for bias as a useless exercise". Because of the care taken in this study to assure that the regression models used were appropriate, and the uncertainty and lack of consistency in transformation results, no correction factor was applied to the sediment load data reported here."*

Comment 5: Page 2-14, 1st paragraph refers to Appendix C; I could not locate this Appendix.

Response: *Perhaps the copy you reviewed did not include the accompanying data CD. Appendix C is on the CD.*

Comment 6: Table 2-8 (page 2-16): it would be helpful to reformat this table by breaking it down by watershed

Response: *We appreciate the suggestion but because there are 64 watersheds and many with only one station we decided that throughout the document we would sort sites by USGS station numbers. This way there is also no confusion because of different naming conventions by different agencies.*

Comment 7: Tables 2-10 and 2-11: include r^2 values for each equation

Response: *r^2 values for each equation are in Appendix C.*

Comment 8: Section 2.7.3 (page 2-15): it would help to add a clarifying statement that yields are loads that have been normalized according to drainage area for each sub-watershed.

Response: *The clarifying statement that you suggest be added was already in the text.*

Comment 9: Section 2.8.2: statement is made that "All tributary channels in each of the Lake Tahoe watersheds simulated by AnnAGNPS is assumed to be stable and therefore not eroding." Because channel sediments were determined to comprise a significant amount of the suspended sediments yielded form modeled watersheds, is this a proper assumption to make? This implies to me that the result is an underestimation of channel sediment contributions – is this correct? If so, it would seem that the amount of underestimation would be directly proportional to the length of stream assumed to be stable. Perhaps information could be provided regarding the length of stream assumed to be stable for each watershed, and how much loadings would increase if these reaches functioned similarly to the contributing stream length of their respective watershed.

Response: *Extensive surveys of all tributaries were not made as part of this project because of the severe time constraint for its completion. During the main channel surveys occasional observations were made on the condition of the tributaries and no significant instabilities in those were found. Localized channel erosion could be present, but its contribution was determined to be minor. With additional time and resources the conditions for all of the tributaries can be determined.*

Comment 10: Section 3-2: is there a significant difference in the climate/precip regime from the 70s to today? how does climate change factor into the differences for average, mean daily flows for Incline and Third Creeks from the 70's to today and can the altered hydrology be related to increase in development/imperviousness in these watersheds?

Response: *We obtained precipitation data from various sources for this study to cover the validation modeling periods. Only one precipitation gage in the basin goes back to the 1930s (Tahoe City). We did not obtain these data and are, therefore, unable to state conclusively that conditions have not changed. This is why the text states that this is an assumption.*

Comment 11: Table 3-2 (page 3-4): it would be helpful to include the prediction interval on this table (predicted high and low load values)

Response: *Concur. This has been added to Appendix E.*

Comment 12: Page 3-6: data for First, Second, and Wood Creeks are from the early 70's – this should be clarified that the only USGS data available is from this time period. NDEP has collected 6 samples per year on these Creeks since 1993 (n is approx 50). I am sure it is too late to incorporate this data into your study, but the data is available if you would like to take a look at it. I was thinking about doing something similar to your study to compare results and see if this data does in fact support your hypothesis that loads have decreased in these watersheds over time. I would love to talk to you further regarding this, as it would be great to get your input. Anyways, justification for not including this data may be that it is two different sampling protocols: we use grab samples and analyze by the TSS method and it is not event based; if anything it is biased towards ambient conditions. This is in stark contrast to the LTIMP event-based sampling program. This also raises a question: since LTIMP data may be biased towards storm/snowmelt events, does this bias the rating curve approach?

Response: *We have made it very clear that the data from First, Second and Wood Creeks are only from the 1970's. As you say, it is too late to add additional data although we sure would have had these additional samples included in our data set. The existence of these data has now been noted in the text. Regarding the different protocols for sampling by your agency and by LTIMP, I would not think that event-based sampling is high-flow biased. Keep in mind that these are the periods (often very short) that transport the bulk of the annual sediment load.*

Comment 13: Figure 3-3, 3-8: It may be helpful to include prediction intervals on these graphs

Response: *Concur. This has been added to Appendix E.*

Comment 14: Table 3-7: can you include a similar table for fine sediment yields? If not, can the fine sediment proportion for First, Second and Wood Creeks be extrapolated from Third and Incline Creeks (see comment regarding section 3-6 below)

Response: *The similar Table you are requesting for fine sediment is Table 3-9.*

Comment 15: Page 3-18, last paragraph: "Over the period of record [26 years], Third Creek produces as much sediment per unit area as unstable streams on the western side of the lake…" Is this true when using the post-97 rating curve for this water? My thought here is that performing this analysis would help to document the recovery of the system.

Response: *Concur. This is exactly what we did to analyze the data. What is the question?*

Comment 16: Table 3-8 (page 3-22): It would be helpful to label the index stations for each watershed.

Response: *Concur. Change has been made to Table 3-8.*

Comment 17: Figure 3-9(page 3-23): would quadratic equations result in better fits for the lower discharges?

Response: *Because of the variability in these relations, different functions were used for different sites.*

Comment 18: It may be helpful to include all charts defining fine sediment relationship to Q for each station as an appendix
Response: *These are included in Appendix D.*

Comment 19: Performing an analysis of the comparability of fine sediment relation to Q between watersheds within quadrants may enable the fine sediment relations to be extrapolated to other watersheds within the same quadrant for which these relationships could not be developed (due to the limited data sets for these watersheds). it may be helpful to include all charts defining fine sediment relationship to Q for each station as an appendix

Response: *There is too much variability to extrapolate to other watershed. Relations are included in Appendix D.*

Comment 20: Section 3-7 (page 3-28), first paragraph: can you please clarify why "median-annual concentrations are greatest at the downstream-most locations of the five watersheds" indicates that progressively more sediment entrained from channel sources. Could the sediment not be derived from runoff from the developed area?

Response: *Good point. The text has been changed to reflect your interpretation.*

Comment 21: Section 3-9:

- 1st paragraph: Is there any way to verify the fundamental assumption that precipitation characteristics over the past 40 years have not changed substantially beyond the stochastic variations inherent in runoff production?
- Another method of developing parallel lines of evidence is using Double Mass Plots; if you would like to include this approach and need more info, please contact me. This method would be applicable to section 3.9.2 in determining shifts in suspended sediment transport ratings
- Should the year 1997 be used as a cutoff date for those watersheds for which the flood was determined to be a high recurrence interval since this may have resulted in flushing and a different transport rating beyond this date? Was this done for the western watersheds?

Response: *See response to comment 10. The use of double mass-curves could not be applied to sediment-transport ratings. We would need to select either annual values or values at a given flow rate. The parallel lines of evidence we have used to determine temporal shifts are sufficient. All watershed were treated the same. 1997 was used as a cutoff because of the objectives of the study…to determine loads before and after the event.*

Comment 22: Section 3.11: it may be helpful to provide a discussion of the statistical tests used for reference, so unfamiliar readers may learn about them; maybe as an appendix?

Response: *This report is not a textbook but a technical report. The description of statistical analyses is sufficient for a well-informed reader*

Comment 23: Section 3.11: it may be helpful to provide a discussion of the statistical tests used for reference, so unfamiliar readers may learn about them; maybe as an appendix?

Response: *This manuscript is not a textbook but a technical report. The description of statistical analyses is sufficient for a well-informed reader*

Comment 24: In many of the figures in Chapter 4, it is difficult to visualize all the colors representing the results of the RGAs or maps of the relative contribution of fine sediments from streambank erosion; try to provide larger figures.

Response: *Producing larger figures (fold-outs) are not possible logistically. We agree that it would be more convenient but differentiating colors is no problem at their given size.*

Comment 25: Section 4.3.2: a more in-depth explanation of the Channel Evolution Model and how the RGAs were performed would certainly be helpful to understand how this was used to evaluate the channel stability.

Response: *Figure 4-4 provides the details of the field data collected during the RGAs. Figure 4-5 provides a detailed schematic of the stages of channel evolution with the associated dominant channel processes. Appropriate references are also provided. We feel that further discussion would be overkill.*

Comment 26: It would be helpful to include a Summary Table of Figures 4-35 through 4-37 located at the beginning or end of section that includes all streams assessed and summarizes the entire length of stream for each category.

Response: *Not quite sure what the reviewer means here. Figures 4-35 to 4-37 are for General Creek. The text provides a statement regarding the length of the reach.*

Comment 27: Table 4-5: the headers should be relabled to distinguish the work by the valley length (include this word in 4th column header) versus the centerline length (include this word in 5th column header).

Response: *Concur. Changes made as suggested.*

Comment 28: Table 4-11: provide the UTM zone in the caption (Nevada is 11, CA is 10)

Response: *Concur. Changes made as suggested.*

Comment 29: Figure 4-41: why is there a break in the evaluation of the relative contribution of fine sediment from streambank erosion along Incline Creek?

Response: *Creek enters a tunnel.*

Comment 30: Regarding Figures 4-52 through 4-55

- Watersheds should be labeled on all Figures
- The overlapping dots in some watersheds are very hard to visualize. Could this figure be modified to present only the unstable areas/reaches (show only the red and orange dots)? Is there some way to come up with an overall stability rating for each watershed? There appears to be a lot of unstable reaches in East Shore watersheds. Does this warrant further discussion or were these watersheds not studied enough to provide further comment?

Response: *Adding labels to the 64 watersheds on these maps would make them extremely difficult to read. Honestly, we do not have difficulty seeing the different dots. To remove the dots representing stable reaches would reduce the value of the basin-wide maps. The comment about the east-side watersheds is well taken. In reviewing the raw data we came across some errors. These have been fixed and the map re-plotted.*

Comment 31: Figure 4-54 is a key figure and key finding of the study since these are the particles that affect Lake clarity the most!

- The maps need to be enlarged; separate the figure into 4-54a & 4-54b.
- Can these figures then be overlaid to provide a Figure 4-54c? This would provide a very good spatial visualization of the most critical areas to focus erosion control efforts – fine sediment producing areas that are unstable

Response: Figure 4-54 will be placed on two pages to make the individual maps larger. Combining the maps is not a good idea because it would provide an un-realistic assessment when comparing streams of different size with dissimilar bank heights.

Comment 32: Were confidence and/or prediction intervals calculated for the measured loads and annual runoff volumes? If not, can they be? If so, it may be helpful for visualization purposes to present Section 5 figures as bar graphs with error bars for the measured loads and runoff volumes (as opposed to line graphs); simulated loads could then appear as large points or dots. This would allow the reader to observe if the simulated value falls within the error bars. I think the way the figures are presented is deceiving- it makes it look like the models simulate much better than they actually do.

Response: *Error bars are not available for the measured data. Quartile measures are now provided in the Appendix to provide a measure of the distribution of values over the period of each record.*

Comment 33: One of the reasons why numerical simulations were conducted was to simulate the effects of the January 1997 runoff event on future sediment loads. However, the section 5.0 summary (section 5.5) said nothing about this.

It seems that the Section 5 summary just presents the results of the numerical simulations. The summary does not do a very good job of drawing conclusions based on information provided through conducting the simulations.

Response: *Text has been added to section 5.5 that addresses the affects of the 1997 event. In further reviewing section 5.5 we feel that conclusions are clearly stated.*

Comment 33: Section 6.1 Introduction states: "The purpose of our basinwide analysis of upland-erosion potential was to determine whether certain climatic and upland parameters could be used to account for differences in total suspended-sediment loads at gaged stations and then extrapolated to other watersheds where no such data were available." After reading the entire section, it is unclear to me if and how this was achieved.

Response: *Section 6.3.3 utilizes the results of the GIS-based analysis with load data from gaging stations to develop the regression relation shown in the figure. The following section clearly states the limitations of this analysis and that it should not be used for predictive purposes.*

D. UC Davis Tahoe Research Group (TRG), September 1, 2003

Comment: AREAS NEEDING ADDITIONAL ATTENTION

1 – A basin-wide estimate of total suspended and fine sediment loading is needed.

Response: *This has been added to Chapter 3.*

2- A fuller integration of the modeling results with field data to address the question about the overall importance of channel erosion to total and fine sediment loads.

Response: *This has been added to Section 5.5*

3- Along this line, we need a basin-wide estimate for tonnes of fines and tonnes of total.

Response: *This has been added to Chapter 3.*

4 – A further analysis based on field measurements of the smallest particle sizes, especially those less than 20 µm.

Response: *Particle-size data for suspended sediment that was obtained from the USGS only included the sand/fine break at 0.062 mm. Load results from measured data, therefore, cannot be provided for the fraction finer than 20um.*

5 – As part of the TMDL process, additional technical discussions with project authors will be needed.

Response: *This has been done.*

CHAPTER 1 – Background

Comment 1: Section 1.1 – Lake Tahoe Management Plan should be Lake Tahoe Interagency Monitoring Program (LTIMP).

Response: *Thanks, this has been changed.*

Comment 2: Do the recent works ID second Creek as a major sediment source. Reuter and Miller do not.

Response: *Thanks, this has been changed.*

Comment 3: Please define the term fine sediment first used in each chapter. The reason is that in the Basin, and for the purpose of Clarity modeling, fines are operationally defined as less than 20 µm. For the purpose of this report they are specifically defined as <63 µm. Just so the reader is clear on this terminology.

Response: *The term "fine" sediment is now clearly defined as suggested.*

CHAPTER 2 – Field-data Collection and Analysis of Sediment-Transport Data

Comment 1: Section 2.7.2 – are we limited to the general category of <62 µm or can we get more refined? * This is applicable for other chapters, but the NSL analyzed fine sediment data from the channels much more detailed, i.e. a number of sub-categories in the <62 µm class. Can these be analyzed in modeling effort?

Response: *We are limited to the finer than 0.062 mm fraction for all measured data. Samples for the Upper Truckee River were analyzed with only the sand/silt break at 0.062mm. All other channel samples were analyzed below 0.062. For the purposes of consistency in this report, results are only reported for fines as previously defined.*

CHAPTER 3 – Annual Suspended-Sediment Loads and Yields

Comment: Chapter 3, an evaluation of suspended sediment loading from the streams is an ideal start for this report. First, by defining the sediment loading characteristics in those tributaries for which there is data, it sets the stage for the following chapter(s) which quantify sources of this material. Second, it provides us with the perhaps most comprehensive evaluation of sediment loads in Lake Tahoe streams to date. This is a very valuable contribution to our understanding of watershed hydrology and sediment loading to the Lake. Is it rather unfortunate that the results of this analysis can not be directly compared to those of Rowe et al. (2002). Given that the later report makes recommendations on new approaches for calculating loads, we should determine the feasibility of adjusting the monthly loading values to annual loading values so a comparison can be made to Simon et al. (2003 – this report).

Response: *Results from Rowe et al. (2202) are expressed in terms of median monthly values. There is no way to compare our annual values to this publication without re-doing a considerable amount of the analyses.*

Comment 1: Section 3.2 – Can a table be placed in this section summarizing the period of record for each of the stream sites where data was available and used in the subsequent analysis. As noted by Simon et al. later in this section, a number of previous analyses have been done; however, a detailed comparison is difficult because of the wide interannual variation on precipitation and flow. It is instructive for the reader to be able to get a 'quick glimpse' of what the time period was for the analyzed data.

Response: *Summary tables as you suggest are located in Chapters 2 and 3 (Tables 2.8, 2.9, and 3.1).*

Comment 2: Section 3.2 – How does the methodology used by Simon et al. for calculating loads compare to thee previous studies, i.e. would any difference in calculation approach significantly effect observed differences in results. My concern is not with this study, but rather with the fact each time an evaluation of stream sediment/nutrient data is done a variation on the load calculation methodology is used – we need to be consistent and perhaps this is the time to address this. Note: this is more of a general comment for the Tahoe basin and not a specific comment on the Simon et al. report.

Response: *The techniques we use to calculate daily, and annual loads are consistent with the literature. We improve on these conventional methods by applying a second linear segment at the upper-end of the rating relation if needed.*

Comment 3: Section 3.2 – If 15-minute flow was not available, what was the time period for the readings used in the analysis?

Response: *The first sentence says mean-daily data. The second sentence of this paragraph gives a range of periods of record and references Table 3.1 that includes the period for each index station.*

Comment 4: Section 3.3 – Be clear early in this section that 'Index' does not mean that these are necessarily most representative sites for the quadrants in all cases.

Response: *We clearly define what we mean by index station as being representative of the stream in a downstream location.*

Comment 5: Section 3.4 – Use of mean and median is appreciated.

Response: *Thanks.*

Comment 6: Section 3.4 – When talking about areal loads (kg/m^2), refer reader specifically to Section 3.5.

Response: *Loads per unit area (yields) are expressed in T/km^2. We have added a sentence as you suggested.*

Comment 7: Section 3.4 – Page 3-6: In last paragraph make it clear that it is the streams drainage the northeast portion of the northern quadrant with high loads. Can't extrapolate to entire northern area because of lack of data.

Response: *Text has been clarified as per your comment.*

Comment 8: Section 3.4 – Page 3-6 and others in this chapter: Inclusion of the early data sets on First, Second and Wood Creeks can be very valuable or misleading depending on the question being asked. Overall, Simon et al. does a good job in informing the reader on this subject; however, in Table such as 3-2 and 3-7 and Figure 3-3, in would be very helpful to denote those data (i.e. during the "dynamic non-equilibrium" period when development was extensive) with a different color or shading, etc. While they are representative when discussing long-term trends, they are not with respect to identifying basins that are currently responsible for significant loads. Simon's team does bring this up in a very careful manner in the text; however, in reading such a comprehensive report a reader might rely on summary information in figures and tables. Note: this is done in Figure 3-8 and is very effective.

Response: *Notes have been added to Tables.*

Comment 9: Section 3.4.1 – Table 3-3 suggests that agreement is within about a factor of 2 not an order of magnitude. This difference is certainly over-whelmed by interannual differences in precipitation and runoff. These large interannual differences which sometimes lead to extended periods (2-5 year) periods of above or below normal runoff, certain affect the reported loading values. This report does a good job in providing the most up-to-date analytical effort.

Response: *Thanks.*

Comment 10: Section 3.4.2 – Loads do varying greatly from year-to-year across the Basin; however, there does appear to some consistency within a given quadrant, with the exception of the eastern region.

Response: *Exactly!*

Comment 11: Section 3.4.4 – Very interesting results showing that the January 1997 event did not have a uniform effect basin-wide.

Response: *Thanks.*

Comment 12: Section 3.4.4 – Estimate on how much was left available for subsequent transport in the major streams?

Response: *This is not possible although both the measured data and the numerical simulations show reduced loads post event.*

Comment 13: Section 3.5 – page 3-17: Disturbed western stream not only produce higher amounts because of human intervention but they act in synergy with the fact that precipitation on this side of the Basin is much higher – as noted several times in this report. Perhaps this comes later, but what would Simon et al. suggest as an approach for separating the effect of human intervention?

Response: *This is not possible although both the measured data and the numerical simulations show reduced loads post event.*

Comment 14: Section 3.5 – First paragraph on page 3-20: Noteworthy observation that sediment yield is not simply a function of gross urban characteristics such as road miles, area of hard surfaces, etc., but rather the cut of land disturbance and underlying geology.

Response: *Thanks.*

Comment 15: Section 3.6 – Either in this section or in chapter 2 it would be helpful to provide a detailed discussion on where the particle size data (<62 µ) came from and the analytical methodology. How often was it collected, etc.

Response: *This is covered in Chapter 2 and in Appendix D. In addition, a sentence has been added.*

Comment 16: Section 3.6 – For the lake particle size distributions in the 2-20 µ range appear to be quite important – any data available for this particular size bin? If not, tell reader that the fine-grained sediment category as defined in this report (<62 µ) will not be representative of that fraction which has the most impact on clarity, especially when it comes to load as weight, i.e. the contribution of those particles >20 to <62 µ will be large because they weight more.

Response: *Text has been added as per your suggestion to clarify.*

Comment 17: Section 3.6 – In line with the two comments above on the issue of fines, as part of the Tahoe TMDL research program specific particle size distributions (8-10 classes in 0.5-20 µ range) are current being analyzed for the major LTIMP stream sites. Could Simon et al. comment on how this new and developing data base be used to update his results when the data becomes available?

Response: *Text has been added as per your suggestion to clarify.*

Comment 18: Section 3.6 – Can a table be provided which shows the relative percent contribution of fines versus total, i.e. ratio of data in Figure 3-11 to Figure 3-7.

Response: *This is included in Table 3.9.*

Comment 19: Section 3.7 – Are the periods of record the same for each of the sites in a given stream. Upstream ward is not and it is duly footnoted. For the uplands (non-'mouth' sites), these were added to LTIMP around 1990 which means that their record could be shorter than the mouth site. Given the large interannual variability as noted above, it is important that the comparison in Table 3-11 be done over similar years for a specific stream.

Response: *The problem with this approach is that (1) a number of station would drop out of the analysis because of relatively short periods of record, and (2) statistical significance would be reduced because we would be removing periods of record from some of the stations to match periods of record.*

Comment 20: Retention pond downstream last monitoring sites should not influence results in Table 3-11. Also, Is it speculation or is there some field data supporting the implication that perhaps the small lake between stations -780 and –790 on Trout Creek may explain the sediment reduction as one goes downstream; or am I simply reading too much into that sentence?

Response: *Our mistake. The text has been edited accordingly.*

Comment 21: Section 3.7 – It would be very helpful to see an evaluation of intra-basin variations based on load values and yield and not one solely based on concentration. Similar discussions on data presented earlier in this report were very informative. This is especially so for the upstream or headwater locations which might be used in future analyses as being representative of undisturbed forest areas.

Response: *They are based on yields!*

Comment 22: Section 3.8 – What about site 10336770 in Trout Creek watershed and upstream Edgewood site – how do these upstream locations compare to their respective disturbed sites? Also can data from Table 3-11 (upstream) be used in the analysis in Section 3.8? Additionally, it appears that while the Incline –993 site might be considered a "reference" site for the north quadrant, this is very relative and it probably not be considered a 'pristine' site for calculation background loads. Could the team comment on this? Based in this discussion, a question for the Simon team is, are we justified in selecting a "reference" site for a quadrant or are there significant differences in "reference" conditions between streams within a given quadrant?

Response: *Text has been added to address these comments. "Reference" for a given quadrant, however, should not vary within the quadrant. This would defeat the purpose of the term "reference".*

Comment 23: Section 3.9 – This is a very interesting and important aspect of stream sediment data analysis. I have two comments which won't necessarily clarity the issue, but which should be taken in account in current and future discussions:

1 – Use of mean-daily concentration data may not be appropriate for this type of analysis. The reason is that with a sample number (n-value of 300-10000) as shown in Table 3-14 it is probable that nearly all relationships will be significantly different from zero, i.e. absolutely flat. Simon et al. do discuss this. My sense is that this particular analysis has much more statistical meaning than actual ecological-hydrologic meaning.

However, the analyses presented in Section 3.9.2, looking at shifts in transport ratings do suggest real changes in some streams. Data in Figure 3-13a do apparently suggest that at a given flow, load is less in recent years.

It is important that we have a comprehensive and agreed upon statistical evaluation of load changes for both sediment and nutrients. Not only does this inform us on how pollutant control has done previously, it is absolutely essential for evaluation of TMDL progress within an adaptive management framework. I strongly suggest that as part of a separate project, we have a hydrologic statistician review the methods used by both Simon et al. and Rowe et al. (2002) to evaluate these approaches and produce a recommendations on the best approach for evaluating long-term trends.

Response: *We concur.*

Comment 24: Section 3.10 – I completely agree with Simon et al. that streams under investigation from the northern quadrant do produce much less sediment than they did 30-40 years ago. This is a valid conclusion that needs to be part of the environmental history of the Tahoe basin. However, I would like to caution the readers that during thee height of this areas development in the 1960s and early 1970s disturbance was very significant. Just the reduction in construction activity in this area no doubt went a long way towards reducing sediment load. Building levels have significantly declined because of what is now known vis-à-vis, environmental protection. The more meaningful analysis is temporal trends in loading since the mid-late 1970s and early1980s when erosion control became more widespread. Interestingly, Simon et al. do provide evidence in Figure 3-14a of a shift in loading characteristics in Incline Creek between the period 1985-1994 and 1995-2002. With their suggestion of evaluating changes in loading on the basis of looking at discharge versus load, Simon et al. provide an interesting tool for assessing change which accounts for annual hydrology.

Response: *Thanks.*

Comment 25: Section 3.11 – I appreciate the link of the sediment load data to the Secchi depth data. In the Jassby et al. (1999) paper on historic Secchi depth in Tahoe the data lead us to hypothesize that sediment loading in the spring was the main feature affecting the spring decline in clarity that is seen nearly every year. Recent work on the Clarity Model further supports this hypothesis. This data provided by Simon et al. continues to substantiate this understanding and will have direct ties to the Clarity Model as it will be used to evaluate management strategies.

Response: *Concur.*

CHAPTER 4 – Channel Erosion and Basin Geomorphology

The bulk of this chapter are the results of ground reconnaissance – RGAs and observations made during stream walks. This provides a detailed accounting for seven of the Basin's streams and highlights areas that may be of concern in developing a potential restoration plan. Data presented highlights the need to evaluate both (1) channel stability (likelihood of erosion) and (2) availability of fine-grained sediment when assessing the potential contribution of channel erosion to fine sediment loading.

Comment 1: Section 4.1 – Chapter 4 uses field observations/data to evaluate channel erosion while Chapter 5 employs modeling for this purpose. Good to clarify this in the introduction to this chapter.

Response: *A sentence has been added to section 4.1.*

Comment 2: Section 4.2.2 – Nice use of historical stream-channel profiles.

Response: *Thanks.*

Comment 3: Section 4.5 – Please clarify what the implications of a positive bank erosion rate yet a negative bed erosion rate are in terms of material actually being transported to the lake. For example, does a negative Total value imply that the bed is acting as a sink on an annual basis and that the eroded bank material is not being transported to the lake or is the interpretation to be done over a much longer time scale? Comments on this would help clarify. In addition, if the 2-20 µ particles are most crucial to lake clarity, these may have passed onto the lake and not have been deposited. Does Table 4-2 yield additional insight if the results are reported as a function of different time periods of observation?

Potential importance of Upper Truckee River (UTR) is highlighted in Table 4-2!

Response: *The following paragraph has been added to provide further clarification. "The combination of net deposition on the channel bed (negative values in Table 4-2) and net erosion from the banks is not uncommon. Materials deposited on the channel bed are predominantly coarse grained. Of particular interest is the net amount and rate of fines eroded from the channel banks on an annual basis. Since virtually no fine-grained materials are found on streambeds, is can be safely assumed that the bulk of this eroded material is transported to the lake."*

Comment 4: Section 4.5.1 – Minor point, but shouldn't it read that UTR delivers 3 times (645 vs. 217) and not 2x) amount of streambank sediment per mile than Blackwood Creek?

Response: *Yes, thanks. Text has been changed.*

Comment 5: Section 4.5.3 – Could Figure 4-9 be explained in more detail, i.e. what is the best way to view this data and in general what are the major conclusions. This may in already in the report and I may have missed it.

Response: *The last sentence of the 2^nd^ paragraph of section 4.5.3 describes the figure. Subsequent text and figures provide analysis of the results shown in Figure 4.5.3.*

Comment 6: Section 4.5.3 – Any idea why the 1941-1952 point for non-golf course reach in Figures 4-12 and 13 are so high?

Response: *Cutoffs constructed by local landowners. This is stated in the text.*

Comment 7: Section 4.5.4 – Page 4-17: Is a portion of the decreasing sediment loads from the UTR due to natural processes of channel correction? Can anything be said about influence of restoration efforts. If nothing more were done to restore the channel would loads continue to decline in any significant manner? My guess is not really base on the figures provided, but a clarification would be helpful.

Response: *Based on the available data and the analyses conducted along the Upper Truckee River, it is not possible to differentiate the effects of natural channel adjustment from restoration activities. This issue could be addressed analytically as well as with CONCEPTS but was not part of the study objectives.*

Comment 8: Section 4.7 – page 4-66, paragraph 2: States that "with streambanks providing a significant proportion of the suspended sediment in streams in the Lake Tahoe watershed…" It is uncertain if the report, up to this point, has in fact conclusively demonstrated this as being true.

Response: *Good point. The text has been changed accordingly.*

Comment 9: Section 4.7 – Is there a possible figure which combines bank failing values with fine-sediment content to summarize those area of potential greatest concern?

Response: *Yes. Figure 4-14 for the Upper Truckee and 4-23 for Blackwood Creek (for example) are what you are asking for.*

Comment 10: Section 4.7 - Would it be helpful to include a discussion linking the historic cross-section data from Table 4-2 to the field reconnaissance observations?

Response: *Concur. Text has been added to the section.*

Comment 11: General comment for entire chapter: Similar to one of the comments for Chapter 3, a breakdown of fine-sediment availability to those particle sizes applicable to the Clarity Model (0.5-1 µm, 1-2 µm, 2-4 µm, 4-8 µm, 8-16 µm, 16-32 µm and 32-64 µm) would be very helpful.

Response: S*imilar response as before. This will apparently be accomplished during follow-up work.*

CHAPTER 5 – Numerical Modeling of General and Ward Creeks and the Upper Truckee River

A detailed evaluation of AnnAGNPS and CONCEPTS, how it was set up and populated with data is outside my area of expertise. Therefore, my comments are very general for the model set-up portion of this chapter. For me to make the most useful comments on the model, I would need to sit down with project authors for more detailed discussions. There is a tremendous amount of material presented in this chapter, all of which is potential very meaningful – and all of which deserves detailed discussion. I view this section of the report as the platform for those discussions. In general, each of scientific reports being produced in support of the TMDL and other planning documents for the Tahoe basin represent the author's best professional judgment. While it is not necessary to reach a scientific consensus as part of the comments on this draft final report, the subsequent use of the data for planning and management will require much further discussion before it is applied in the Basin. I strongly urge that arrangements be made for 1-2 day meeting, subsequent to the initial presentation (8/18/03) where the primary authors and principle scientific stakeholders can engage in such an extended discussion of the results.
Response: *Concur. This meeting has not taken place.*

Comment 1: Section 5.1 – Be more specific in the scope and sub-goals of objective #1. Which watersheds, how will this data be used in concern with findings in previous chapters and will an attempt be made to extrapolate to entire basin.

Response: *More specific text has been added to objective 1 describing the scope and subgoals.*

Comment 2: Section 5.2.1 – What modifications were made to DEM and were the urban features that are not captured on current DEM maps an issue?

Response: *Description of the DEM modifications is in section 5.2.3. Section 5.2.1 mentions issues that can be a problem. Additional text has been placed in 5.2.1 to explain what urban features were not captured.*

Comment 3: Section 5.2.3 – General Creek has a discussion of location of tributary confluences; was a similar analysis done for the Upper Truckee and Ward?

Response: *A similar analysis for tributary confluences was performed on Upper Truckee and Ward and references in those sections were made to the procedures used in General Creek. Additional text has been added to further explain this.*

Comment 4: Section 5.2.4 – Discuss possible limitations of available MET data to results, especially with regard to determining the relative contribution of overland versus stream channel erosion as contributors to fine sediment.

How long of a time series of data was needed to calibrate and validate model? I can see that a long time series was needed to run out over 50 years but were there other stations that could have been used to test model?

Some discussion of what was needed in the data base would help, e.g. hourly values, event values, etc.

How did results compare to current isohyetal map for Tahoe?

Highlights the need within the Tahoe basin to coordinate MET data collection and have a central clearinghouse. The TIIMS (Tahoe Integrated Information Management System) should be a good platform for this, once developed.

Response: *Additional text has been added to section 5.2.4 to compliment and expand on the text in the summary. Calibration was not performed, but measured and commonly accepted values were used as model input parameters. The period of record in the comparisons is reported for each watershed. No other acceptable weather stations were available that provided a period of record that could be used. For AnnAGNPS, daily values were used for the weather parameters. Comparisons to the current isohyetal map are shown in Figures 5-21 and 5-22.*

Comment 5: Section 5.3.1 – What is the importance of modeling reaches further upstream than cross section #1 on General Creek, Ward Creek and the Upper Truckee River?

Response: *If there is significant streambank or bed erosion upstream of the first modeled cross section, the modeling reaches should be extended. This is not the case for General Creek and the Upper Truckee River (UTR), except for 1995 for UTR where the loads at cross section 1 (see Fig. 5-55) are underpredicted by AnnAGNPS. This difference may have been caused by channel erosion in the headwaters. Channel erosion upstream of the first modeled cross section appears to be important for Ward Creek (see Fig. 5-73). For this watershed it may be necessary to extend the modeling reach upstream.*

Comment 6: Section 5.4.1 – Could the Ward Creek Snotel site have been used for modeling General Creek instead of Tahoe City? If Tahoe City data was not adequate as stated, could a combination of a relationship between the Echo Summit, Tahoe City and Ward sites have been used in combination with the Tahoe isohyetal map to get a better precipitation data set for General Creek?

Response: *The report states that the Tahoe City weather station was not adequate to describe all snowfall events at higher elevations. Although, within AnnAGNPS there is the capability to determine the temperature gradient with elevation that would then impact whether an event was estimated as snowfall or rainfall. This part seemed adequate to produce the average monthly and annual values but would not capture individual events. Additional text has been added to expand on this.*

Comment 7: Section 5.4.1 – How does the conclusion that the Tahoe City MET data perhaps not being adequate for all year effect the analysis of the monthly runoff data?

Response: *Section 5.4.1 states that the runoff simulations performed on General Creek watershed were good, particularly on an average annual basis, but that better climate information would have improved the simulation results for individual years and months.*

Comment 8: Section 5.4.1 – page 5-36; this applies to all three of the simulated watersheds – validation of AnnAGNPS by itself is difficult since the stream monitoring data for sediment includes both upland and channel erosion sources. The section on "Annual Fine-Sediment Loads" in this and similar sections for the other two tributaries appears to be saying that since AnnAGNPS output was low relative to the gage data this argues for the importance of channel erosion. While this might be true, this is the section where validation is supposed to be presented. How do we know that AnnAGNPS is not just underestimating upland contributions? Is this really validation of AnnAGNPS? Since CONCEPTS can bee validated by using cross section data to show changes in channel morphology, perhaps that should be presented first.
On page 5-36 it is stated, and correctly so that it is critical that snowmelt be accurately reflected. Did this happen in accordance with the modelers expectations. If not, clearly state what resulting errors could be.

Response: *The reviewer correctly states that AnnAGNPS can not be validated for sediment with the current gaged record, especially since there are channel sources that AnnAGNPS does not completely simulate. This is the reason CONCEPTS was used. Validation for runoff volume can be performed for AnnAGNPS. Since AnnAGNPS provides the loadings into CONCEPTS, results are described for AnnAGNPS. Input values for AnnAGNPS were developed by many years of* *research on similar type conditions that provide confidence that the model results are producing reasonable results. Additional monitoring stations would be needed to provide a complete validation of the sediment produced from AnnAGNPS for Lake Tahoe watersheds.*

Comment 9: Section 5.4.1 – page 5-37; perhaps a minor point but under the heading of 'Sources' it states that Fig 5-39 provides further evidence; however, it seems that Fig 5-39 was also used on the previous page so it is not 'further evidence'.

Response: *The statement 'further evidence' has been changed.*

Comment 10: Section 5.4.1 – page 5-37; peak discharge values are given by both AnnAGNPS and CONCEPTS – are these independent estimates?

Response: *The estimate of peak discharge values for CONCEPTS are based on the loadings from AnnAGNPS and then routed downstream. The AnnAGNPS values are when AnnAGNPS would route the loadings downstream.*

Comment 11: Section 5.4.1 – Fig. 5-41; were any of the zones that showed large contributions validated in the field?

Response: *The location of the sources for landscape erosion were not and could not be validated as part of this project. Additional measured data would have been needed to perform this.*

Comment 12: Section 5.4.1 – page 5-40; please explain in more detail the comment regarding the Feb 1986 simulated adjustment probably occurring in Jan 97.

Response: The second paragraph in the "Sediment Load" section has been expanded to address the reviewers comment.

Comment 13: Section 5.4.1 – page 5-40; please explain the difference between Fig 5-39 and 5-44. Is 5-44 a combination of AnnAGNPS and CONCEPTS. Is the region of less agreement at the lower loads in Fig 5-44 due to the lack of agreement in precipitation and flow as shown in Fig 5-37?

Response: *The mean-monthly suspended loads simulated by CONCEPTS are a combination of sediments eroded from the landscape (AnnAGNPS) and from the channel (CONCEPTS), which are routed to the outlet by CONCEPTS. At low flows, no sediments are eroded from the channel, fines in transport originate from the landscape (AnnAGNPS). The latter are underpredicted by AnnAGNPS (see Fig. 5-37).*

Comment 14: Section 5.4.1 – page 5-40; I am not clear on the channel erosion scale – is channel erosion happening year after year, i.e. some each year or are the observed differences seen, e.g. 1983-2002 (General Creek) happening primarily in a few very high flow years.

Response: *By comparing Figs. 5-38 and 5-45, it can be observed that simulated channel erosion occurs every year, not just during high runoff years. The difference between Fig. 5-45 and 5-38 is the net contribution (= channel erosion – channel deposition) of the channel.*

Comment 14a: Would this be the section in the report where changes in stream channel profiles are used to estimate sediment loss which then could be compared to CONCEPTS output to see if the two agree, i.e. validation. I didn't see that analysis clearly laid out in this chapter.

Response: *Changes in cross section geometry are discussed in the section "Changes in cross section geometry" on page 5-40. These areal changes are converted to sediment mass (T) and then reported by CONCEPTS at the end of the simulation.*

Comment 15: Section 5.4.1 – page 5-44; could authors discuss relationship between Tables 5-6 and 5-7; i.e. what is the bottom line for the 50-year simulations? (again for all three tributaries). In table 5-6 and similar tables for the other two watersheds, I am assuming that the combination of AnnAGNPS and CONCEPTS integrates the relative contribution of upland and channel sources over the course of the modeled tributary.

**Along with this, and applicable to all the modeled watersheds, does the data from Chapters 3 and 4 confirm any of these results. Little attempt is made to integrate all the chapters.

Response*:* *Table 5-6 lists the relative magnitudes of sediments eroded from upland and streambank for the General Ck validation case. Table 5-7 lists theses values for the 50-year simulation. Similar tables are included in the report for the Upper Truckee River and Ward Creek. For all three watersheds, these tables show that average annual suspended load for the 50-year simulation is smaller than that for the validation. The reduction is mainly in the sand fraction, which are mainly streambank contributions. Hence, it can be concluded that the channel adjustment has led to a more stable channel, and therefore reduced streambank erosion. This has been mentioned in the text, e.g. page 5-44 in case of General Creek.*

*** See section 5.5.*

Comment 15b: Section 5.4.1 – page 5-44, figure 5-46; agreement between observed and modeled values for sand and TSS are not good during the winter; on the other hand, fines seem to agree much better.

Response: *TSS and sands also compare favorably in the winter. The disagreement in January and February is caused by the incorrectly predicted timing of bank failures (February 1986 versus January 1997).*

Comment 16: Section 5.4.2 – page 5-47; please explain implications of observation that annual runoff match well for Upper Truckee but monthlies do not.

Response: *Additional text has been added to explain that AnnAGNPS has been designed to estimate the long term impacts of watershed characteristics using some model input parameters* *that are developed as average annual parameters. Thus, individual events or monthly values may not match as well as annual values.*

Comment 17: Section 5.4.2 – page 5-56; stated that for changes in cross section geometries, the simulated changes agree quite well with those observed. For cross section 19 (Fig 5-61) it appears as though the 2002 values do not match the 2002 value at all. This comment could be due to my inexperience in reading this type of paragraph.

Response*: Changes in the geometry of cross section 19 are: 1) scour of the outer bank (left bank), and 2) reworking of point bar at the inner bank. The retreat of the left bank is accurately simulated. Although CONCEPTS predicts deposition on the point bar, it does not match that observed. Changes of the point bar are mainly driven by the highly three-dimensional flow in this meander bend, and hence cannot be captured by a one-dimensional model such as CONCEPTS. In view of this limitation, the changes in geometry are simulated quite well.*

Comment 17a: On Table 5-11 and similar table for each stream modeled, are the values an integration of the entire stream channel or a reflection of the three gauged stations. Does the relative contribution by overland versus channel erosion change by location?

Response: The values listed in table 5-11 and similar tables are an integration of the entire stream channel and landscape, because they are reported at the outlet of the stream channel. The relative contribution of overland and streambank erosion will change by location, e.g. at the upstream boundary of CONCEPTS all sediments are produced by overland erosion.

Comment 18: Section 5.4.2 – page 5-64; What is the best interpretation for the large discrepancies between measured TSS and simulated TSS, e.g. in May-June at station -092.

Response: As stated on page 5-60, it appears there is too much simulated runoff in the winter, and insufficient runoff in the spring. This then must be related to snowmelt already occurring in the winter months, yielding a smaller snowpack and therefore a smaller runoff in the spring. Temperatures in the winter are likely too large.

Comment 19: Section 5.4.3 – page 5-65 and Fig 5-77&78; what is exact location of Ward Valley badlands? My impression is that they are located in the southwest portion of the watershed. Does AnnAGNPS identify these areas as large sources? Figure 6-7 which shows calculated erosion potential from upland areas suggests that most of the western border of the Ward watershed should be much higher in simulated erosion and sediment yield than shown in Figs 5-77&78; i.e. did the model get it right?

Response: *The areas shown as high erosion potential in Figure 6-7 are designated as rock outcrops in the NRCS soil database and thus has no soil erodibility to produce erosion as defined by AnnAGNPS. While Chapter 6 uses a lowest soil erodibility class of 1, AnnAGNPS designates areas of rock outcrop as having no erodibility and, therefore, no soil erosion is possible. These rock outcrops have a k-factor value of zero while the lowest value used in Chapter 6 is 0.01. If there was soil present in those high erosion potential areas shown in Figure 6-7 then there would be a significant amount of erosion.*

Comment 20: Section 5.5 – page 5-81; please explain the comment in the first full paragraph which states that the 50-yr simulation for the Upper Truckee River predicts 770 T/y of sediment of which 90% (690/770) will be fines. Should this reflect same data that is in Table 5-12.

Response: *The number listed on page 5-81 is the amount of sediment reaching the outlet. This is not the same as the numbers listed in Table 5-12, which denote the amount of sediment delivered to the stream. Because of deposition of part of these sediments along the Upper Truckee (especially in the flat, marshy area near the outlet), the tonnage at the outlet is smaller.*

Comment 21: Section 5.5 – needs a good discussion on how well the modelers think they did and how this may be supported by data from Chapters 3 and 4. This is done to some extent on section 5.5, but it could be expanded.

Does modeling tell us where in the watershed fines generation is happening. Also does the model do an analysis of disturbed versus undisturbed areas?

Discuss in relation to Hill and Nolan work on importance of channel erosion.

Response: *Text has been added to describe how well AnnAGNPS performed. Text and a table have been added to Sections 5.5 and 7.1 to clarify the modeling results with regard to the generation of fine-grained materials. The models do not explicitly separate disturbed and undisturbed areas but integrate them based on the parameters provided to the model for different areas and channels. It is difficult to compare results with the Nolan and Hill work because for the watershed covered by both studies (General Creek) Nolan and Hill did not determine upland contributions.*

CHAPTER 6 – GIS Analysis of Erosion Potential from Upland Areas

I very much appreciated the goal of this chapter. There have been somewhat similar attempts to approach this topic. This is best viewed as an initial attempt to create a working erosion potential map. I am sure that a number of the factors can be defined in more detail or perhaps some other factors could be included, but this represents a very nice start. In this regard, it is best viewed as a research product in progress.

Figure 6-8 is very intriguing. It is interesting that only three watersheds did not fit the regression equation of erosion potential versus sediment yield. While the comment is made that all have substantial contributions from channel erosion, are there streams which also have high channel erosion yet fit the regression. This analysis shows that other factors (e.g. channel erosion potential) need to be included in this analysis to develop an integrated erosion potential map (upland plus channel). I realize that this is beyond the current scope of the project, but again, it is research in progress and very worth while.

Response: *Concur. This aspect of the study requires more attention…perhaps at a later date.*

CHAPTER 7 – Summary, Conclusions and Future Research

Comment 1: Section 7.1 – 1st paragraph: also important goal was to quantify the contribution of overland and channel sources to fines and total sediment.

Response: *This is stated in the 2nd paragraph.*

Comment 2: Section 7.1 – page 7-2: I would not dwell on fact that sediment load has been declining in northern streams since the 1970s, since in Chapter 3 it is noted that the 1970s were a time when intensive development resulted in abnormally high erosion.

Response: *Concur. There is one sentence that refers to this.*

Comment 3: Do the authors have suggestions for what values to use along north and south shores with respect to loading from undisturbed watersheds. That is, what might we use to determine background on a whole-basin basis.

Response: *This is something that is going to require additional work. For example, the upstream station on the Upper Truckee is used as a "reference" for the south quadrant while an upstream site on Incline is used for the north. Whether these can be used to represent loadings to the lake at a downstream location (per unit area) would need to be validated.*

Comment 4: Last paragraph: Can authors quantify the "error" that results from simulating precipitation as rain instead of snow. Would it lead to fundamentally different conclusions about the importance of channel erosion.

Response: *Not entirely sure what part of the text this comment is addressing.*

Comment 5: page 7-3, Table 7-1: why is Blackwood on this table? Why are there data for Ward "measured'?

Response: *Blackwood is included for comparison purposes. The data for Ward are in the simulated columns.*

Comment 6: General Creek give a very agreement between simulated and measured for both total sediment and fines. Ward, we cannot evaluate because no data for ward measured (again, why is this not available).

Response: *There was virtually no measured cross-section data for Ward. This was not one of the streams surveyed by Nolan et al. Stubblefield's data was extremely limited.*

Comment 7: As we discussed at August 2003 presentation, please explain/re-evaluate values in Table 7-1 for Upper Truckee. There is a big difference.

Response: *The difference between simulated and measured values along the Upper Truckee is a function of the respective stream lengths and locations covered by the analysis. These data are expressed in* m^3*/y/km. The measured data covers only the short Washoe Meadows reach where active bank erosion has been ongoing. The simulated data covers an order of magnitude longer reach so values per unit km are lower.*

Comment 8: Need a better discussion linking Chapters 4 and 5 with input from Chapter 3.

Response: *Additional material from Chapter 5, particularly section 5.5 has been added to Chapter 7.*

Comment 9: Can a table be made showing values for channel sediment loss as evaluated by analysis of cross section data for each stream where data are available. Next to those that were modeled, included those values as well.

Response: *To a certain extent, that is what is displayed in Table 7-1. General Creek and the Upper Truckee River are the only two streams with sufficient data for both.*

Finally

Comment 1: An estimate of total sediment and fine sediment loading from all the streams combined is needed.

Response: *This has been added to Chapter 3 and restated in Chapter 7.*

Comment 2: An estimate of basin-wide values for the percent contribution of channel erosion to both total sediment and fines is needed.

Response: *This, only from those three watersheds where upland and channel processes were simulated. An additional table has been provided in Section 5.5 and 7.1 for these streams.*

Comment 3: What conclusions can be made regarding the contribution of channel erosion to total sediment and fines based on the results of Chapters 3 and 4 alone?

Response: *Results from Chapter 3, representing gaged data does not provide a means to determine the contributions from channel sources. Results from Chapter 4 can provide a relative view of the magnitude of contributions from channel sources when comparing one stream to another. However, one cannot determine the relative proportions of uplands versus channel sources from the data in Chapters 3 and 4.*

E. US Geological Survey, Nevada District, October 2, 2003

Comment 1: Although it is certainly the case that sediment transport in the Incline Village area during the early 1970's was almost certainly greater than during more recent times, some caution needs to be revealed between Glancy's sediment data set from the early 1970's, and the more recent LTIMP data set. It needs to be pointed out that the sediment data collection techniques between Glancy and LTIMP are different. On page 3 in Glancy's 1988 report he points out that he collected total sediment data (SSC plus bedload) rather than the more traditional suspended sediment data (SSC) that LTIMP has collected. I suggest that the reader be cautioned of this difference between the two data sets and if possible to give a sense of magnitude that this difference may have.

Response: *Total transport values from Glancy (1988) were calculated based on depth integrated samples without a nozzle on the sample bottle. Since gravel is generally not transported in suspension, we do not feel that the differences will be great.*

Comment 2: Throughout the report there is significant reference to large loading originating from Second Creek in the Incline Village/North Shore area. The report does adequately caution the reader that this extreme loading from a small stream was observed during a period of time of rapid development and thus large-scale disturbance. However, it is my belief that although the development probably played a large part in the Second Creek loading, the majority of the excessive load measured by Glancy in the early 1970's was probably due to the instability of the stream channel and watershed that was generated by the large scale debris flow/mudflow event of August 25th, 1967 (which is documented in: Glancy, P.A., 1969, A Mudflow in the Second Creek Drainage, Lake Tahoe Basin, Nevada, and its Relation to Sedimentation and Urbanization: U.S. Geological Survey Professional Paper 650-C, p. C195-C200.). I suggest that this debris-flow event be discussed as a significant part of the source of sediment when discussing the large loads originating from the Second Creek drainage in the early 1970's.

Response: *Text has been added to further accentuate the effects of the thunderstorm-induced debris floe events in Second and Third Creeks.*

Comment 3: In section 3.4.1 a comparison with previous loading estimates is made. However, the loadings from Rowe and others, 2002, was not used in this comparison because "Data from a recent report by Rowe et al., (2002) are not comparable because they are expressed as median monthly values." This comparison should be possible though if the actual monthly loads given in Rowe and others (2002) are tallied to get annual loads and than the average and median annual loads over his period of analysis are determined. The estimated monthly loads were only published on the web as an appendix to his report and are available for download at http://water.usgs.gov/pubs/wri/wri024030/text/appendix.htm . I think it would be very interesting to see the overall difference between the load computations for the two studies as I think other Tahoe stakeholders would be interested in this as well.

Response: *You are mistaken. Median monthly values cannot be summed to produce a reliable annual value, only means can be treated this way. We agree that it would be interesting to compare the values reported by the two studies as we have done with other published data however, we would have to redo our analyses to get them in a format comparable to Rowe et al. (2002). We are not prepared to do this as part of this study.*

Comment 4: On page 3-20, it is stated that high long-term suspended sediment yield from Third Creek is believed to be a ". . . combination of upland mass-wasting processes in the undeveloped, upstream part of the basin (Entrix, 2001), combined with erosion from cut slopes and streambanks in the downstream developed areas. . .”. In more recent times (since 1995) I tend to disagree with the mass-wasting processes in the upstream part of the basin. This is due to my personal field experience where I rarely noticed much sediment in the upper Third Creek waters (at two miscellaneous sampling sites), while the lowest site (10336698) frequently had significant concentrations. I agree with the possibility of the observed sediment coming from cut slopes and streambanks in the downstream developed areas, but I think that a significant amount of sediment has been contributed by a small tributary to Third Creek in the lower part of the watershed called Rosewood Creek. It is pretty well known locally that Rosewood Creek is a fairly disturbed stream and has been transporting a significant amount of sediment for its size. It may be worthwhile to check this interpretation with existing instantaneous loading data for the two upstream sites on Third Creek (103366965 and 103366958) and compare them with instantaneous loading values at the lower Third Creek site (10336698) collected during similar periods. The following paragraph is a review response I had a couple of years ago to a very similar interpretation on upland sources of sediment to Third Creek.

”The interpretations that the high suspended sediment and iron yields in Third Creek are a result of exposed soil caused by a large snow and rock avalanche of February 1986 is not supported by the data. If this interpretation were true you would expect to see high sediment and iron concentrations at the TRV miscellaneous site [103366965], which is below the area of the avalanche and above TCC [10336698], especially because of the sample design for the miscellaneous sites. However, looking at figures 28a, 34a, and 35a, they indicate that concentrations at TRV are significantly lower than at TCC. This indicates that a large fraction of the sediment and Fe are coming into Third Creek below TCV and above TCC. To me, it is more likely that the contribution from the unstable tributary of Rosewood Ck is causing these inflated yields. Most likely though, the high yields are a combination of these two interpretations (and possibly other reasons as well).”

Response: *We don’t see much difference between what we wrote and what you are stating here. Thanks for your comments on Rosewood. Since we did not spend time on this specific tributary we were not able to provide this detailed interpretation.*

Comment 5: In many places throughout the report it is brought to the readers attention that the loads in the western streams are not increasing with time as reported by other workers. Rather than just discrediting the work of others, it would probably be more scientifically diplomatic to point out the differences in the two trend analysis and more importantly to point out the two different periods of records that the trend analysis cover. In particular, it should be noted that the results from this report indicate that the 1997 flood event had a flushing effect on most streams (rather than rejuvenation), tending to give the streams less available sediment for transport than prior to the 1997 event. Since the analysis by Rowe and others was based on observations through the end of WY 1998, they had only 1.5 years of post 1997 flood data in their analysis. This may not have been enough post 1997 event data to accurately observe the decreasing loading characteristic that is observed in this study, which is based on observations through the end of ??.

Response: *Firstly, we don't think that we have discredited the work of Rowe et al. (2002) by stating that our results differ just that his report provides several lines of parallel evidence to support its interpretations. We also used stricter statistical parameters in our sum of squares analyses. We don't think that the issue causing the different interpretations for temporal transport trends for the western streams is the 1997 event but a longer adjustment period.*

Comment 6: This comment is in regard to various aspects of the loading analysis on Trout Creek.

a. On figure 3-12 b: Where does the suspended sediment data for 1066780 come from for the period after 1988? Or is this an extrapolation from the sediment rating curves developed for the period prior to 1988?

Response: *It is based on post 1988 flow data and the transport relation.*

b. On Table 3-7: It is interesting that at site 10336775 (mid basin site) the median annual yield is 5.4 tonnes, at site 10336780 (between mid and lower basin site) the median annual yield is 12.5 tonnes and at 10336790 (lower basin site) the median annual yield is 3.4 tonnes? What is the cause of this apparent discrepancy?

Response: *What discrepancy are you referring to? The difference in these yield values reflect different magnitudes of sediment-transport processes.*

c. Again, on Table 3-11, this same apparent discrepancy takes place?

Response: *Same as above.*

d. On page 3-28 it is stated "Trout Creek contains a small lake between stations 10336780 and 10336790 that traps sediment." This is not true, there is no lake between these two stations.

Response: *Thanks for pointing this out. The text has been modified accordingly.*

e. It is recognized that there are some difficulties in doing loading computations on Trout Creek because the SSC data is collected at the highway 50 bridge without an associated streamgage (10336790), and that streamflow is collected 2.1 km upstream at Martin Avenue without associated SSC data (10336780). It would be helpful for the people who are aware of this situation to see how you worked your way around this difficulty.

Response: *Load calculations for station 10336790 were conducted the same for this site as for all others. Sediment-transport relations were derived from instantaneous data obtained from the USGS and applied to mean-daily flow data for that station, also provided by the USGS.*

Comment 7: It is apparent from the discussion in the text and from several of the review comments above that it would be quite helpful to the reader if there were a table in the methods section which listed the periods of record for which data were analyzed and compared.

Response: *The Tables that you refer to are included in the report (Chapter 2 and in the Appendix).*

Comment 8: There are many instances where site ID numbers are not correct (example: pg 3-15 Third Creek is given ID of 10336695?). Since these numbers are the principal identifiers in all watersheds with multiple sites, I suggest having them double-checked to make sure they are correct.

Response: *Thanks, we'll check these and edit where necessary.*

Comment 9: On page 1-2 reference is made to a LTMP (Lake Tahoe Management Plan). This should be LTIMP (Lake Tahoe Interagency Monitoring Program).

Response: *This has been changed.*

Comment 10: On Tables 4-7, 4-8, 4-9, 4-10, 4-11, 4-12, 4-13, it would probably be helpful to the reader if you also listed identifying marks (as was done on fig 4-7 with highways and other landmarks including streamgages). Also, another column for river distance would help to give some sort of perspective to location rather than just the UTM's.

Response: Concur. *Gaging stations are on the figures. Because of their scale, however,we felt that adding roads would make the figures more difficult to read.*