Estimates of Fine-Sediment Loadings to Lake Tahoe from Channel and Watershed Sources

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INTRODUCTION

Over the past 35 years, a trend of decreasing water clarity has been documented in Lake Tahoe, attributable in part to the delivery of fine-grained sediments emanating from upland and channel sources. The term *fine sediment* can be defined in several ways, with much of the confusion based on how the threshold diameter is defined. In sediment-transport analyses, fine sediment is generally considered to be those particles finer than 0.063mm whose transport is not a function of size and weight, but of availability to a flow. This threshold represents the distinction between sand- and silt-sized particles. Coarser sediments are hydraulically controlled with entrainment being function of the energy, stream power, or shear stress of the flow relative to the size and weight of the particle. With regards to lake clarity, however, it is the finest particles that are of the greatest interest because they tend to stay in suspension for extended periods of time. Thus, *fine sediment* can also be considered as those particles finer than 0.020 mm, representing the distinction between silt- and clay-sized particles.

Suspended-sediment-loadings to Lake Tahoe from selected watersheds were reported by Rowe *et al*. (2002) and by Simon *et al*. (2003). Both reports identified streams such as Blackwood, Trout, Third and Ward Creeks, and the Upper Truckee River as major contributors of suspended sediment. Using suspended-sediment particle-size data from the U.S. Geological Survey which distinguishes between particles coarser or finer than 0.063mm, Simon *et al*. (2003) provided initial estimates of fine-sediment loads (T/y) and yields (T/y/km^2) from 14 streams around the basin. This study also highlighted important distinctions in sediment production from different sides (quadrants) of the basin and from different sources. With extensive reconnaissance-level field work throughout the basin and by re-surveying monumented cross sections originally established in the 1980’s (Hill *et al*. 1990), streambank erosion was identified as an important source of suspended sediment from several watersheds, including Blackwood and Ward Creeks, and the Upper Truckee River.

Estimates of fine-sediment loadings from all contributing watersheds and particularly from streambank sources are required to:

1. validate estimates of fine-sediment loadings being simulated by others using a watershed model, and
2. effectively simulate current and future water-clarity conditions in Lake Tahoe using a lake-clarity model.

The research undertaken and described in this report is only one of numerous projects being conducted by academic institutions, government agencies and private firms to improve knowledge about the causes and consequences of declining lake clarity. A synthesis of the products generated from all of this research and development of a TMDL for Lake Tahoe will rely heavily on numerical simulations of lake clarity being conducted by the University of

California, Davis. The reliability and of this modeling effort is, in part, a function of the quality of the data provided to the modelers from various sources. Data on flow and sediment inputs, and water temperature are critical.

Whereas most sediment-transport studies express loadings in units of mass (such as Megagrams or tonnes) or volume (such as cubic meters), the lake clarity model requires loadings in *numbers of particles*. An important data-collection program conducted by the University of California, Davis and the U.S. Geological Survey has recently provided fine particle-size data in the 0.005 – 0.020 mm (5-20 μm) range (Rabidoux, 2005). These data provide a means by which to calculate the number of particles in this important size class that is transported to Lake Tahoe from the sampled streams. The Rabidoux (2005) dataset, in combination with suspended-sediment transport relations, measured and simulated rates of streambank erosion, and semi-quantitative evaluations of the relative stability of stream channels throughout the basin (Simon et al. 2003) provide the means to estimate fine-sediment loadings from all watersheds draining to Lake Tahoe.

OBJECTIVES AND SCOPE

The overall objective of the research reported here was to determine the amount of fine sediment delivered to Lake Tahoe from each of the 63 contributing watersheds (Figure 1). Because the watershed modeling being conducted by others does not account for channel processes, a second critical objective was to provide estimates of stream-channel contributions, particularly fine sediment emanating from streambank erosion. This was also to be accomplished for each contributing watershed. More specifically, this study aimed to provide three forms of fine-sediment loadings data for each contributing stream in the Lake Tahoe Basin:

1. Average, annual fine-sediment (<0.063mm) loadings in tonnes per year (T/y);
2. Average, annual fine-sediment (<0.020mm) loadings in number of particles per year (*n*/y); and
3. Average, annual fine-sediment (<0.063mm) loadings in T/y from streambank erosion.

RESEARCH APPROACH

A large amount of useful data on flow, suspended sediment and channel characteristics were available from previous studies conducted in the Lake Tahoe Basin (Jorgensen *et al*. 1978; Hill *et al*., 1990; Nolan and Hill, 1991; Rowe *et al*, 2002; Simon *et al*. 2003; Rabidoux, 2005). Still, without resources to conduct detailed numerical simulations of channel processes for each stream as was done for the Upper Truckee River, and Ward and General Creeks (Simon *et al*. 2003), a combination of empirical methods were required to address the study objectives. An approach that was used successfully by Simon *et al*. (2003) to initially sort streams by similar basin characteristics was the concept of basin quadrants.

In the Lake Tahoe Basin, precipitation, geology, 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 were separated into the four principle directional quadrants; north, south, east, and west (Figure 2). Streams referred to as “northern” include First,

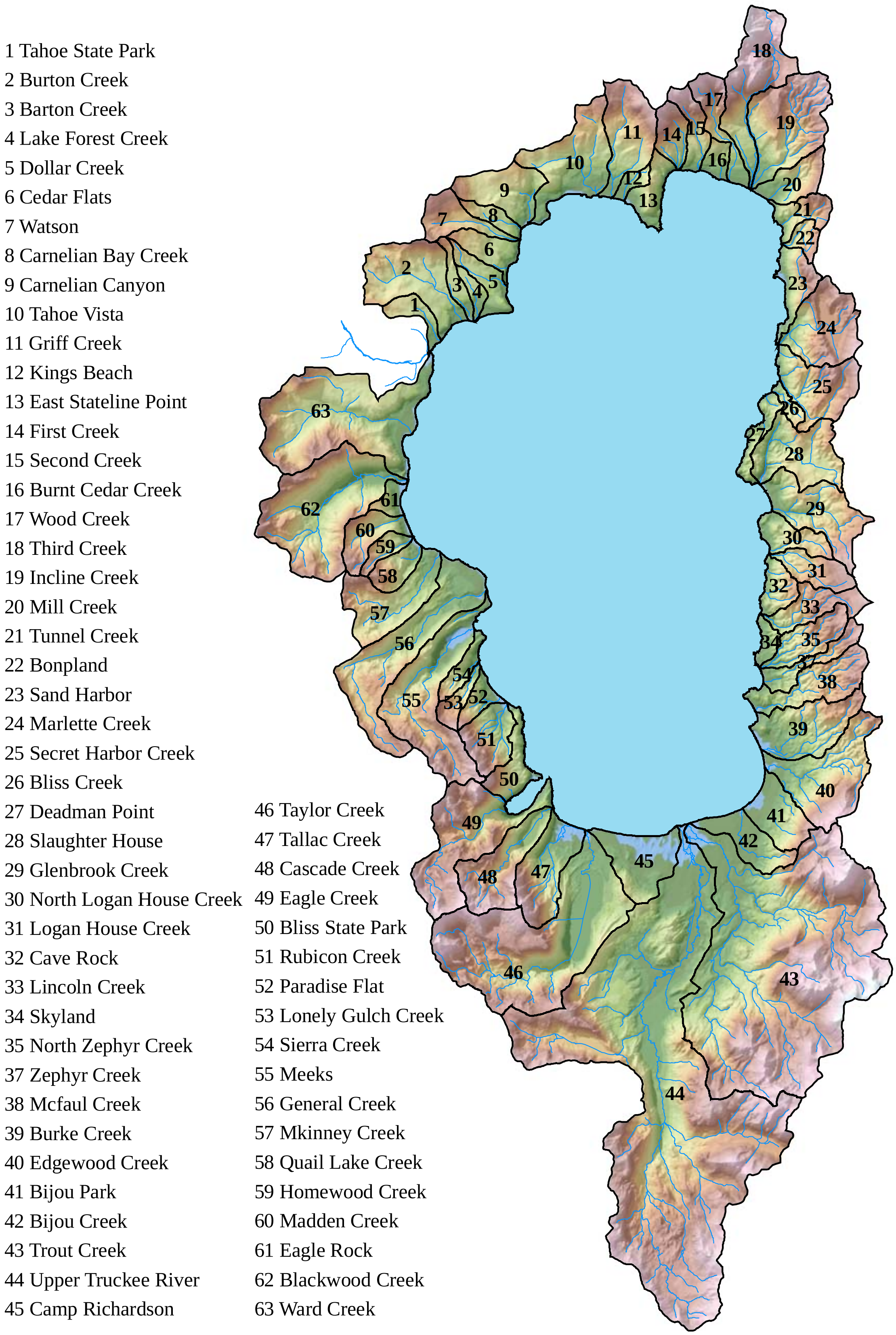

Figure 1. Map of the Lake Tahoe Basin showing the 63 watersheds draining to the lake.

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.

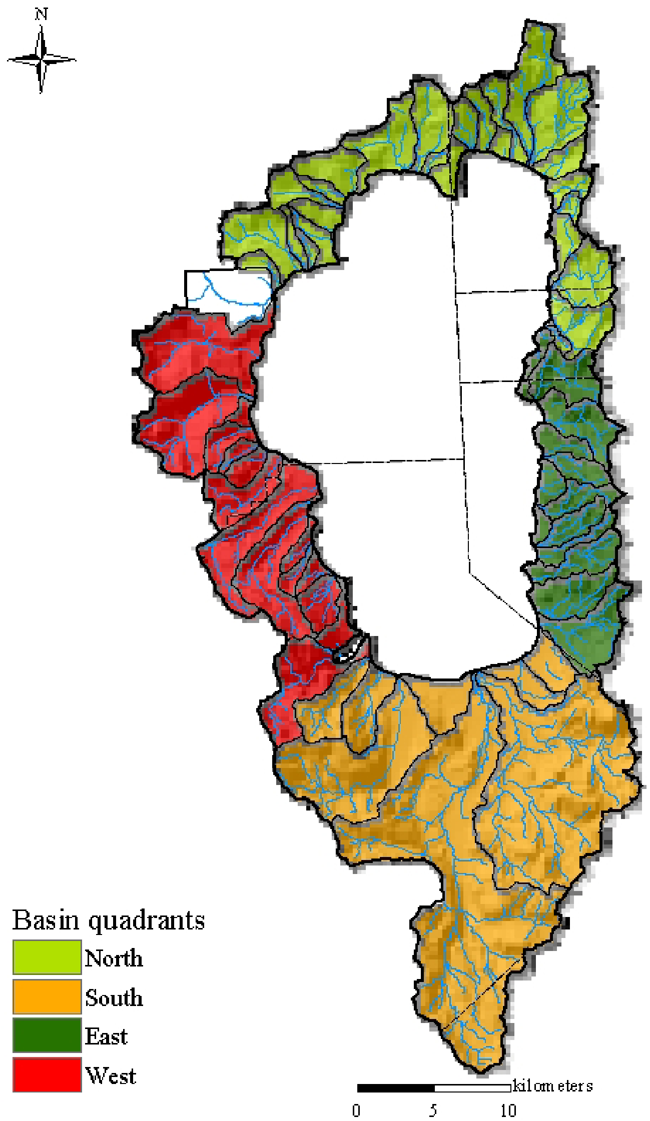

Figure 2. Map of the Lake Tahoe watershed showing designation of four basin quadrants.

Existing Suspended-Sediment Transport Data and Relations for Fine Sediment

Determination of fine-sediment (<0.063mm) loadings (in T/y) was straightforward for streams with historical flow, concentration, and particle size data. The methods employed, and results are presented and mapped in detail in Simon *et al*. (2003). Results for index sites are reproduced here in Table 1 with their period of record in Table 2. 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 that watershed. Selections of these stations were 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 were then used to interpret similarities and differences in sediment delivery to the lake.

Table 1- Annual fine-sediment loadings (<0.063mm) derived from measured data for index stations. (Modified from Simon *et al*., 2003). [1] = Data from Kroll (1976).

Stream	Station number	Annual Fine Load		Contribution of fines (%)	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
Incline	10336700	320	**129**	67	17	18.1
General	10336645	69.2	**53.3**	29	20	19.3
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
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

Table 2. Period of record for index stations.

Stream	Station number	Basin quadrant	Distance above mouth (km)	Period of record (y)
Third	10336698	N	0.19	26
Incline	10336700	N	0.27	17
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
Ward	10336676	W	0.44	28

The rationale that was used to extrapolate suspended-sediment loadings from streams with measured data to streams without historical data was based on the concepts of basin quadrants and relative channel stability. The idea behind this approach was that streams exhibiting similar attributes of channel stability within a zone of similar precipitation, geology, land use and topographic characteristics would yield similar amounts of sediment per unit area. In contrast, stable and unstable streams from the same zone would have markedly different sediment yields.

Thus differences in stability can be used to differentiate suspended-sediment yields from similar areas, zones, or regions. This concept has been used successfully to determine “background” or “natural” rates of suspended-sediment transport rates, and to distinguish between stable and unstable streams for ecoregions across the United States (Simon *et al*., 2004). The techniques are being used by state agencies and others to develop TMDLs for sediment.

Because streams draining larger basin areas in a given quadrant and condition will tend to transport more sediment than smaller ones, loadings data were divided by basin area to establish fine-grained (<0.063mm) suspended-sediment yields (in T/y/km^2). The distribution of yield data (10th, 25th, 50th, 75th, and 90th percentiles) was then calculated by basin quadrant (Table 3).

Table 3- Distributions of annual fine-sediment (<0.063mm) yields (in T/y/km^2) for the four basin quadrants.

Percentiles (T/y/km^2)					**Quadrant**
10th	**25th**	**50th**	**75th**	**90th**	
0.46	0.55	0.70	1.05	1.26	E
1.87	3.83	7.10	13.65	17.58	N
5.12	5.45	6.00	6.55	6.88	S
0.81	0.91	1.93	13.0	18.95	W

Channel Conditions and Rapid Geomorphic Assessments

Evaluation of relative channel stability was accomplished using 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. In addition, samples of bed and bank material were obtained at all ground reconnaissance sites during the previous study (Simon *et al*. 2003) for determining the amount of fine-grained sediment (<0.063mm) in streambank materials (Figure 4).

Information from RGAs were supplemented by more detailed geomorphic evaluations conducted by Simon *et al*. (2003) where specific sources of fine-grained streambank materials were identified and sampled during stream walks. About 300 RGAs were conducted during 2002 and reported in Simon et al. (2003). An additional 53 RGAs were conducted in 2004 as part of this study to fill gaps in the data network.

Combined stability-index data collected during RGAs were averaged for each stream and sorted by basin quadrant (Table 4). The range and distribution of values were then calculated for each quadrant (Table 5).

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

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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

____
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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

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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

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12. Severity of side-slope erosion

None	Low	Moderate	High
0	0.5	1.5	2

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TOTAL ____

Figure 3. Combined-stability index field form and ranking scheme.

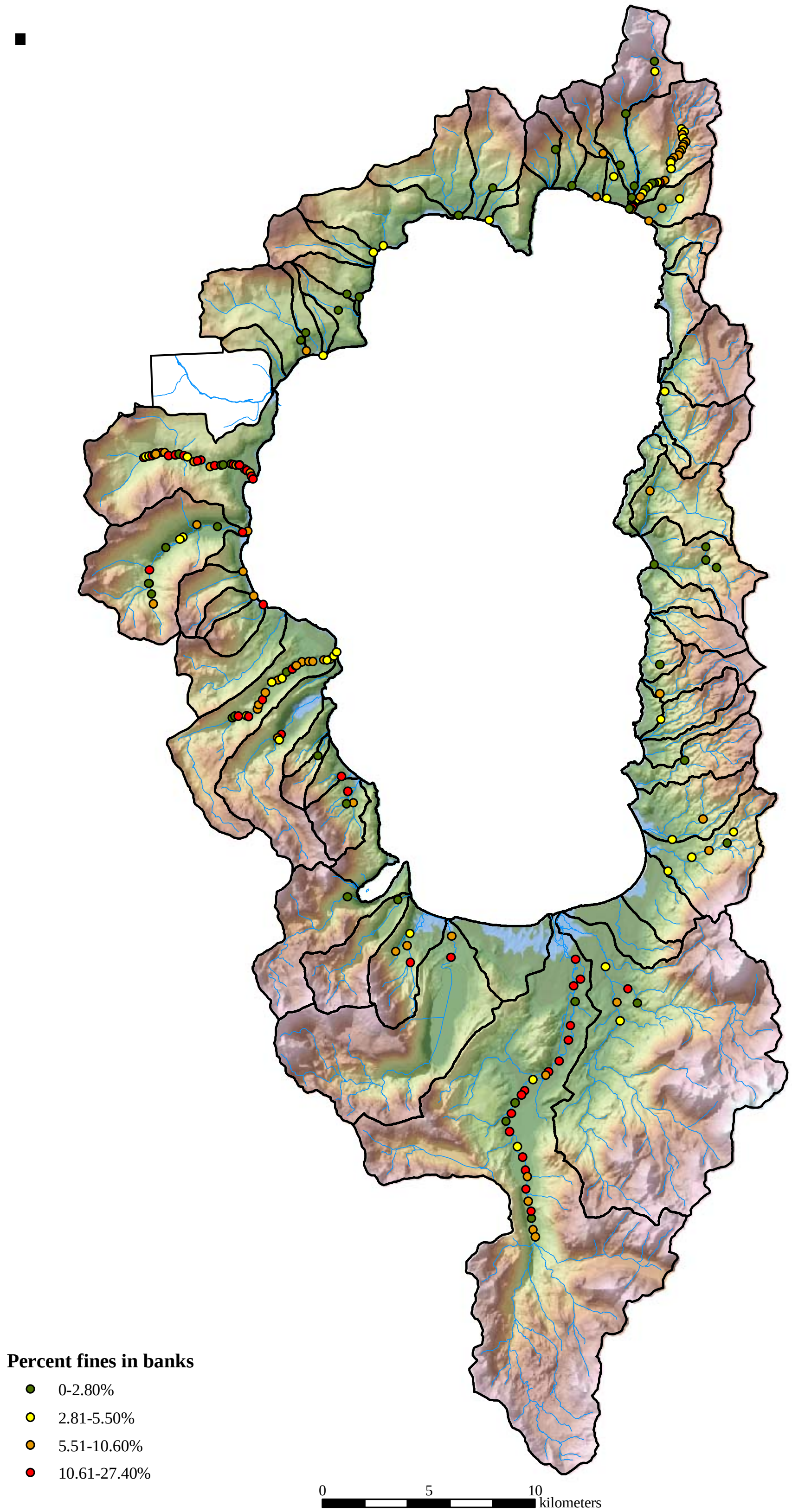

Figure 4. Spatial distribution of fine-grained (<0.063mm) bank materials.

Table 4- Average, combined-stability index for streams draining to Lake Tahoe. Values are based on criteria shown in Figure 3.

Watershed	Stream	Combined stability-index	Basin area $(km)^2$	Quadrant
39	Burke	10.0	12.8	E
32	Cave Rock	16.8	4.1	E
27	Dead Mans Point	13.5	3.5	E
40	**Edgewood**	17.8	17.2	E
29	**Glenbrook**	19.3	13.0	E
33	Lincoln	14.5	6.7	E
31	**Logan House**	12.9	5.6	E
38	McFaul	17.6	10.2	E
30	North Logan House	15.0	5.3	E
35	North Zephyr	16.3	6.8	E
	Skyland		2.0	E
28	Slaughterhouse	15.3	12.3	E
37	Zephyr	21.0	4.9	E
3	Barton	6.5	2.6	N
22	Bonpland	9.0	2.3	N
16	Burnt	16.3	2.3	N
2	Burton	9.1	14.8	N
8	Carnelian Bay	7.0	2.6	N
9	Carnelian Canyon	7.5	9.2	N
6	Cedar Flats	8.3	4.7	N
5	Dollar	6.5	4.7	N
	East Stateline Point		4.8	N
14	First	15.6	4.5	N
11	Griff	13.6	11.8	N
19	**Incline**	17.5	17.4	N
12	Kings Beach	14.5	1.6	N
4	Lake Forest	4.2	1.8	N
24	Marlette	21.8	11.3	N
20	Mill	17.3	12.4	N
	Sand Harbor		5.6	N
15	Second	19.1	4.8	N
25	Secret Harbour	12.2	11.1	N
1	Tahoe State Park	10.0	3.1	N
10	Tahoe Vista	11.4	15.5	N
18	**Third**	14.2	15.5	N
21	Tunnel	14.1	4.4	N
7	Watson	4.3	6.0	N
17	Wood	13.0	6.1	N
42	Bijou	11.7	7.3	S
41	Bijou Park	18.5	8.0	S
	Camp Richardson		10.1	S
48	Cascade	12.0	11.1	S
47	Tallac	8.4	11.9	S

46	Taylor	8.0	41.0	S
43	**Trout**	14.9	106.6	S
44	**Upper Truckee**	16.6	144.2	S
62	**Blackwood**	17.4	28.8	W
26	Bliss	14.0	1.6	W
50	Bliss State Park	5.5	5.4	W
49	**Eagle**	7.0	20.4	W
	Eagle Rock		2.1	W
45	**General**	16.1	23.3	W
59	Homewood	13.1	2.6	W
53	Lonely Gulch	8.3	2.8	W
60	Madden	9.3	5.9	W
57	McKinney	7.2	22.2	W
55	Meeks	13.0	5.7	W
52	Paradise Flat	18.0	2.9	W
58	Quail Lake	6.5	4.2	W
51	Rubicon	9.2	7.4	W
54	Sierra	6.0	3.1	W
63	**Ward**	13.9	34.2	W

Table 5- Distribution of average, combined stability-index by basin quadrant.

Combined stability-index percentiles					**Quadrant**
10th	**25th**	**50th**	**75th**	**90th**	
13.0	14.3	15.8	17.6	19.1	E
6.5	7.9	12.2	15.1	17.5	N
8.2	10.0	12.0	15.7	17.4	S
6.2	7.1	9.3	13.9	16.9	W

Estimates of Fine-Sediment Loadings: T/y <0.063 mm

Initial analysis of fine-sediment (<0.063 mm) loadings in T/y to Lake Tahoe from all 63 watersheds were conducted using the distributions of fine-sediment yields and the combined-stability index, and applied to streams with no historical loadings data. The procedure was:

1. Determine the average, combined stability index for the stream (Table 4);
2. Calculate the distribution of average values by basin quadrant (10th, 25th, 50th, 75th, and 90th) (Table 5);
3. For a given stream, use the appropriate percentile class based on the combined-stability index distribution, and apply to the same percentile of the distribution of fine-grained (<0.063mm) suspended-sediment yield (Table 3);
4. Obtain the fine-grained (<0.063mm) suspended-sediment yield from the table and multiply by basin area to obtain average, annual fine-sediment load in T/y.

On average, approximately 5,200 T/y of fine (<0.063 mm) sediment is delivered to Lake Tahoe from the 63 contributing watersheds. Loadings from the north, south and west quadrants are similar, with contributions representing 32%, 37% and 30%, respectively. Results are mapped in

Figures 5 and 6 showing annual fine-sediment loadings in T/y and percent contribution to the lake.

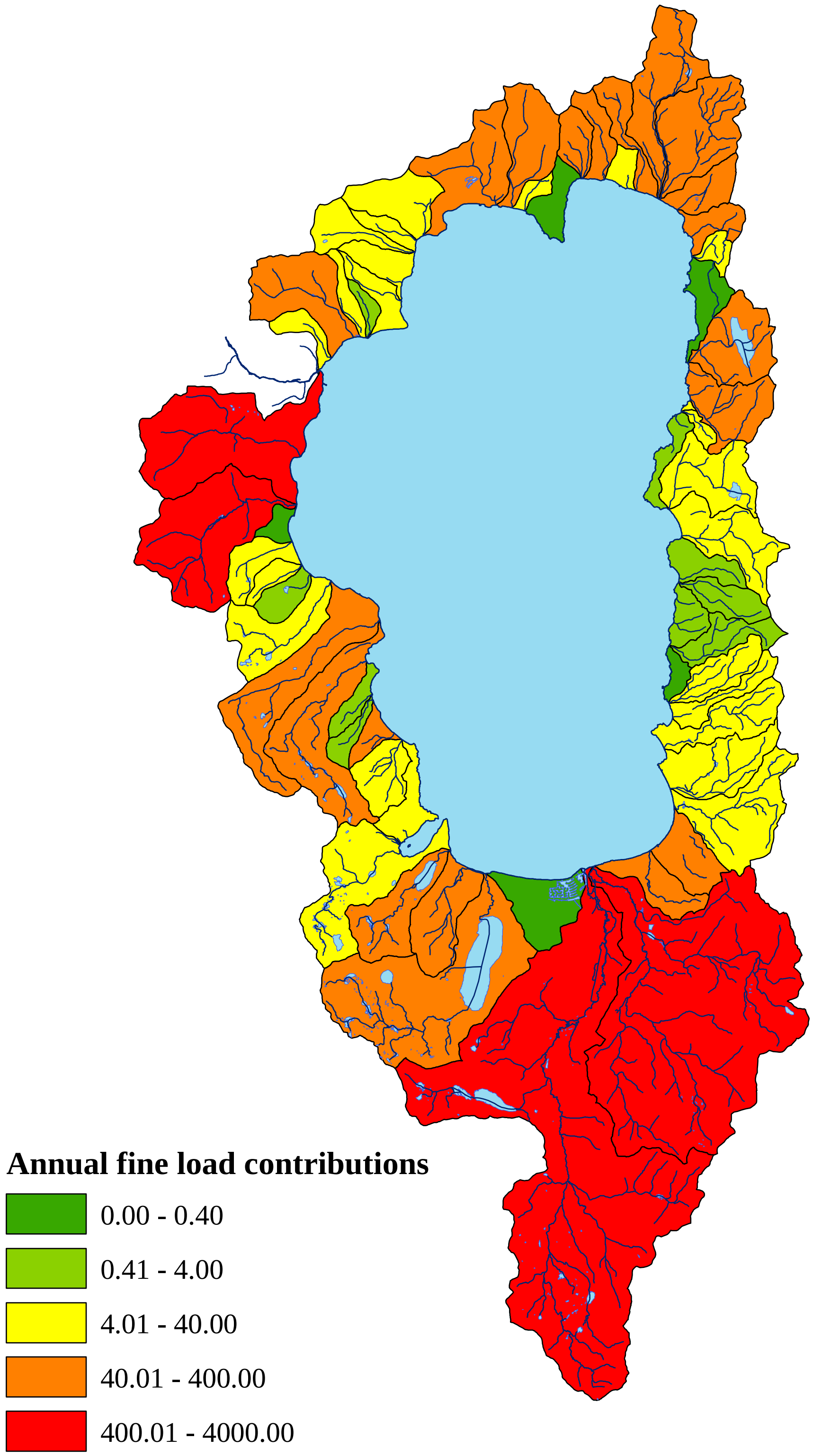

Figure 5. Median, annual contribution of fine sediment (<63um) in T/y.

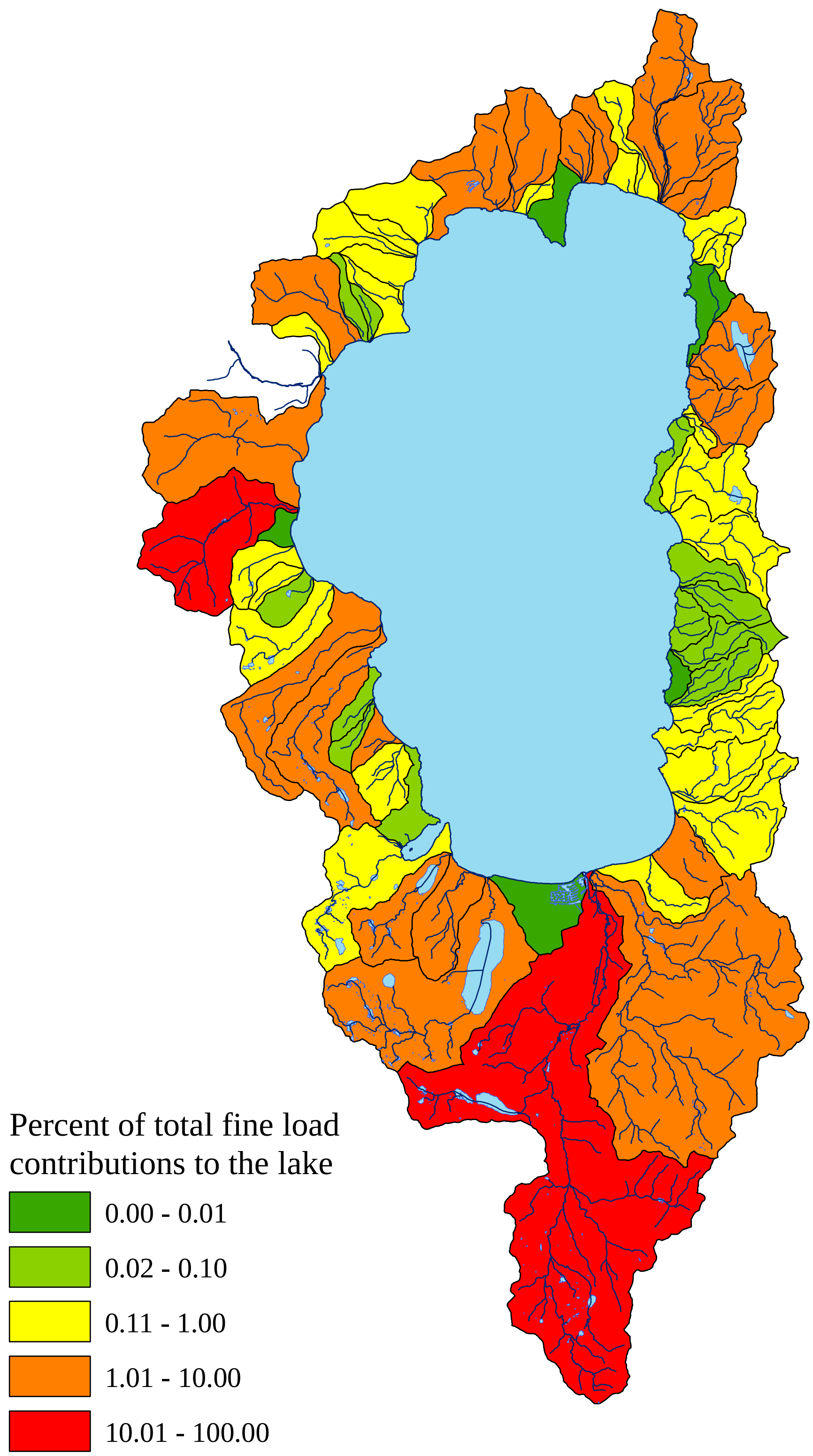

Figure 6. Percent of annual contribution of fine suspended sediment (<63um).

Estimates of Fine-Sediment Particle Flux: *n*/y <0.020 mm

The fundamental approach to developing estimates of basinwide fine-particle flux to Lake Tahoe were based on similar techniques to those used above. That is, using distributions of particle flux by basin quadrant from measured data and regression relations and then applying those relations to streams with no fine-particle flux data. Particle flux is defined as the product of the concentration of particles per volume of water times the flow rate:

$$n = C\, Q\, \alpha \tag{1}$$

where n = particle flux, the number of particles per second; C = concentration in mg/l; Q = discharge in ft^3/s; and α = factor to convert from per milliliter to per ft^3.

Rabidoux (2005) used relations between flow discharge and particle flux to develop loadings estimates for sites with measured fine-particle data (Table 6).

Table 6- Sampling sites of water-sediment mixtures by U. California, Davis between 2002 and 2004 (Rabidoux, 2005). Note: * = additional samples taken at other sites along stream.

Stream	USGS station number	Number of samples
Blackwood Creek	10336660	71
Eagle Rock Creek	103367592	59
Edgewood Creek	10336760	62
General Creek	10336645	69
Glenwood Creek	10336730	59
Incline Creek*	10336700	73
Logan House Creek	10336740	59
Third Creek	10336698	72
Trout Creek*	10336790	65
Upper Truckee River*	10336610	72
Ward Creek	10336676	75

Preliminary analysis of relations between flow discharge and particle concentration in *n*/ml undertaken in this study using the same data set showed extremely low regression coefficients and flat regression slopes (Figure 7). An example of the regression for Blackwood Creek is shown in Figure 8. The lack of significant relations between concentration of fine particles and flow is not surprising given that particles finer than sand, and particularly those finer than silt, are not hydraulically controlled. Thus relations between particle flux and water discharge are almost akin to multiplying discharge by a constant particle concentration. This provides an explanation for the strength of the relations reported by Rabidoux (2005) (Figure 9).

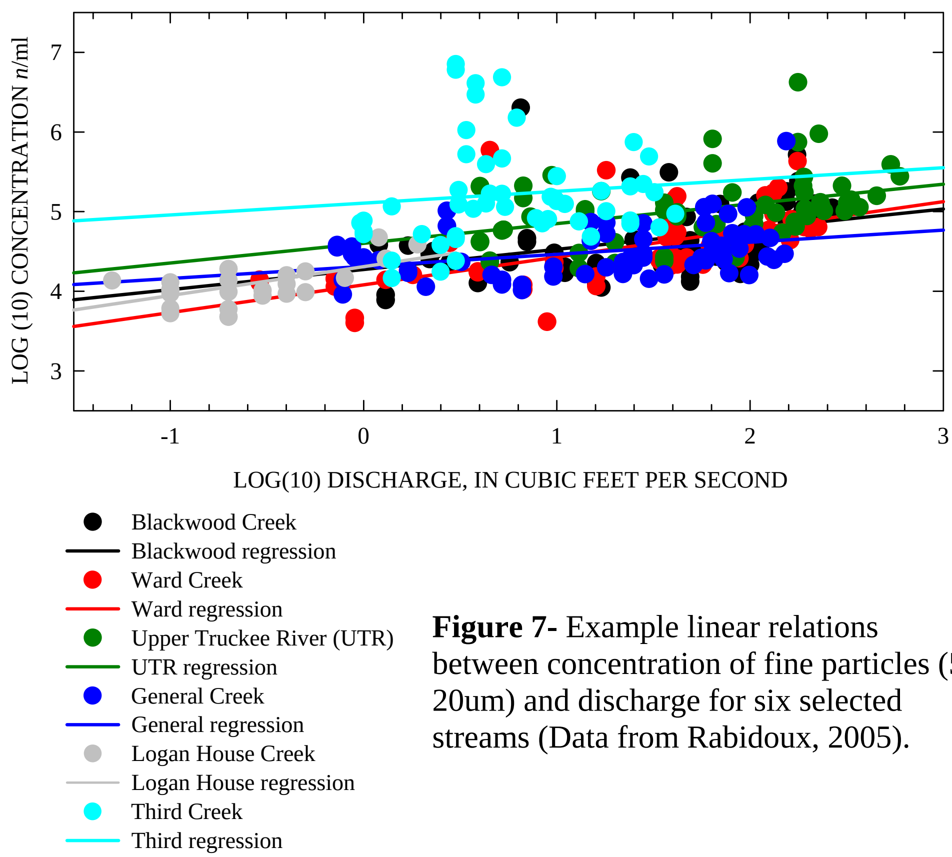

Figure 7- Example linear relations between concentration of fine particles (5-20um) and discharge for six selected streams (Data from Rabidoux, 2005).

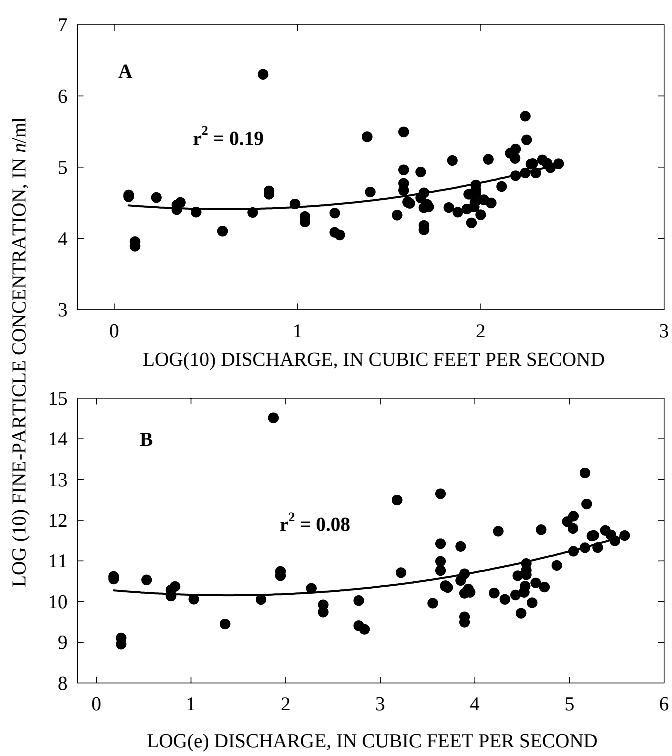

Figure 8. Example quadratic relations of fine-particle concentration (5-20µm) regressed against discharge for Blackwood Creek using data from Rabidoux (2005) and showing very low coefficients of determination between variables using log base 10 (A), and natural log (B).

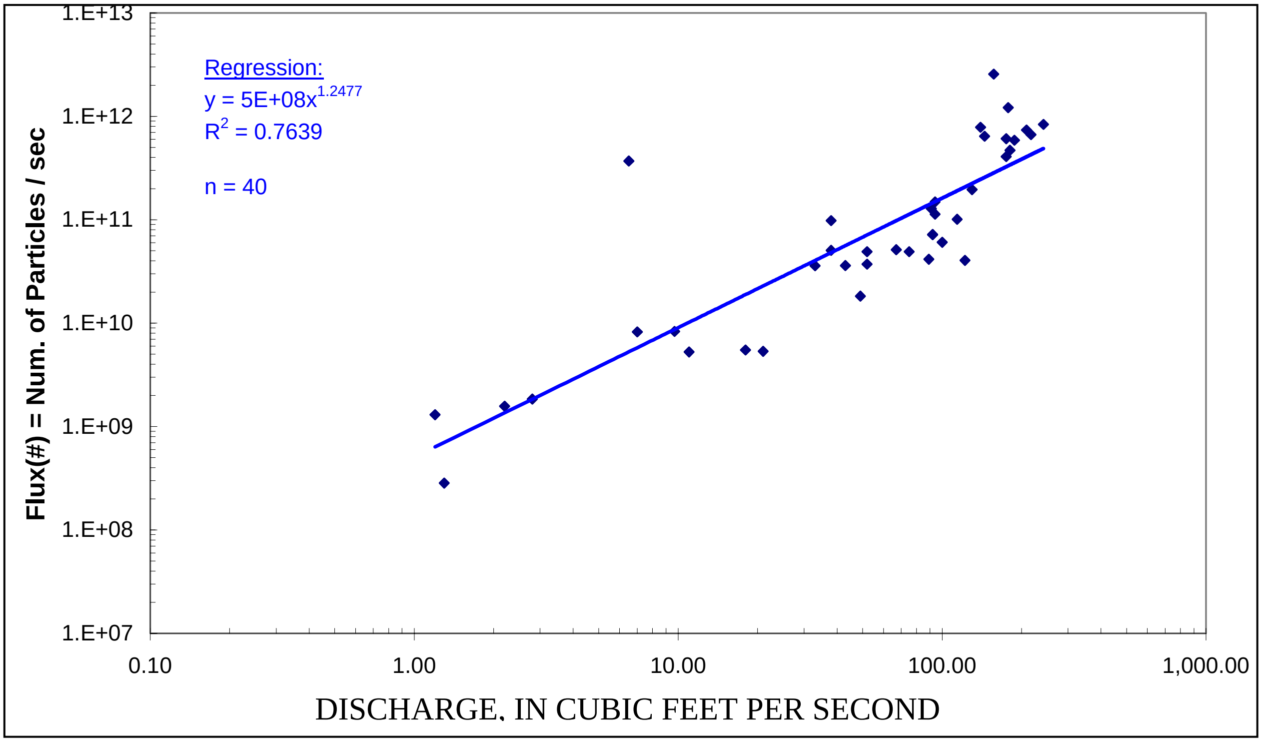

Figure 9- Relation between flow discharge and fine=particle (<0.020mm) flux for Blackwood Creek. Modified from written commun., A. Rabidoux (2005).

More meaningful relations for extrapolating annual particle flux (in *n*/y) were obtained by regressing total, suspended-sediment concentration (in mg/l) as analyzed by the USGS using conventional methods, with particle concentration of the 5 -20 µm fraction (in *n*/ml) analyzed using the Liquilaz instrument (Table 6). The improvement in r^2 values can be seen by comparing the values for the selected stations shown in Table 7. That the slope of the regression lines are significantly greater than 0.0 also attests to the improved viability of the regressions. Relations developed in log-log space for the 11 sites with particle flux data are shown in Figure 10. Regression of these two variables provides a functional link between the total mass of suspended-sediment transported at a given time and the number of particles in the 5 -20 µm fraction.

Table 7- Coefficients of determination (r^2-values) and regression slopes for relations between fine-particle (5-20µm) concentration and discharge (*Q*) and total suspended-sediment concentration (*C*) for selected stations. Note the improved relations for regressions of *n* with *C*.

Particle concentration (*n*) vs. *Q*			**Particle concentration (*n*) vs. *C***		
Stream	**r^2**	**Slope of regression**	**Stream**	**r^2**	**Slope of regression**
Blackwood	0.16	0.25	Blackwood	0.67	0.79
Ward	0.35	0.35	Ward	0.74	0.74
Upper Truckee	0.14	0.25	Upper Truckee	0.52	0.51
General	0.13	0.15	General	0.31	0.39
Logan House	0.40	0.36	Logan House	0.62	0.55
Third	0.01	0.15	Third	0.36	0.51

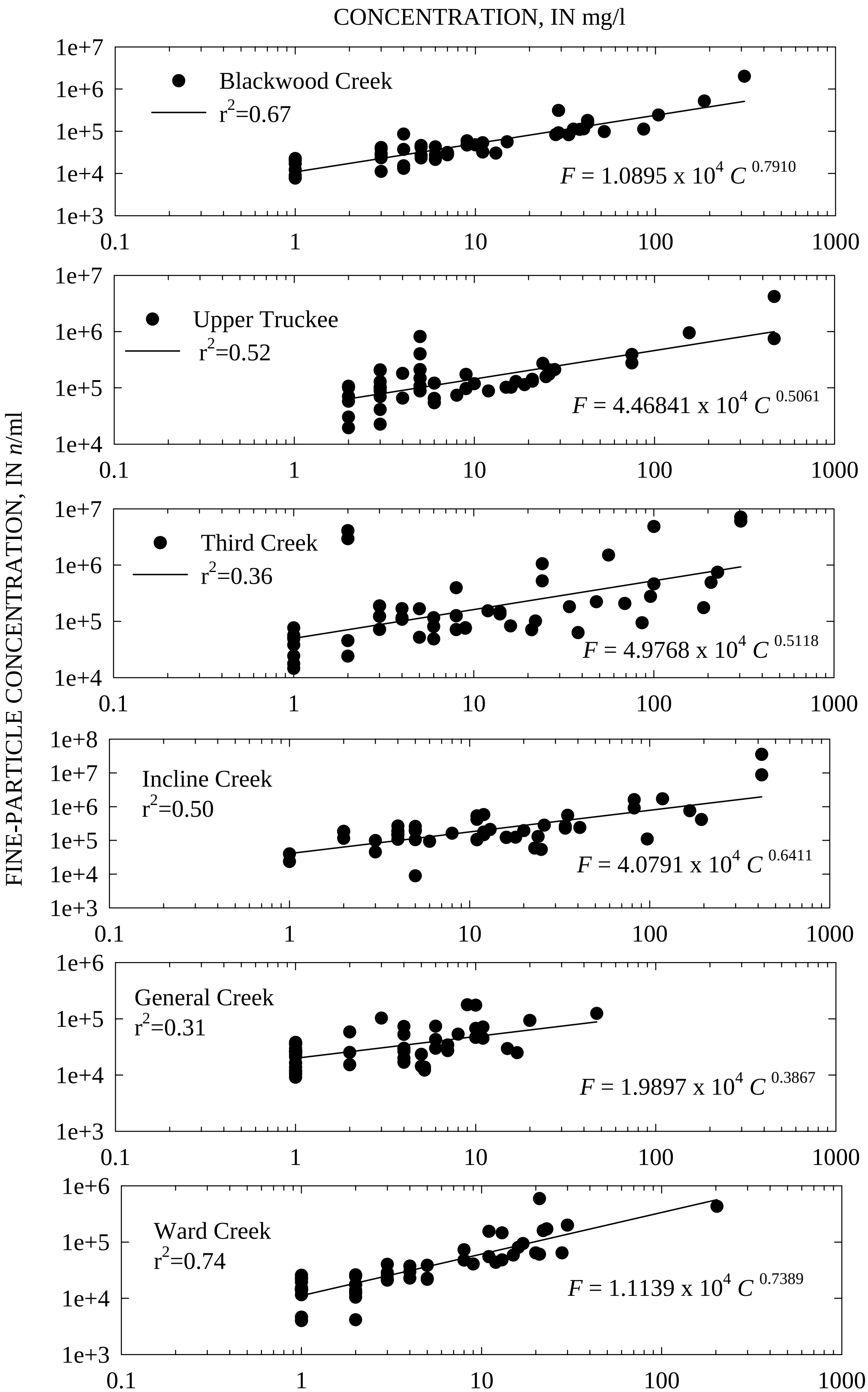

Figure 10- Regressions between fine-particle (5-20μm) concentration in *n*/ml and total, suspended-sediment concentration in mg/l.

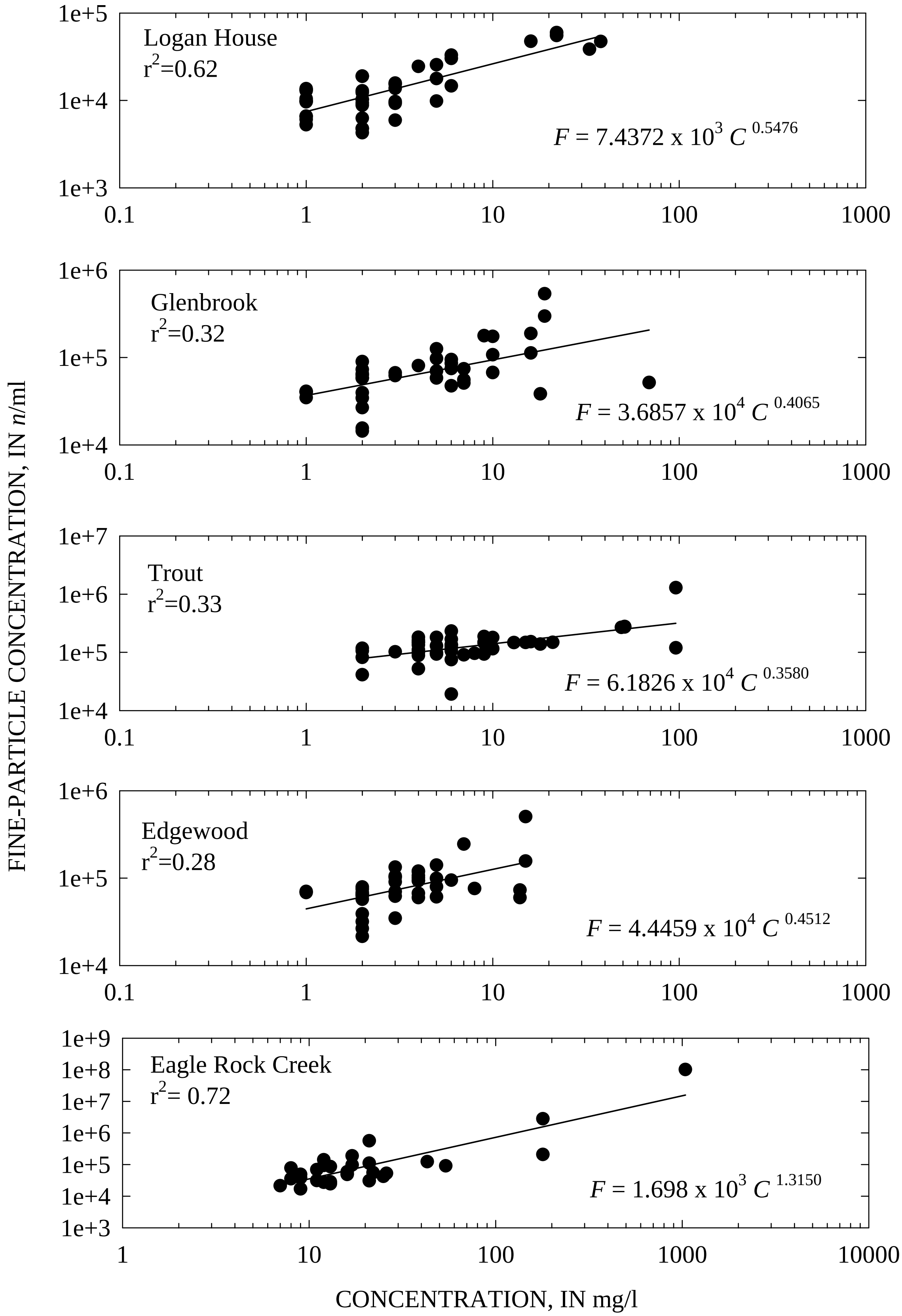

Figure 10- cont'd.

To obtain estimates of annual, fine-particle (5-20 μm) flux, the relations shown in Figure 10 were to be applied to total, suspended-sediment load data for each of the stations over their daily-values period of record. Thus, the daily suspended-sediment loads calculated in Simon *et al*. (2003) for the index stations were used. As it serves as a basis for annual flux estimates, a review of the procedures used in this earlier study to calculate daily loads is appropriate.

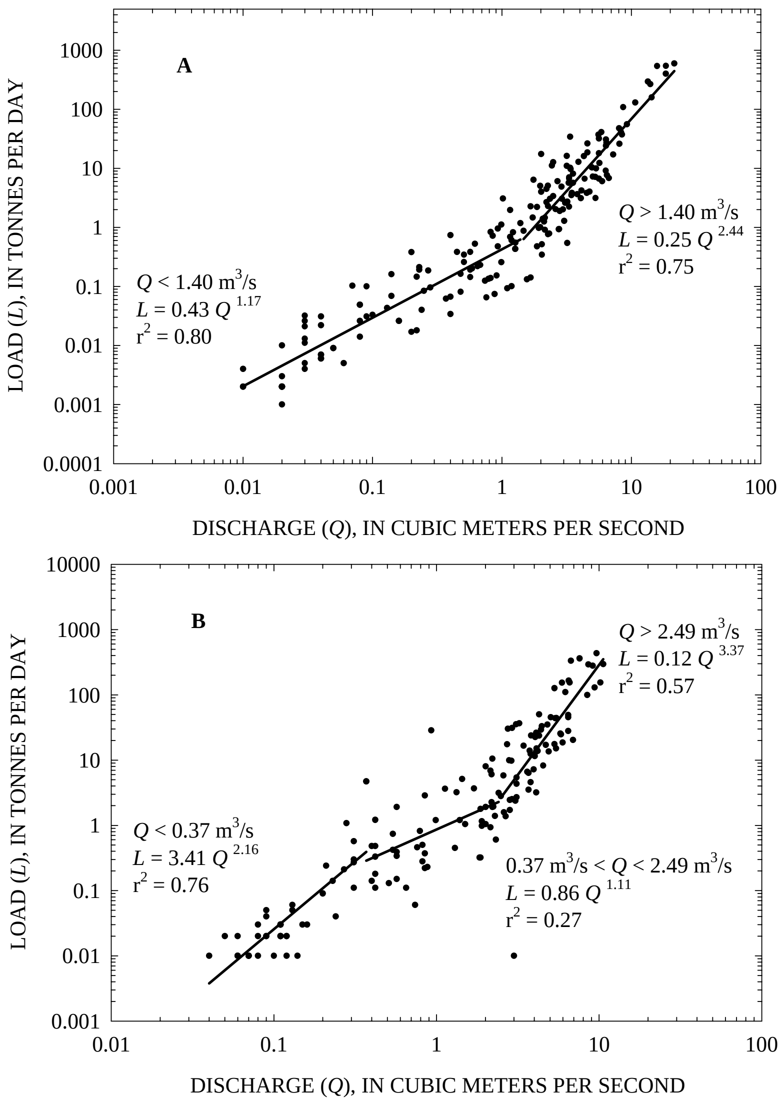

Figure 11. Example of two- and three-segment suspended-sediment rating relations for Blackwood Creek (A), and General Creek (B).

Daily suspended-sediment load data were calculated for each of the index stations from mean-daily flow data and the sediment-rating relations developed in Simon *et al*. (2003). These suspended-sediment transport ratings represent flow and concentration (or load) data collected over extended periods (up to 40 years; Table 2). In a number of cases, the transport relations were not represented by a single linear segment (in log-log space) but were split into several segments to appropriately represent the relation between flow and load over the range of possible discharges (Figure 11). In addition, rating relations for a given site displayed shifts with time, requiring different relations to be used for different time periods. These were generally split into pre- and post-1997, thus accounting for the effects of the large New Year's Day rainstorm in 1997 that created super-saturated snow packs and resulted in large runoff events throughout the Lake Tahoe Basin. Suspended-sediment loads resulting from this event were very high, representing the peak of record in some watersheds (Simon *et al*. 2003). A summary of the number and type of rating relations used to calculate daily, suspended-sediment loads from each of the index stations in shown in Table 8 while the pre- and post-1997 rating equations are shown in Tables 9 and 10, respectively..

Table 8- Number and type of suspended-sediment rating relations used to calculate mean-daily suspended-sediment loads.

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	10336760	10/1/92-9/30/00	8/20/92-9/13/02	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
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
UTR	10336610	10/1/71-9/30/01	11/4/72-9/12/02	Y	1	1
Ward	10336676	10/1/72-9/30/01	12/20/72-9/19/02	Y	2	2

Table 9- Pre-1997 suspended-sediment rating relations used to calculate mean daily suspended-sediment loads.

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	$L = .07Q^{1.48}$	$Q < 1.47$	$L=1.15Q^{2.09}$	$1.47 < Q < 10.62$	$L =1.35Q^{2.18}$	$Q > 10.6$
Eagle Rock	103367592	$L = 9.3Q^{1.82}$	All flows				
Edgewood	10336760	$L=3.29Q^{1.84}$	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				
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	10336770	$L =1.96Q^{2.04}$	All flows				
UTR	10336610	$L =.991Q^{1.55}$	All flows				
Ward	10336676	$L =1.26Q^{1.43}$	$Q < 2.00$	$L =.404Q^{2.69}$	$Q >2.00$		

Table 10- Post-1997 suspended-sediment rating relations used to calculate mean-daily suspended-sediment loads.

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	10336760	$L=1.32Q^{1.57}$	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	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		
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	10336610	$L=.784Q^{1.33}$	All flows				
Ward	10336676	$L=.58Q^{1.41}$	Q < 2.00	$L=.158Q^{2.98}$	2.0<Q<16.0	Pre-1997 eq 2	Q > 16.0

The number of fine particles (5-20 μm) transported on a given day was thus calculated for each day at each index station based on the equations in Figure 10 transposed to relations between fine-particle flux (in *n*/d) and suspended-sediment load (in T/d) (Table 11). This was done because the daily, sediment loadings data sets from Simon *et al*. (2003) were expressed in T/d. Summing the daily values for each year provided an annual fine-particle flux for each year of record. An example from the Upper Truckee River (station 10336610) is shown in Table 12.

Table 11- Regression equations between fine-particle flux (in *n*/d) and suspended-sediment load (in T/d) used to calculate the daily and annual flux for each index station.

Stream	Function	Basin Area (km^2)	Median Annual Flux	Median Annual-Flux Yield
Trout Creek 10336790	$F = 1.3358 \times 10^{16} L^{0.6310}$	106.6	4.18E+18 (8.16E+18)[1]	4.00E+16 (8.59E+16)[1]
Glenbrook Creek 10336730	$F = 5.2060 \times 10^{15} L^{0.7632}$	13.0	1.03E+17	9.81E+15
Edgewood Creek 10336760	$F = 7.1390 \times 10^{15} L^{0.6894}$	17.2	4.67E+17	3.28E+16
Incline Creek 10336700	$F = 9.0419 \times 10^{15} L^{0.6834}$	17.4	2.42E+18	1.33E+17
Logan House Creek 10336740	$F = 1.4239 \times 10^{15} L^{0..8100}$	5.6	9.29E+15	1.72E+15
General Creek 10336645	$F = 1.3679 \times 10^{15} L^{0..7499}$	23.3	2.05E+17	1.06E+16
Third Creek 10336698	$F = 7.6192 \times 10^{15} L^{0.6174}$	15.5	3.37E+18	2.15E+17
Ward Creek 10336676	$F = 6.6512 \times 10^{15} L^{0.9080}$	34.2	4.56E+18	1.82E+17
Upper Truckee River 10336610	$F = 1.7579 \times 10^{16} L^{0.7141}$	144.2	1.93E+19	1.36E+17

Blackwood Creek 10336660	$F = 5.1054 \times 10^{15} L^{0.8126}$	28.8	5.44E+18	1.88E+17
Eagle Rock Creek 103367592	$F = 8.1701 \times 10^{15} L^{1.1836}$	1.53	1.74E+16	1.14E+16

F = fine-particle (0.5 – 20μm) flux, in number per day (*n*/d); *L* = suspended-sediment load in Tonnes per day (T/d).

[1] = Values calculated using flux-load relation from station 10336790 with flow and load data from 10336780.

Table 12- Calculation of annual fine-particle (<0.020mm) flux and flux yield for the Upper Truckee River (station 1033610)

Year	Annual Load (T)	Yield (T/km^2)	Annual Flux (*n*)	Annual Flux Yield (*n*/y)
1972	2370	16.67	1.93E+19	1.36E+17
1973	3325	23.38	2.40E+19	1.69E+17
1977	293	2.06	4.35E+18	3.06E+16
1981	1840	12.94	1.52E+19	1.07E+17
1982	7320	51.49	4.29E+19	3.02E+17
1983	8903	62.62	5.13E+19	3.61E+17
1984	4333	30.47	2.84E+19	2.00E+17
1985	1407	9.90	1.29E+19	9.08E+16
1986	5848	41.13	3.46E+19	2.44E+17
1987	641	4.51	7.16E+18	5.04E+16
1988	403	2.83	5.60E+18	3.94E+16
1989	2493	17.53	1.94E+19	1.37E+17
1990	755	5.31	8.34E+18	5.87E+16
1991	977	6.87	9.60E+18	6.76E+16
1992	516	3.63	6.49E+18	4.56E+16
1993	3965	27.89	2.72E+19	1.91E+17
1994	474	3.33	6.03E+18	4.24E+16
1995	8652	60.85	4.80E+19	3.38E+17
1996	5146	36.19	3.44E+19	2.42E+17
1997	2678	18.83	2.00E+19	1.41E+17
1998	2430	17.09	2.02E+19	1.42E+17
1999	2034	14.31	1.71E+19	1.20E+17
2000	1079	7.59	1.11E+19	7.78E+16
Mean	**2951**	**20.8**	**2.06E+19**	**1.45E+17**
Median	**2370**	**16.7**	**1.93E+19**	**1.36E+17**
Max	**8903**	**62.6**	**5.13E+19**	**3.61E+17**

To summarize, estimates of fine-sediment (<0.020 mm) flux in *n*/y from each index station were obtained using the following procedure.

1. Relations were developed between total, suspended-sediment concentration (in mg/l) and particle concentration (in *n*/ml) of the 5-20mm fraction (Figure 10);

2. Relations from (1) above, were converted to fine-particle concentration (in *n*/d) and suspended-sediment load (in T/d) (Table 11);
3. Particle flux in *n*/d were calculated for each day of historic flow record at each site from the equations in Table 11;
4. Data for each year were summed to obtain an annual value;
5. An average, annual value was calculated by summing the number of particles transported during each year of flow record, and dividing by the number of years (See Table 12); and
6. Average, annual particle flux (in *n*/y) was divided by basin area to obtain an average, annual particle-flux yield (in n/y/km^2).

The procedure for extrapolating average, annual fine-particle flux yield data to ungaged watersheds was accomplished by first sorting the average, annual values (in n/y/km^2) by basin quadrant and determining the distribution within each quadrant. As done previously, distributions for each quadrant were defined in terms of the 10th, 25th, 50th, 75th, and 90th percentiles. For a given stream, the correct quadrant and appropriate percentile class is selected based on the combined-stability index distribution (Table 5). That same quadrant, percentile class is then selected from the average, annual flux yield distribution in Table 13. By multiplying that value by the basin area (in km^2) the average, annual particle flux of the 5-20μm fraction (in n/y/km^2) was obtained.

Table 13- Distribution of average, annual flux yields in n/y/km^2 by basin quadrant.

Percentiles of average, annual flux yield in n/y/km^2					Quadrant
10th	**25th**	**50th**	**75th**	**90th**	
3.34E+15	5.77E+15	9.81E+15	2.13E+16	2.82E+16	E
1.41E+17	1.54E+17	1.74E+17	1.95E+17	2.07E+17	N
4.92E+16	6.30E+16	8.59E+16	1.11E+17	1.26E+17	S
4.49E+16	9.63E+16	1.82E+17	1.85E+17	1.87E+17	W

A summary of the results, using the above procedure is shown in Table 14. On average, a total of 7.79E+19 fine particles (<0.020 mm) are delivered to Lake Tahoe on an annual basis from the 63 contributing watersheds. The spatial distribution of fine-particle flux in *n*/y and the relative contribution (in percent) from each watershed are displayed in Figures 12 and 13, respectively.

Table 14- Summary of annual fine load (<0.063mm) and annual fine-particle flux (<0.020mm) for watersheds draining to Lake Tahoe.

Watershed	Stream name	Quadrant	Annual Fine Load (<63um) tonnes/y	% of Load (<63um)	% by Quadrant (<63um)	Annual Flux (0.5 - 20 um) number/y	% of Load (0.5 - 20 um)	% by Quadrant (0.5 - 20 um)
39	Burke	E	5.9	0.11		4.28E+16	0.05	
32	Cave Rock	E	3.5	0.07		6.12E+16	0.08	
27	Dead Mans Point	E	1.8	0.03		1.58E+16	0.02	
40	**Edgewood**	E	**11.4**	0.22		**4.67E+17**	0.60	
29	**Glenbrook**	E	**7.0**	0.13		**1.03E+17**	0.13	
33	Lincoln	E	3.7	0.07		3.84E+16	0.05	
31	**Logan House**	E	**2.3**	0.04		**9.29E+15**	0.01	
38	McFaul	E	10.7	0.21		2.17E+17	0.28	
30	North Logan House	E	3.3	0.06		4.12E+16	0.05	
35	North Zephyr	E	4.7	0.09		6.65E+16	0.09	
	Skyland	E	-	-		-	-	
28	Slaughterhouse	E	8.6	0.17		1.21E+17	0.15	
37	Zephyr	E	6.1	0.12	1.3	1.37E+17	0.18	1.7
3	Barton	N	4.9	0.09		3.70E+17	0.48	
22	Bonpland	N	8.7	0.17		3.49E+17	0.45	
16	Burnt	N	36.2	0.70		4.69E+17	0.60	
2	Burton	N	79.9	1.53		2.43E+18	3.12	
8	Carnelian Bay	N	7.8	0.15		1.16E+17	0.15	
9	Carnelian Canyon	N	35.4	0.68		1.42E+18	1.82	
6	Cedar Flats	N	18.0	0.35		7.23E+17	0.93	
5	Dollar	N	8.8	0.17		6.62E+17	0.85	
	East Stateline Point	N	-	-		-	-	
14	First	N	61.7	1.18		8.79E+17	1.13	
11	Griff	N	121	2.33		2.16E+18	2.78	
19	**Incline**	N	**129**	2.48		**1.63E+18**	2.09	
12	Kings Beach	N	22.4	0.43		3.02E+17	0.39	
4	Lake Forest	N	3.4	0.06		2.56E+17	0.33	
24	Marlette	N	199.2	3.83		2.34E+18	3.01	
20	Mill	N	218.8	4.20		2.57E+18	3.30	
	Sand Harbor	N		0.00		-	-	
15	Second	N	84.0	1.61		9.89E+17	1.27	
25	Secret Harbour	N	78.5	1.51		1.92E+18	2.47	
1	Tahoe State Park	N	8.8	0.17		5.14E+17	0.66	
10	Tahoe Vista	N	110	2.11		2.69E+18	3.46	
18	**Third**	N	318	6.11		3.37E+18	4.33	
21	Tunnel	N	44.2	0.85		8.13E+17	1.04	
7	Watson	N	11.2	0.22		8.49E+17	1.09	
17	Wood	N	43.5	0.83	31.8	1.07E+18	1.37	37.1
42	Bijou	S	43.9	0.84		6.28E+17	0.81	
41	Bijou Park	S	55.0	1.06		1.01E+18	1.29	
	Camp Richardson	S	-	-		-	-	
48	Cascade	S	66.8	1.28		9.57E+17	1.23	
47	Tallac	S	60.7	1.17		5.83E+17	0.75	
46	Taylor	S	210	4.03		2.01E+18	2.59	
43	**Trout**	S	**462**	8.87		**4.18E+18**	5.37	
44	**Upper Truckee**	S	**1010**	19.40	36.6	**1.93E+19**	24.8	36.8
62	**Blackwood**	W	**846**	16.25		**5.44E+18**	6.98	
26	Bliss	W	20.8	0.40		2.96E+17	0.38	
50	Bliss State Park	W	4.4	0.08		2.43E+17	0.31	
49	**Eagle**	W	**21.8**	0.42		1.96E+18	2.52	
	Eagle Rock	W	-	-		-	-	
45	**General**	W	**53.3**	1.02		**2.05E+17**	0.26	
59	Homewood	W	33.9	0.65		4.83E+17	0.62	
53	Lonely Gulch	W	3.9	0.08		3.92E+16	0.05	
60	Madden	W	11.4	0.22		1.07E+18	1.37	
57	McKinney	W	20.2	0.39		2.14E+18	2.74	
55	Meeks	W	73.8	1.42		2.55E+17	0.33	
52	Paradise Flat	W	54.3	1.04		5.35E+17	0.69	
58	Quail Lake	W	3.4	0.06		2.93E+17	0.38	
51	Rubicon	W	14.3	0.27		1.35E+18	1.73	
54	Sierra	W	2.5	0.05		1.38E+17	0.18	
63	**Ward**	W	**412**	7.91	30.3	**4.56E+18**	5.85	24.4
	Total		5206	100		7.79E+19	100	100

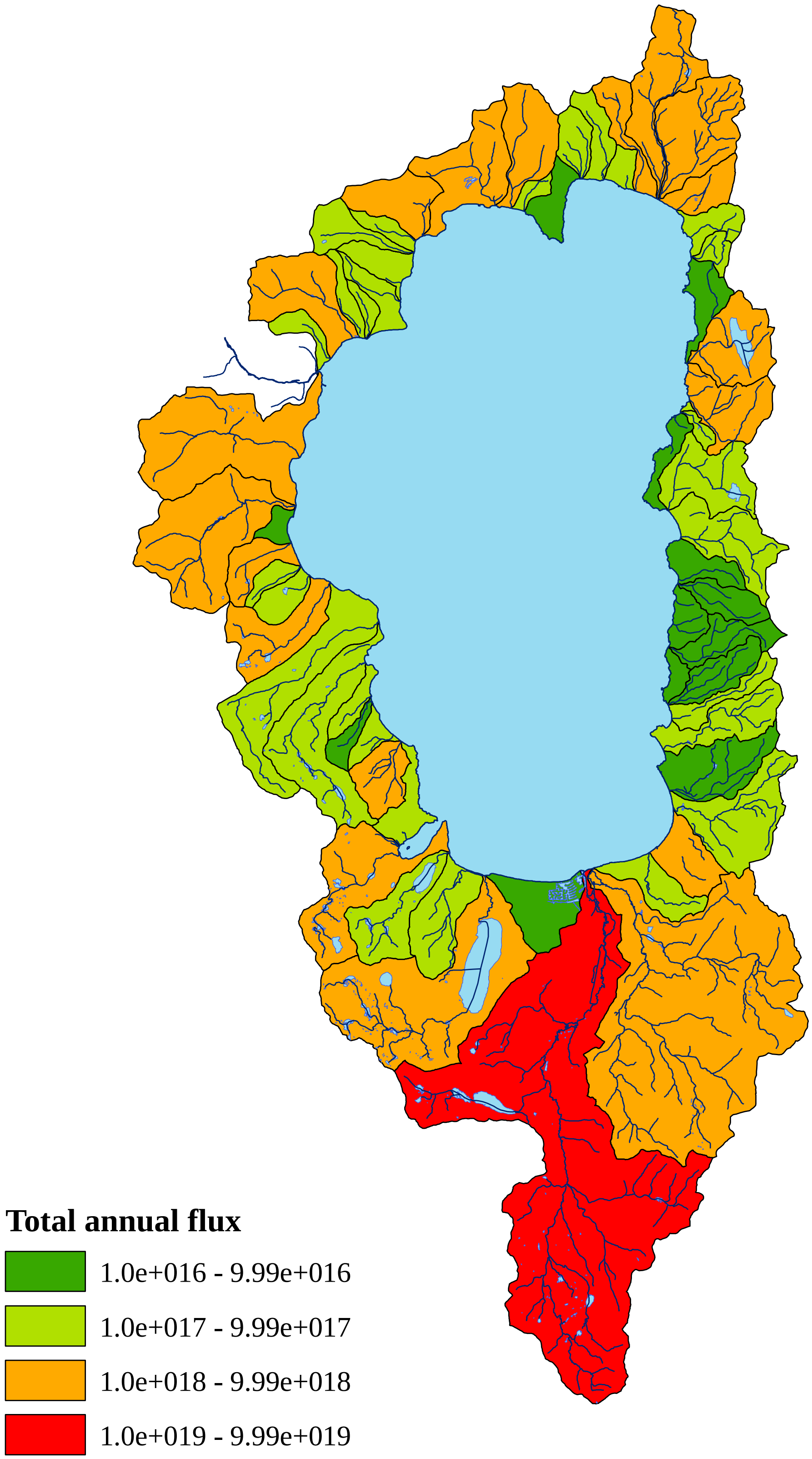

Figure 12. Median annual fine-particle flux (0.5 – 20 um) to Lake Tahoe, in *n*/y.

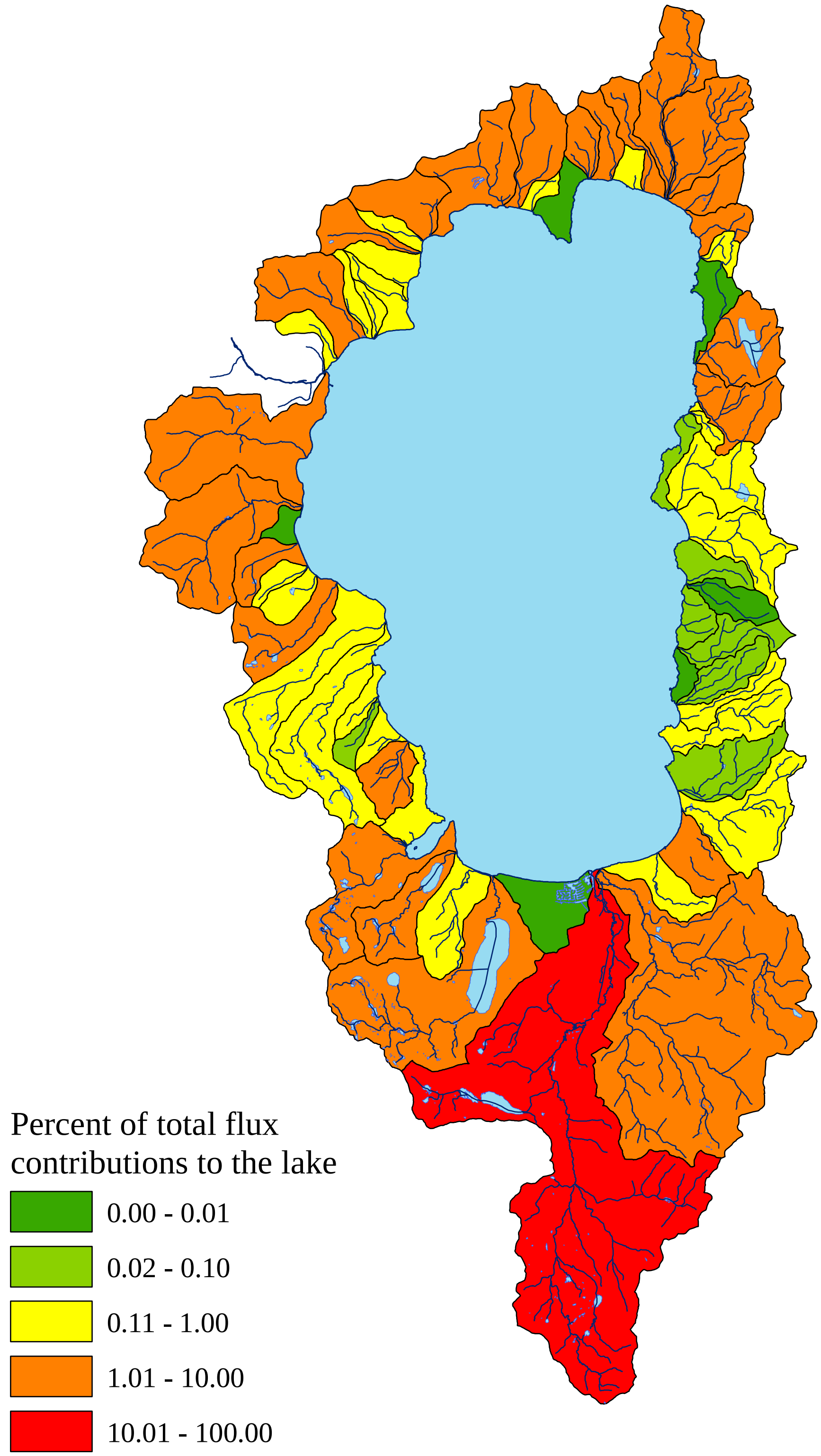

Figure 13. Percent contribution of annual fine-particle flux (0.5 – 20 um) to Lake Tahoe.

Estimates of Fine-Sediment Contributions from Streambank Erosion: <0.063 mm

Whereas estimates of fine-particle loadings and flux to Lake Tahoe relied on generating relations between total, suspended-sediment loadings and fine-particle loadings or flux from measured data at various index stations, estimates of fine-sediment contributions from streambank erosion presented a different challenge. In this case, the fine-particle loadings or flux measured at the index stations or estimated by the previously discussed procedures, represent fine-sediment loadings from all possible sources. This could include floodplains, slopes and channel beds and banks. Once again, in the absence of resources to perform deterministic, numerical simulations of all contributing streams, empirical procedures were utilized. In general, the technique to estimate basinwide fine-sediment contributions from streambank erosion relied on extrapolating rates of streambank erosion obtained from time-series measurements of monumented cross sections or from numerical simulations with the CONCEPTS channel evolution model (Nolan and Hill, 1991; Simon *et al*., 2003)

Availability of Data: Time-Series Cross Sections

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 and summer of 2004. Time-series cross sections of the Upper Truckee River were originally surveyed in 1992 and had been 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 15.

Table 15- 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.)

Calculation of Rates of Streambank Erosion

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 14. 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.

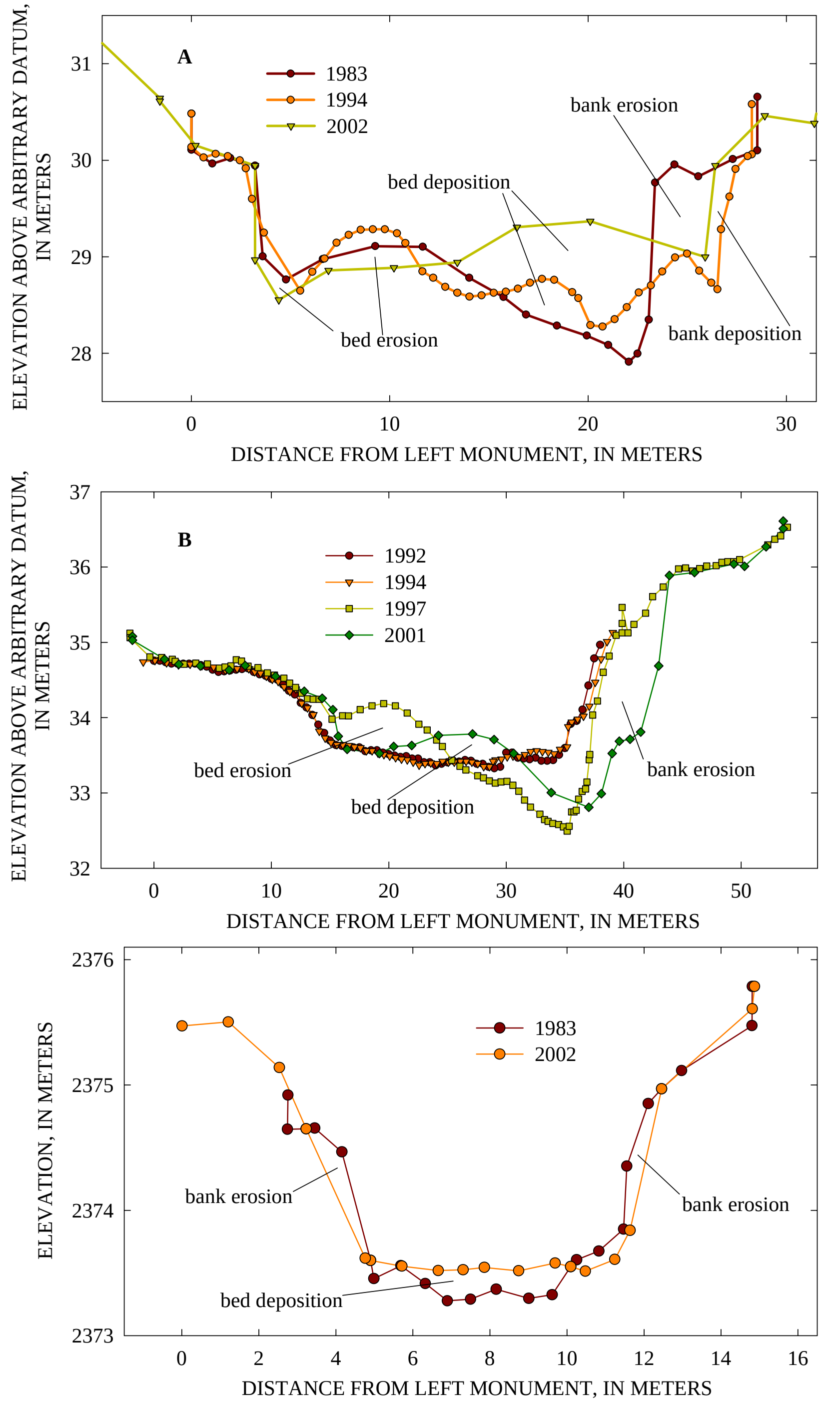

Figure 14. Examples of overlain surveys from Blackwood Creek (A), Upper Truckee River (B) and General Creek (C).

Simulations of Streambank Erosion

As part of a previous study, the deterministic, channel-evolution model CONCEPTS was used to simulate channel erosion and deposition along General and Ward Creeks and the Upper Truckee River (Simon *et al*., 2003). The CONCEPTS numerical model was used to simulate 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). Required input data such as geotechnical shear strength, bank-toe erodibility and particle size distribution of bank materials were measured or sampled in the field (Simon *et al*., 2003). An example is shown in Figure 15.

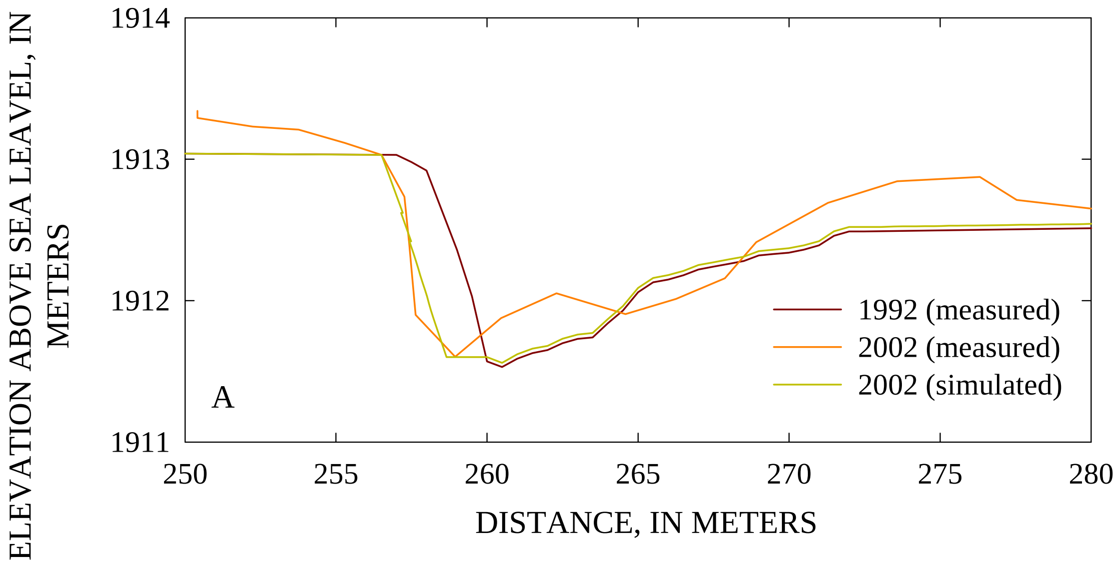

Figure 15- Example comparison of simulated and measured streambank erosion between 1992 and 2002 along the Upper Truckee River. Modified from Simon et al. (2003).

Unit rates of streambank erosion were derived from the numerical simulations by:

1. Calculating the area eroded in each cross section;
2. Taking the average eroded area between successive cross sections;
3. Multiplying by the distance between the midpoint of successive cross sections;
4. Dividing by the number of years of simulation to obtain a rate in m^3/y; and
5. Dividing by the total reach length to obtain a rate in m^3/y/km of channel.

This provided a unit streambank erosion rate in the same units as those calculated from time-series cross section calculations.

Extrapolation of Measured and Simulated Streambank Erosion Rates

To obtain the rate of streambank erosion of fine sediment (<0.063 mm) from the measured and simulated unit erosion rates, values were multiplied by the average percentage of silt-clay in the channel banks. The resulting rates of fine, streambank erosion are expressed in m^3/y/km and listed in Table 16.

Table 16- Measured and simulated average, annual rates of streambank erosion.

Stream	Bank composition (% finer 0.063 mm)*	Erosion rate (m^3/y/km)	Type of data	Source of data
Blackwood Creek	5.6	12.2	Measured	Simon *et al*. 2003
Edgewood Creek	4.9	0.09	Measured	Nolan and Hill, 1991
General Creek	7.4	0.92	Simulated	Simon *et al*. 2003
Logan House Creek	-	0.002	Measured	Nolan and Hill, 1991
Upper Truckee River	9.5	9.50	Simulated	Simon *et al*. 2003
Ward Creek	10.4	4.40	Simulated	Simon *et al*. 2003

* = Data from Simon *et al*. (2003)

To extrapolate this limited data set to the entire Lake Tahoe Basin, diagnostic information obtained during the RGAs were used. Question 6 of the RGA field form (Figure 3) describing relative bank instability as the percentage (longitudinally) of each side of the channel that has experienced recent mass failure was used. Observed conditions ranged from 0% (stable banks) to 100% where the entire reach contained failing streambanks. An example from Blackwood Creek shows the average, longitudinal extent of bank failures evaluated at 17 sites along the creek (Figure 16). Each bank was assigned a numerical value based on the extent of failures (Table 17). This value was termed the bank-stability index (I_B). The index attempts to synthesize more quantitative evaluations of streambank stability that might include parameters such as bank height, bank angle, geotechnical strength, and bank-toe erodibility. A summary of all field data is provided in Table 18 with the average I_B values for each stream, in Table 19.

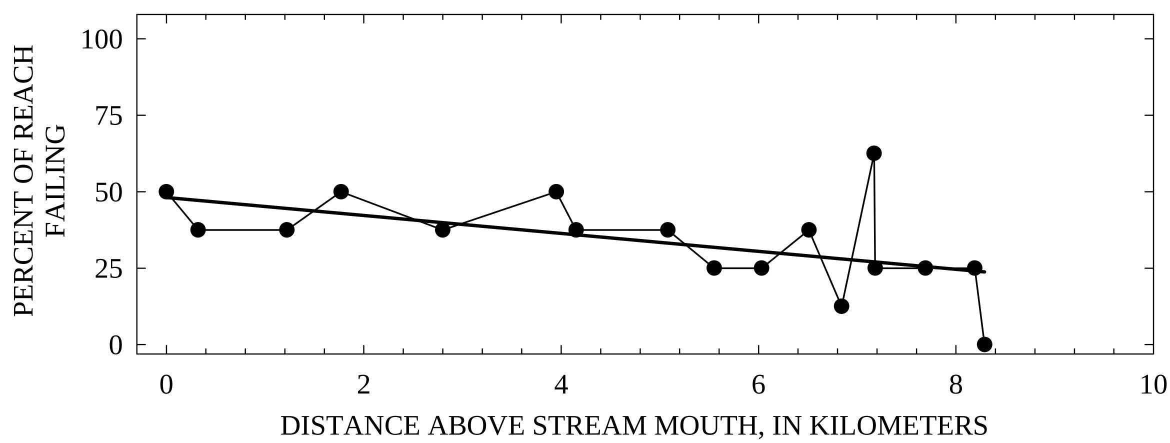

Figure 16. Observations of the extent of streambank instability along Blackwood Creek

Table 17- Assigned values for the bank-stability index (I_B) based on the percent of reach length with failing banks.

Criteria					
Percent of reach with failing banks*	0-10%	11-25%	26-50%	51-75%	76-100%
Assigned index value*	0	0.5	1.0	1.5	2.0
* = Evaluations and calculations are done for each bank and summed to obtain a value for the reach. A maximum value of 4.0, therefore, is possible for a reach.					

Table 18- Sites with field data used to calculate bank-stability index (I_B). rkm= distance above mouth in kilometers.

Basin	Stream	rkm	Streambank erosion, left	Streambank erosion, right	Streambank instability, left	Streambank instability, right
1	Tahoe State Park	0.019	None	None	0-10%	0-10%
1	Tahoe State Park	0.897	None	None	0-10%	0-10%
2	Burton Creek	0.255	Fluvial	None	26-50%	0-10%
2	Burton Creek	0.848	Fluvial	None	11-25%	0-10%
3	Barton Creek	0.408	None	None	0-10%	0-10%
3	Barton Creek	1.056	None	None	0-10%	0-10%
4	Lake Forest Creek	0.016	None	None	0-10%	0-10%
4	Lake Forest Creek	1.036				
4	Lake Forest Creek	1.847	None	None	0-10%	0-10%
5	Dollar Creek	0.305	Fluvial	None	11-25%	0-10%
5	Dollar Creek	1.217	None	None	0-10%	0-10%
6	Cedar Flats Creek	0.057	None	None	0-10%	0-10%
6	Cedar Flats Creek	0.672	Fluvial	Fluvial	11-25%	11-25%
7	Watson Creek	0.038	None	None	0-10%	0-10%
7	Watson Creek	1.113	None	None	0-10%	0-10%
8	Carnelian Bay Creek	0.114	None	None	0-10%	0-10%
9	Carnelian Canyon Creek	0.026	None	Fluvial	0-10%	0-10%
9	Carnelian Canyon Creek	1.303	None	None	0-10%	0-10%
9	Carnelian Canyon Creek	1.898	None	None	0-10%	0-10%
10	Tahoe Vista	0.113	None	None	0-10%	0-10%
10	Tahoe Vista	0.017	Fluvial	Fluvial	26-50%	11-25%
10	Tahoe Vista	1.270	None	None	0-10%	0-10%
10	Tahoe Vista	2.881	Mass Wasting	Mass Wasting	11-25%	11-25%
10	Tahoe Vista	2.324	Fluvial	Fluvial	0-10%	0-10%
11	Griff Creek	0.088	Fluvial	None	0-10%	0-10%
11	Griff Creek	0.945	Fluvial	Fluvial	11-25%	11-25%
11	Griff Creek	1.928	Fluvial	Fluvial	26-50%	26-50%
11	Griff Creek	3.064	Fluvial	Fluvial	0-10%	0-10%
11	Griff Creek	1.914	None	Fluvial	0-10%	0-10%
12	Kings Beach	0.083	Fluvial	Fluvial	0-10%	0-10%
14	First Creek	0.032	None	None	0-10%	0-10%
14	First Creek	0.251	Fluvial	Fluvial	0-10%	0-10%
14	First Creek	0.778	Fluvial	Fluvial	0-10%	0-10%
14	First Creek	1.920	None	None	0-10%	0-10%

14	First Creek	1.920	Fluvial	Mass Wasting	11-25%	51-75%
15	Second Creek	0.177	Mass Wasting	Mass Wasting	11-25%	26-50%
15	Second Creek	1.192	Fluvial	None	0-10%	0-10%
16	Burnt Creek	0.128	Mass Wasting	Fluvial	11-25%	11-25%
16	Burnt Creek	1.250	Fluvial	Fluvial	11-25%	11-25%
16	Burnt Creek	2.171	Fluvial	Fluvial	11-25%	0-10%
17	Wood Creek	0.060	None	None	0-10%	0-10%
18	Third Creek	0.045	Mass Wasting	Fluvial	11-25%	0-10%
18	Third Creek	0.587	Fluvial	Fluvial	11-25%	0-10%
18	Third Creek	1.152	Fluvial	None	0-10%	0-10%
18	Third Creek	2.974	Fluvial	Fluvial	0-10%	11-25%
18	Third Creek	4.870	Fluvial	None	11-25%	0-10%
18	Third Creek	7.610	Fluvial	Fluvial	11-25%	11-25%
18	Third Creek	8.099	Fluvial	Fluvial	11-25%	11-25%
18	Third Creek	2.312	Fluvial	Fluvial	11-25%	26-50%
19	Incline	5.690	None	None	0-10%	0-10%
19	Incline	5.607	None	None	0-10%	0-10%
19	Incline	5.442	None	None	11-25%	11-25%
19	Incline	5.393	None	None	0-10%	0-10%
19	Incline	5.224	None	Fluvial	11-25%	0-10%
19	Incline	5.040	None	None	0-10%	0-10%
19	Incline	4.809	Mass Wasting	Mass Wasting	76-100%	76-100%
19	Incline	4.637	Fluvial	None	0-10%	0-10%
19	Incline	4.526	Fluvial	None	0-10%	0-10%
19	Incline	4.339	Fluvial	Fluvial	0-10%	0-10%
19	Incline	4.218	Fluvial	None	0-10%	0-10%
19	Incline	4.052	Fluvial	Fluvial	0-10%	0-10%
19	Incline	3.778	Fluvial	Fluvial	0-10%	0-10%
19	Incline	3.537	None	None	0-10%	0-10%
19	Incline	3.527	None	None	11-25%	11-25%
19	Incline	3.419	None	Fluvial	0-10%	11-25%
19	Incline	3.399	None	Fluvial	0-10%	11-25%
19	Incline	3.050	Fluvial	Fluvial	0-10%	0-10%
19	Incline	2.407	Fluvial	Fluvial	0-10%	0-10%
19	Incline	2.169	Fluvial	Fluvial	11-25%	0-10%
19	Incline	2.055	None	Fluvial	0-10%	11-25%
19	Incline	1.901	Fluvial	Fluvial	51-75%	11-25%
19	Incline	1.773	Fluvial	Fluvial	0-10%	0-10%
19	Incline	1.607	None	None	0-10%	0-10%
19	Incline	1.552	Fluvial	Fluvial	0-10%	0-10%
19	Incline	1.316	Fluvial	Fluvial	0-10%	11-25%

19	Incline	1.218	None	None	0-10%	0-10%
19	Incline	1.082	Fluvial	Fluvial	0-10%	0-10%
19	Incline	0.849	Fluvial	Fluvial	0-10%	0-10%
19	Incline	0.717	Fluvial	Fluvial	0-10%	0-10%
19	Incline	0.568	None	Fluvial	0-10%	11-25%
19	Incline	0.404	Fluvial	None	26-50%	0-10%
19	Incline	0.264	Fluvial	Fluvial	51-75%	11-25%
19	Incline	0.212	None	Fluvial	0-10%	51-75%
19	Incline	0.164	Mass Wasting	Fluvial	76-100%	11-25%
19	Incline	0.045	Fluvial	None	0-10%	0-10%
20	Mill Creek	0.012	Fluvial	Fluvial	11-25%	11-25%
20	Mill Creek	0.889	None	None	0-10%	0-10%
20	Mill Creek	1.896	None	None	0-10%	0-10%
21	Tunnel Creek	0.066	Fluvial	Fluvial	0-10%	0-10%
21	Tunnel Creek	1.223	None	None	0-10%	0-10%
22	Bonpland	0.071	None	None	0-10%	0-10%
24	Marlette Creek	0.014	Fluvial	Fluvial	0-10%	0-10%
24	Marlette Creek	0.916	Fluvial	Fluvial	0-10%	11-25%
24	Marlette Creek	1.279	Fluvial	Fluvial	26-50%	11-25%
25	Secret Harbour	0.204	None	None	0-10%	0-10%
25	Secret Harbour	0.546	Fluvial	Fluvial	0-10%	11-25%
25	Secret Harbour	0.037	None	None	0-10%	0-10%
25	Secret Harbour	1.268	None	None	0-10%	0-10%
26	Bliss Creek	0.386	Fluvial	Fluvial	11-25%	11-25%
26	Bliss Creek	1.197	None	None	0-10%	0-10%
27	Dead Mans Point	0.043	None	None	0-10%	0-10%
27	Dead Mans Point	0.591	None	None	0-10%	0-10%
28	Slaughterhouse	0.231	None	None	0-10%	0-10%
28	Slaughterhouse	2.245	Fluvial	Fluvial	11-25%	11-25%
28	Slaughterhouse	4.510	None	None	0-10%	0-10%
29	Glenbrook Creek	0.030	None	Fluvial	0-10%	0-10%
29	Glenbrook Creek	0.765	None	Fluvial	0-10%	11-25%
29	Glenbrook Creek	2.700	Fluvial	Fluvial	11-25%	11-25%
29	Glenbrook Creek	3.216	Mass Wasting	Mass Wasting	26-50%	26-50%
29	Glenbrook Creek	3.348	Fluvial	Fluvial	0-10%	0-10%
30	North Logan House Creek	0.483	Fluvial	Fluvial	0-10%	0-10%
31	Logan House Creek	3.94	None	None	0-10%	0-10%
31	Logan House Creek	3.02	None	None	0-10%	0-10%
31	Logan House Creek	2.55	None	None	0-10%	0-10%
31	Logan House Creek	1.71	None	None	0-10%	0-10%
31	Logan House Creek	1.21	None	None	0-10%	0-10%

32	Cave Rock	0.189	None	None	0-10%	0-10%
32	Cave Rock	0.087	None	None	0-10%	0-10%
32	Cave Rock	0.893	Fluvial	Fluvial	0-10%	0-10%
33	Lincoln Creek	0.219	Fluvial	Fluvial	0-10%	0-10%
33	Lincoln Creek	1.195	Fluvial	Fluvial	11-25%	11-25%
35	North Zephyr Creek	0.284	Fluvial	Fluvial	0-10%	0-10%
35	North Zephyr Creek	1.263	Mass Wasting	Fluvial	0-10%	0-10%
35	North Zephyr Creek	1.593	Mass Wasting	Fluvial	11-25%	11-25%
37	Zephyr Creek	0.131	Fluvial	Fluvial	0-10%	0-10%
37	Zephyr Creek	0.993	Fluvial	Mass Wasting	11-25%	11-25%
38	McFaul Creek	0.520	Mass Wasting	Fluvial	11-25%	11-25%
38	McFaul Creek	1.691	Fluvial	Fluvial	0-10%	0-10%
38	McFaul Creek	3.226	Mass Wasting	Mass Wasting	0-10%	11-25%
39	Burke Creek	0.135	Fluvial	Fluvial	0-10%	0-10%
39	Burke Creek	1.579	Fluvial	Fluvial	0-10%	0-10%
39	Burke Creek	3.200	None	None	0-10%	0-10%
39	Burke Creek	3.212	Fluvial	None	0-10%	0-10%
39	Burke Creek	3.580	Fluvial	Fluvial	11-25%	11-25%
39	Burke Creek	4.128	None	None	0-10%	0-10%
39	Burke Creek	6.247	None	None	0-10%	0-10%
40	Edgewood Creek	7.220	None	None	0-10%	0-10%
40	Edgewood Creek	7.210	Mass Wasting	Fluvial	51-75%	11-25%
40	Edgewood Creek	7.230	Fluvial	Fluvial	0-10%	0-10%
40	Edgewood Creek	6.410	None	Fluvial	0-10%	0-10%
40	Edgewood Creek	6.220	None	None	0-10%	0-10%
40	Edgewood Creek	6.150	Fluvial	Fluvial	11-25%	11-25%
40	Edgewood Creek	5.620	Fluvial	Fluvial	26-50%	11-25%
40	Edgewood Creek	4.960	Fluvial	Fluvial	0-10%	0-10%
40	Edgewood Creek	3.830	Fluvial	Fluvial	11-25%	11-25%
40	Edgewood Creek	3.090	Mass Wasting	Fluvial	26-50%	11-25%
40	Edgewood Creek	1.200	Fluvial	Fluvial	0-10%	0-10%
40	Edgewood Creek	0.200	None	None	0-10%	0-10%
41	Bijou Park	1.317	Fluvial	Fluvial	0-10%	0-10%
41	Bijou Park	1.884	Fluvial	Fluvial	11-25%	0-10%
42	Bijou Creek	0.543	Fluvial	None	0-10%	0-10%
42	Bijou Creek	2.162	None	None	0-10%	0-10%
42	Bijou Creek	3.442	None	None	0-10%	0-10%
43	Trout Creek	1.454	None	None	0-10%	0-10%
43	Trout Creek	2.485	Fluvial	Fluvial	11-25%	0-10%
43	Trout Creek	4.711	Fluvial	Fluvial	0-10%	0-10%
43	Trout Creek	7.047	Mass Wasting	Fluvial	26-50%	0-10%

43	Trout Creek	6.516	Fluvial	Mass Wasting	11-25%	26-50%
43	Trout Creek	7.473	Fluvial	Mass Wasting	0-10%	11-25%
43	Trout Creek	8.127	Fluvial	Fluvial	0-10%	0-10%
44	Upper Truckee	24.187	Fluvial	Fluvial	0-10%	0-10%
44	Upper Truckee	23.009	None	Fluvial	0-10%	11-25%
44	Upper Truckee	22.538	None	Mass Wasting	0-10%	76-100%
44	Upper Truckee	21.769	Mass Wasting	None	0-10%	0-10%
44	Upper Truckee	21.369	Fluvial	Fluvial	0-10%	0-10%
44	Upper Truckee	20.749	Mass Wasting	Mass Wasting	51-75%	11-25%
44	Upper Truckee	19.940	Mass Wasting	Fluvial	51-75%	0-10%
44	Upper Truckee	19.261	Fluvial	Mass Wasting	11-25%	51-75%
44	Upper Truckee	18.5731	None	Mass Wasting	0-10%	76-100%
44	Upper Truckee	17.999	Fluvial	Fluvial	0-10%	0-10%
44	Upper Truckee	17.779	None	Mass Wasting	0-10%	76-100%
44	Upper Truckee	16.898	Fluvial	Fluvial	11-25%	0-10%
44	Upper Truckee	16.40	Fluvial	Fluvial	11-25%	11-25%
44	Upper Truckee	15.870	None	None	0-10%	0-10%
44	Upper Truckee	15.277	None	Fluvial	0-10%	26-50%
44	Upper Truckee	14.768	None	Mass Wasting	0-10%	76-100%
44	Upper Truckee	14.071	Fluvial	None	0-10%	0-10%
44	Upper Truckee	13.519	None	Mass Wasting	0-10%	76-100%
44	Upper Truckee	13.146	Mass Wasting	Mass Wasting	51-75%	26-50%
44	Upper Truckee	12.070	None	Mass Wasting	0-10%	0-10%
44	Upper Truckee	11.207	Fluvial	Mass Wasting	26-50%	51-75%
44	Upper Truckee	10.838	Mass Wasting	Fluvial	51-75%	0-10%
44	Upper Truckee	10.037	None	Fluvial	0-10%	11-25%
44	Upper Truckee	8.455	None	Mass Wasting	0-10%	76-100%
44	Upper Truckee	7.137	None	Mass Wasting	0-10%	76-100%
44	Upper Truckee	5.837	None	None	0-10%	0-10%
44	Upper Truckee	5.055	Fluvial	Mass Wasting	26-50%	26-50%
44	Upper Truckee	4.511	Fluvial	Fluvial	0-10%	0-10%
44	Upper Truckee	2.941	Mass Wasting	None	51-75%	11-25%
46	Taylor Creek	0.903	Fluvial	None	11-25%	0-10%
46	Taylor Creek	2.328	Fluvial	None	11-25%	0-10%
47	Tallac Creek	1.374	Fluvial	None	26-50%	0-10%
47	Tallac Creek	2.202	Fluvial	None	11-25%	0-10%
47	Tallac Creek	2.546	None	None	0-10%	0-10%
47	Tallac Creek	3.053	None	None	0-10%	0-10%
47	Tallac Creek	2.948	None	None	0-10%	0-10%
48	Cascade Creek	0.693	None	None	0-10%	0-10%
49	Eagle Creek	0.584	None	None	0-10%	0-10%

50	Bliss State Park	0.410	None	None	0-10%	0-10%
51	Rubicon Creek	0.919	None	None	0-10%	0-10%
51	Rubicon Creek	1.271	Fluvial	Fluvial	11-25%	11-25%
51	Rubicon Creek	1.596	Fluvial	Fluvial	0-10%	0-10%
51	Rubicon Creek	1.707	None	None	0-10%	0-10%
51	Rubicon Creek	2.113	None	None	0-10%	0-10%
52	Paradise Flat	0.624	Fluvial	Fluvial	11-25%	0-10%
53	Lonely Gulch Creek	0.807	None	None	0-10%	0-10%
53	Lonely Gulch Creek	1.236	None	None	0-10%	0-10%
54	Sierra creek	0.885	None	None	0-10%	0-10%
55	Meeks Creek	1.226	None	None	0-10%	11-25%
55	Meeks Creek	3.149	Fluvial	None	11-25%	0-10%
55	Meeks Creek	3.499	None	Fluvial	0-10%	26-50%
55	Meeks Creek	3.496	Fluvial	None	11-25%	11-25%
56	General	6.800	None	Fluvial	0-10%	0-10%
56	General	6.660	None	Fluvial	0-10%	0-10%
56	General	6.500	None	Fluvial	0-10%	11-25%
56	General	6.060	None	Fluvial	0-10%	11-25%
56	General	5.900	None	Fluvial	0-10%	26-50%
56	General	5.330	Fluvial	Fluvial	11-25%	11-25%
56	General	5.250	Fluvial	Fluvial	11-25%	11-25%
56	General	5.050	Fluvial	Fluvial	0-10%	11-25%
56	General	4.730	None	Mass Wasting	0-10%	11-25%
56	General	4.210	None	Fluvial	0-10%	0-10%
56	General	3.620	Fluvial	None	0-10%	0-10%
56	General	3.600	Fluvial	Mass Wasting	0-10%	26-50%
56	General	3.590	Fluvial	Fluvial	0-10%	11-25%
56	General	3.250	Fluvial	Mass Wasting	0-10%	76-100%
56	General	2.970	None	None	0-10%	0-10%
56	General	2.580	Fluvial	Mass Wasting	0-10%	51-75%
56	General	2.200	None	Mass Wasting	0-10%	76-100%
56	General	1.940	None	Fluvial	0-10%	26-50%
56	General	1.930	Fluvial	Fluvial	0-10%	0-10%
56	General	1.540	None	Mass Wasting	0-10%	51-75%
56	General	1.170	None	Mass Wasting	0-10%	11-25%
56	General	0.950	Fluvial	Mass Wasting	11-25%	76-100%
56	General	0.890	Fluvial	Mass Wasting	0-10%	11-25%
56	General	0.710	None	Fluvial	0-10%	11-25%
56	General	0.570	None	None	0-10%	0-10%
56	General	0.300	None	Fluvial	0-10%	0-10%
56	General	0.010	Mass Wasting	None	26-50%	0-10%

56	General	8.077	None	None	0-10%	0-10%
57	General		Fluvial	None	0-10%	0-10%
57	McKinney Creek	0.276	None	None	0-10%	0-10%
57	McKinney Creek	1.248	None	None	0-10%	0-10%
58	Quail Lane Creek	0.024	None	None	0-10%	0-10%
58	Quail Lane Creek	0.212	None	None	0-10%	0-10%
59	Homewood Creek	0.094	Fluvial	Fluvial	11-25%	11-25%
59	Homewood Creek	0.407	Fluvial	Fluvial	11-25%	11-25%
60	Madden Creek	0.097	None	None	0-10%	0-10%
62	Blackwood Creek	8.290	None	None	0-10%	0-10%
62	Blackwood Creek	8.190	Fluvial	None	0-10%	26-50%
62	Blackwood Creek	7.690	Fluvial	Fluvial	11-25%	11-25%
62	Blackwood Creek	7.180	Fluvial	Fluvial	11-25%	11-25%
62	Blackwood Creek	7.170	Fluvial	Mass Wasting	11-25%	76-100%
62	Blackwood Creek	6.840	None	Mass Wasting	0-10%	11-25%
62	Blackwood Creek	6.510	None	Mass Wasting	0-10%	51-75%
62	Blackwood Creek	5.550	None	Fluvial	0-10%	26-50%
62	Blackwood Creek	6.030	None	Mass Wasting	0-10%	26-50%
62	Blackwood Creek	5.080	None	Mass Wasting	0-10%	51-75%
62	Blackwood Creek	4.150	Fluvial	Fluvial	26-50%	11-25%
62	Blackwood Creek	3.950	None	Mass Wasting	0-10%	76-100%
62	Blackwood Creek	2.800	Mass Wasting	None	51-75%	0-10%
62	Blackwood Creek	1.970	Fluvial	Mass Wasting	26-50%	11-25%
62	Blackwood Creek	1.770	Fluvial	Mass Wasting	11-25%	51-75%
62	Blackwood Creek	0.320	Mass Wasting	None	51-75%	0-10%
62	Blackwood Creek	0.000	None	None	26-50%	26-50%
63	Ward	6.553	None	Fluvial	0-10%	26-50%
63	Ward	6.455	Fluvial	Fluvial	0-10%	11-25%
63	Ward	6.416	None	None	0-10%	0-10%
63	Ward	6.270	None	Fluvial	0-10%	11-25%
63	Ward	6.167	Fluvial	None	11-25%	0-10%
63	Ward	6.102	Fluvial	None	11-25%	0-10%
63	Ward	5.938	None	Mass Wasting	0-10%	76-100%
63	Ward	5.868	None	Fluvial	0-10%	0-10%
63	Ward	5.805	Fluvial	Fluvial	0-10%	11-25%
63	Ward	5.526	Fluvial	Fluvial	11-25%	0-10%
63	Ward	5.360	None	Fluvial	0-10%	26-50%
63	Ward	5.124	Fluvial	Mass Wasting	0-10%	26-50%
63	Ward	4.740	None	Mass Wasting	0-10%	76-100%
63	Ward	4.522	Fluvial	Fluvial	11-25%	11-25%
63	Ward	4.250	Mass Wasting	None	26-50%	0-10%

63	Ward	4.059	Fluvial	Fluvial	11-25%	11-25%
63	Ward	3.641	Mass Wasting	Fluvial	51-75%	26-50%
63	Ward	3.506	Fluvial	Mass Wasting	11-25%	51-75%
63	Ward	3.279	None	Mass Wasting	0-10%	0-10%
63	Ward	2.639	None	Fluvial	0-10%	0-10%
63	Ward	2.382	Fluvial	Mass Wasting	11-25%	51-75%
63	Ward	2.084	Fluvial	Fluvial	0-10%	0-10%
63	Ward	1.971	Fluvial	Fluvial	0-10%	0-10%
63	Ward	1.545	Fluvial	Fluvial	0-10%	0-10%
63	Ward	1.417	Mass Wasting	Fluvial	26-50%	0-10%
63	Ward	1.292	None	Mass Wasting	0-10%	51-75%
63	Ward	1.140	None	Fluvial	0-10%	11-25%
63	Ward	1.125	Mass Wasting	Fluvial	26-50%	0-10%
63	Ward	1.110	Fluvial	Fluvial	26-50%	0-10%
63	Ward	0.778	Mass Wasting	Fluvial	51-75%	11-25%
63	Ward	0.629	Fluvial	Mass Wasting	0-10%	26-50%
63	Ward	0.505	None	Fluvial	0-10%	11-25%
63	Ward	0.435	Mass Wasting	Mass Wasting	76-100%	11-25%
63	Ward	0.254	Mass Wasting	Fluvial	26-50%	26-50%
63	Ward	0.093	None	None	0-10%	0-10%

Table 19- Average bank-stability index for each stream based on summing the index value for each site visited an dividing by the number of sites (Table 18).

Watershed	Stream	Average Bank-Stability Index
1	Tahoe State Park	0.000
2	Burton Creek	0.400
3	Barton Creek	0.000
4	Lake Forest Creek	0.000
5	Dollar Creek	0.250
6	Cedar Flats Creek	0.500
7	Watson Creek	0.000
8	Carnelian Bay Creek	0.000
9	Carnelian Canyon Creek	0.000
10	Tahoe Vista	0.400
11	Griff Creek	0.600
12	Kings Beach	0.000
14	First Creek	0.400
15	Second Creek	0.375
16	Burnt Creek	0.830
17	Wood Creek	0.000
18	Third Creek	0.750
19	Incline	0.514
20	Mill Creek	0.333
21	Tunnel Creek	0.000
22	Bonpland	0.000
24	Marlette Creek	0.830
25	Secret Harbour	0.125
26	Bliss Creek	0.500
27	Dead Mans Point	0.000
28	Slaughterhouse	0.333
29	Glenbrook Creek	0.600
30	North Logan House Creek	0.000
31	Logan House Creek	0.000
32	Cave Rock	0.000
33	Lincoln Creek	0.000
35	North Zephyr Creek	0.333
37	Zephyr Creek	0.500
38	McFaul Creek	0.500

39	Burke Creek	0.143
40	Edgewood Creek	0.583
41	Bijou Park	0.250
42	Bijou Creek	0.000
43	Trout Creek	0.500
44	Upper Truckee	1.120
46	Taylor Creek	0.500
47	Tallac Creek	0.300
48	Cascade Creek	0.000
49	Eagle Creek	0.000
50	Bliss State Park	0.000
51	Rubicon Creek	0.400
52	Paradise Flat	0.500
53	Lonely Gulch Creek	0.000
54	Sierra Creek	0.000
55	Meeks Creek	0.750
56	General	0.670
57	McKinney Creek	0.000
58	Quail Lane Creek	0.000
59	Homewood Creek	0.167
60	Madden Creek	0.000
62	Blackwood Creek	1.353
63	Ward	0.929

Relation between Bank-Stability Index (I_B) and Streambank Erosion Rate

With an average bank-stability index (I_B) calculated for each stream from observed conditions, a relation between this parameter and measured streambank erosion rates was required for extrapolation to streams without measured data. Using data from the six streams with measured or simulated data (Table 16) a regression was performed using a sigmoidal 3-parameter equation based on the general shape of the relation (Figure 17). This equation takes the general form:

$$y = \frac{a}{1 + e^{-\frac{(x - x_0)}{b}}} \tag{2}$$

and yields the following relation ($r^2 = 0.99$):

$$E_r = \frac{12.6939}{1 + e^{-\frac{(I_B - 1.0217)}{0.1129}}} \tag{3}$$

where E_r = erosion rate of fine (<0.063mm) bank sediment in m^3/y/km of channel; I_B = average bank-stability index (percent of reach length with failing banks)

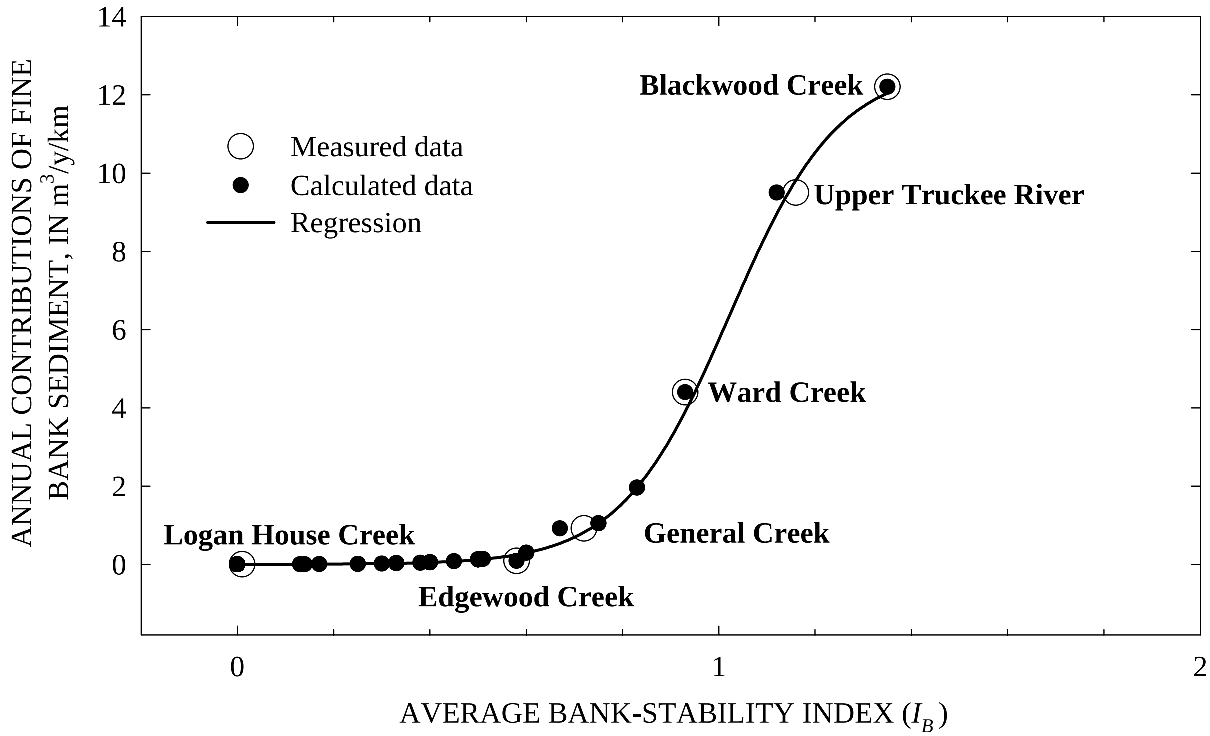

Figure 17- Relation between average, annual streambank erosion rates and average bank-stability index (I_B). Regression is a 3-parameter sigmoidal equation; $r^2 = 0.99$.

Unit Streambank Erosion Rate. An erosion rate for each stream was obtained by substituting the stream's value into the above regression equation (eq. 3) to provide an average, annual erosion rate of fine (<0.063mm) sediment per unit length of channel (Table 20). This unit, streambank erosion rate, expressed in m^3/y/km, can be used to differentiate those streams with the most actively eroding banks, and ones where streambank stabilization measures may be considered appropriate (Figure 18). Blackwood Creek manifests the highest streambank erosion rates per unit length of channel (12.2 m^3/y/km) followed by the Upper Truckee River (9.5 m^3/y/km) and Ward Creek (4.4 m^3/y/km), respectively.

Streambank Erosion Rate. The average, annual volume (in m^3) of streambank erosion for each stream was then determined by multiplying the unit streambank erosion rate (Table 20) by the total length of main channels as calculated by Jorgensen *et al.* (1978). Modifications were made to some of these reported lengths based on tributary contributions and contributing areas. These are shaded in yellow in Table 21. The volume of fine sediment (<0.063 mm) eroded from streambanks was converted to kilonewtons by multiplying by an average bulk unit weight of 17.3 kN/m^3, and then to metric tonnes (T).

Table 20- Average, annual bank-erosion rates of fines (<0.063mm) per kilometer of main-stem channel length for streams draining to Lake Tahoe.

Watershed	Stream	Erosion rate (m^3/y/km)
1	Tahoe State Park	0.001491
2	Burton Creek	0.051325
3	Barton Creek	0.001491
4	Lake Forest Creek	0.001491
5	Dollar Creek	0.013634
6	Cedar Flats Creek	0.123740
7	Watson Creek	0.001491
8	Carnelian Bay Creek	0.001491
9	Carnelian Canyon Creek	0.001491
10	Tahoe Vista	0.051325
11	Griff Creek	0.295931
12	Kings Beach	0.001491
14	First Creek	0.051325
15	Second Creek	0.041164
16	Burnt Creek	1.964148
17	Wood Creek	0.001491
18	Third Creek	1.049460
19	Incline	0.139760
20	Mill Creek	0.028405
21	Tunnel Creek	0.001491
22	Bonpland	0.001491
24	Marlette Creek	1.964148
25	Secret Harbour	0.004509
26	Bliss Creek	0.123740
27	Dead Mans Point	0.001491
28	Slaughterhouse	0.028405
29	Glenbrook Creek	0.295931
30	North Logan House Creek	0.001491
31	Logan House Creek	0.001491
32	Cave Rock	0.001491
33	Lincoln Creek	0.001491
35	North Zephyr Creek	0.028488
37	Zephyr Creek	0.123740
38	McFaul Creek	0.123740

39	Burke Creek	0.005281
40	Edgewood Creek	0.090000
41	Bijou Park	0.013634
42	Bijou Creek	0.001491
43	Trout Creek	0..123740
44	Upper Truckee	9.500000
46	Taylor Creek	0.123740
47	Tallac Creek	0.021217
48	Cascade Creek	0.001491
49	Eagle Creek	0.001491
50	Bliss State Park	0.001491
51	Rubicon Creek	0.051325
52	Paradise Flat	0.123740
53	Lonely Gulch Creek	0.001491
54	Sierra Creek	0.001491
55	Meeks Creek	1.049460
56	General	0.920000
57	McKinney Creek	0.001491
58	Quail Lane Creek	0.001491
59	Homewood Creek	0.006523
60	Madden Creek	0.001491
62	Blackwood Creek	12.200000
63	Ward	4.400000

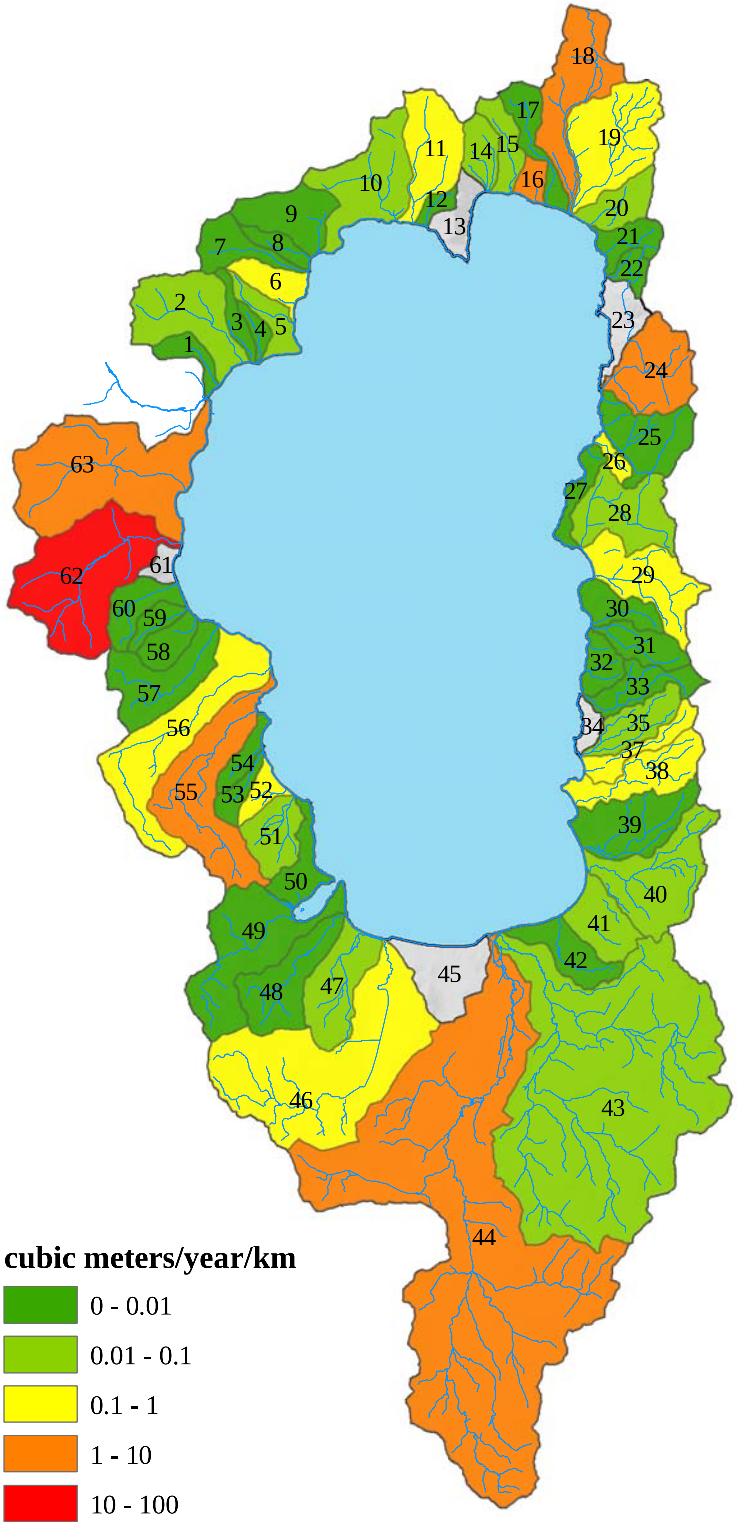

Figure 18- Unit volume of fine-sediment (<0.063mm) contributions from streambank erosion per kilometer of main channels. Gray shading indicates no data available.

Table 21- Stream lengths as reported by Jorgensen *et al*. (1978) with modifications (shaded in yellow) to account for tributaries and, in some cases, reduced contributing areas.

Watershed	Stream	Length (mi)	Length (km)
1	Tahoe State Park		2.430
2	Burton Creek	6.220	10.008
3	Barton Creek		2.470
4	Lake Forest Creek	2.000	3.218
5	Dollar Creek	2.880	4.634
6	Cedar Flats Creek	0.570	0.917
7	Watson Creek	3.320	5.342
8	Carnelian Bay Creek	1.940	3.121
9	Carnelian Canyon Creek	2.800	4.505
10	Tahoe Vista	5.910	9.509
11	Griff Creek	5.780	9.300
12	Kings Beach	1.880	3.025
14	First Creek	4.340	6.983
15	Second Creek	3.040	4.891
16	Burnt Creek		0.700
17	Wood Creek	3.940	6.339
18	Third Creek	10.550	16.975
19	Incline	11.910	19.163
20	Mill Creek	4.462	7.180
21	Tunnel Creek	2.040	3.282
22	Bonpland	1.960	3.154
24	Marlette Creek	3.440	5.535
25	Secret Harbour	4.950	7.965
26	Bliss Creek	1.520	2.446
27	Dead Mans Point		1.500
28	Slaughterhouse	7.000	11.263
29	Glenbrook Creek	3.920	6.307
30	North Logan House Creek	2.530	4.071
31	Logan House Creek	3.300	5.310
32	Cave Rock	2.570	4.135
33	Lincoln Creek	6.140	9.879
35	North Zephyr Creek	6.750	10.861
37	Zephyr Creek	4.040	6.500
38	McFaul Creek	8.050	12.952
39	Burke Creek	7.850	12.631

41	Bijou Park		5.940
42	Bijou Creek	3.330	5.358
43	Trout Creek	31.540	50.748
44	Upper Truckee	24.900	40.064
46	Taylor Creek	11.000	17.699
47	Tallac Creek	6.910	11.118
48	Cascade Creek	4.730	7.611
49	Eagle Creek	5.820	9.364
50	Bliss State Park		0.850
51	Rubicon Creek	5.400	8.689
52	Paradise Flat	2.050	3.298
53	Lonely Gulch Creek	2.180	3.508
54	Sierra Creek	1.350	2.172
55	Meeks Creek	4.500	7.241
56	General	9.170	14.755
57	McKinney Creek	5.750	9.252
58	Quail Lane Creek	1.850	2.977
59	Homewood Creek	2.100	3.379
60	Madden Creek	3.070	4.940
62	Blackwood Creek	12.700	20.434
63	Ward	8.670	13.950

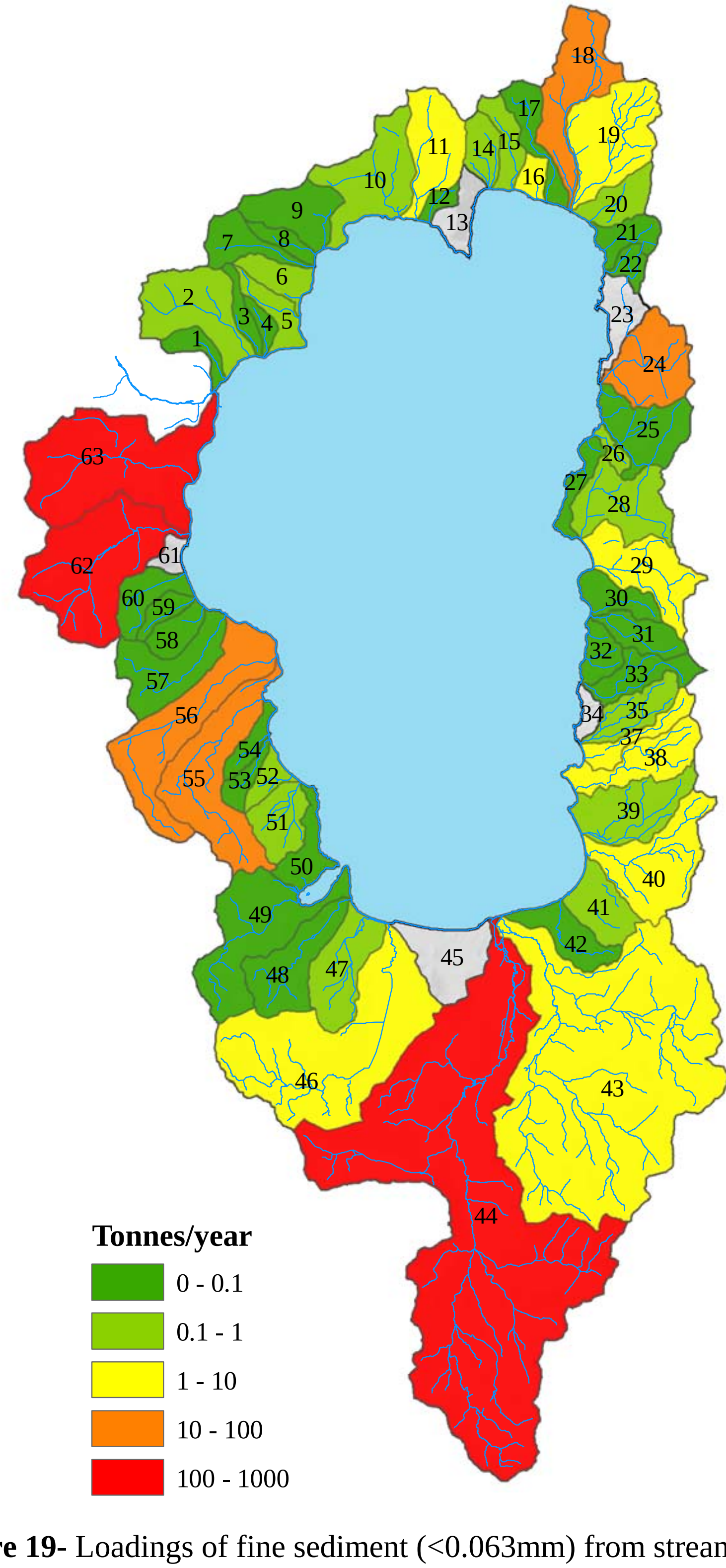

Figure 19- Loadings of fine sediment (<0.063mm) from streambank erosion. Gray shading indicates no data available.

Fine-Sediment Loadings from Streambank Erosion

Using the above procedures, average, annual erosion and delivery of fine sediment to Lake Tahoe were calculated for each stream. Resulting values are summarized in Table 22 and mapped in Figure 19. Summing the values calculated for each of the 63 watersheds gives an annual, average of 1305 T/y of fine (<0.063 mm) sediment delivered to Lake Tahoe from streambank erosion. From what has been learned in this and previous studies, it is no surprise that the three largest contributors of fine, streambank sediment are the Upper Truckee River (639 T/y), Blackwood Creek (431 T/y), and Ward Creek (104 T/y) (Figure 20).

About 25% of the fine sediment delivered to the lake emanates from streambank erosion when compared to the total fine-loadings calculated in this report (5206 T/y). In fact, about 20% of all fine sediment delivered to Lake Tahoe comes from the banks of the Upper Truckee River and Blackwood Creek. If Ward Creek is included, this figure becomes 22%. This is shown most clearly in Figure 20b and helps to emphasize the potential importance of concentrating bank-stabilization efforts in these watersheds.

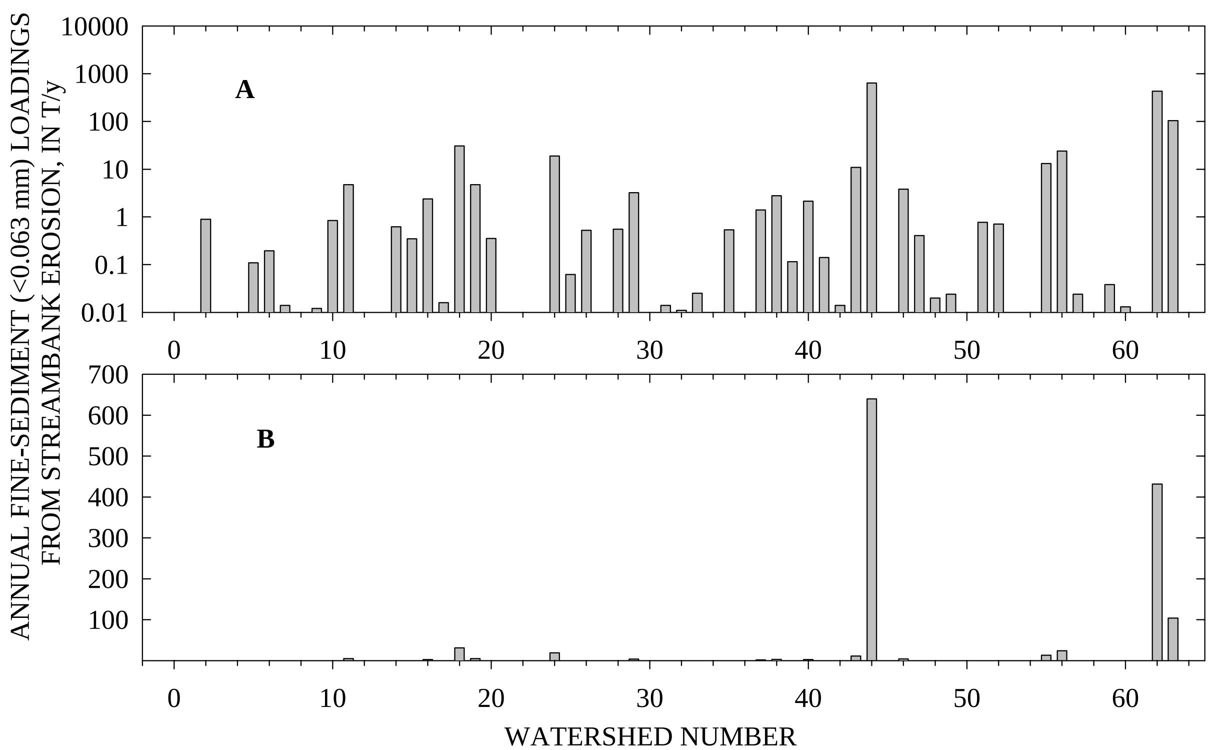

Figure 20- Annual, fine-sediment (0.063 mm) loadings in tonnes per year from streambank erosion plotted with $\log_{10}$ scale (A) and arithmetic scale (B). Note the relatively large contributions from the Upper Truckee River (#44), Blackwood Creek (#62), and Ward Creek (#63).

Table 22- Average, annual bank-erosion rates of fines (<0.063mm) for streams draining to Lake Tahoe.

Watershed	Creek Name	T/y
1	Tahoe State Park	**0.006**
2	Burton Creek	**0.889**
3	Barton Creek	**0.006**
4	Lake Forest Creek	**0.008**
5	Dollar Creek	**0.109**
6	Cedar Flats Creek	**0.196**
7	Watson Creek	**0.014**
8	Carnelian Bay Creek	**0.008**
9	Carnelian Canyon Creek	**0.012**
10	Tahoe Vista	**0.844**
11	Griff Creek	**4.76**
12	Kings Beach	**0.008**
14	First Creek	**0.620**
15	Second Creek	**0.348**
16	Burnt Creek	**2.38**
17	Wood Creek	**0.016**
18	Third Creek	**30.8**
19	Incline	**4.72**
20	Mill Creek	**0.353**
21	Tunnel Creek	**0.008**
22	Bonpland	**0.008**
24	Marlette Creek	**18.8**
25	Secret Harbour	**0.062**
26	Bliss Creek	**0.524**
27	Dead Mans Point	**0.004**
28	Slaughterhouse	**0.553**
29	Glenbrook Creek	**3.23**
30	North Logan House Creek	**0.010**
31	Logan House Creek	**0.014**
32	Cave Rock	**0.011**
33	Lincoln Creek	**0.025**
35	North Zephyr Creek	**0.535**
37	Zephyr Creek	**1.39**
38	McFaul Creek	**2.77**
39	Burke Creek	**0.115**
40	Edgewood Creek	**2.14**
41	Bijou Park	**0.140**
42	Bijou Creek	**0.014**

43	Trout Creek	**10.9**
44	Upper Truckee	**639**
46	Taylor Creek	**3.79**
47	Tallac Creek	**0.408**
48	Cascade Creek	**0.020**
49	Eagle Creek	**0.024**
50	Bliss State Park	**0.002**
51	Rubicon Creek	**0.771**
52	Paradise Flat	**0.706**
53	Lonely Gulch Creek	**0.009**
54	Sierra Creek	**0.006**
55	Meeks Creek	**13.1**
56	General	**23.9**
57	McKinney Creek	**0.024**
58	Quail Lake Creek	**0.008**
59	Homewood Creek	**0.038**
60	Madden Creek	**0.013**
62	Blackwood Creek	**431**
63	Ward	**104**
	Total	**1305**

The relative importance of fine-sediment erosion from streambanks was calculated by comparing average, annual loadings of fine, streambank sediment to total, fine sediment from all sources for the nine watersheds where fine loads had been calculated from measured data in Simon *et al*., (2003). For these streams, values range from 63% for the Upper Truckee River to 2.4% for Trout Creek (Table 23). It is interesting that the maximum and minimum values occur in adjacent watersheds within the same basin quadrant (South), indicating that anthropogenic disturbances to the channels of the Upper Truckee River have played an important role in destabilizing streambanks and creating conditions where streambanks have become the dominant source of fine sediment. The relatively low value for Third Creek (10%) suggests that the dominant sources of fine sediments in this basin are probably the steep, bare upland slopes and urbanized areas. The low percentage for Incline Creek (3.6%) is probably attributable to greater contributions from urban areas compared to streambanks.

Table 23 – Comparison between measured, median annual fine-sediment (<0.063 mm) loadings (From Simon *et al*., 2003) and estimated, fine-grained (<0.063 mm) loadings from streambanks.

Stream	**Fine load, all sources (T/y)**	**Fine load, streambanks (T/y)**	**Fine-grained contribution from streambanks (%)**
Upper Truckee River	1010	639	63
Blackwood Creek	846	431	51
Ward Creek	412	104	25
Third Creek	318	30.8	10
General Creek	53	23.9	45

Trout Creek	462	10.9	2.4
Incline Creek	129	4.7	3.6
Glenbrook Creek	7.0	3.2	46
Edgewood Creek	11.4	2.1	18

A broader comparison of the relative importance of streambank erosion compared to all other sources of fine sediment in each of the 63 basins was made by comparing fine-sediment loadings estimates from all sources (Table 14 and Figure 5) with those solely from streambanks (Table 22 and Figure 19). Results are shown graphically by watershed number (Figure 21) and spatially (Figure 22).

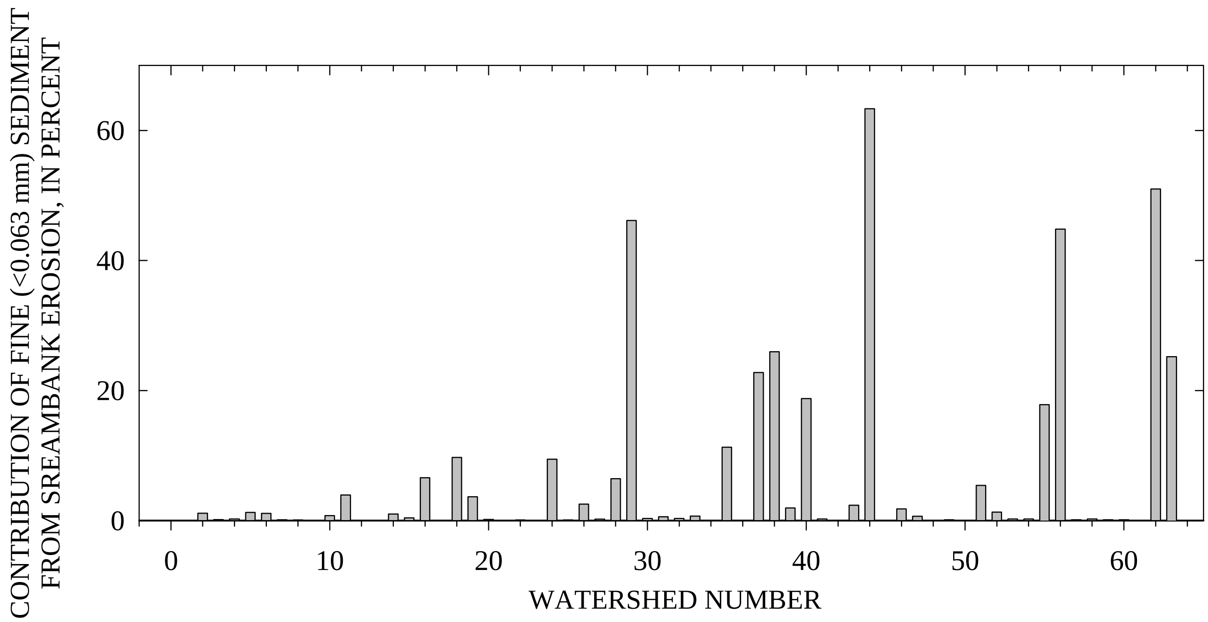

Figure 21- Contribution of fine (<0.063 mm) sediment from streambank erosion relative to all sources within each watershed.

SUMMARY AND CONCLUSIONS

The delivery of fine-grained sediment from tributary basins is listed as a major cause of water-clarity deterioration in Lake Tahoe. Efforts to control the discharge of fine sediment to the lake require knowledge of the volumes, rates and sources of this material. Similarly, use of a lake-clarity model to predict future clarity conditions and the effectiveness of management alternatives also require these types of data. The research described in this report used combinations of field-based observations of channel and bank stability with measured and simulated data on fine-sediment loadings to estimate fine-sediment loadings from un-monitored basins throughout the Lake Tahoe Basin. Loadings were expressed in the conventional format of mass per unit time (tonnes per year) but also in the number of particles finer than 20 μm, the latter for use in a lake-clarity model operated by the University of California, Davis.

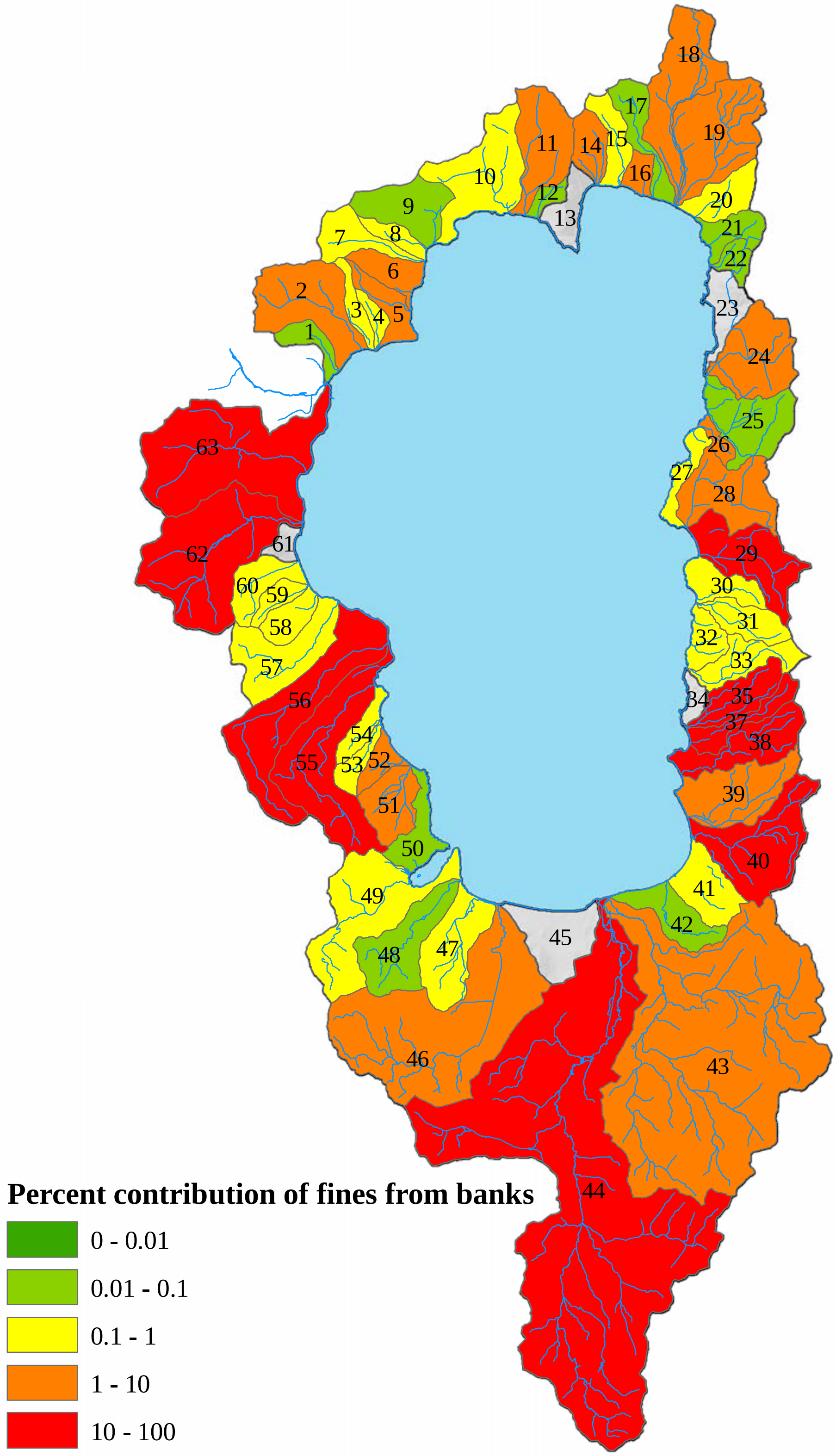

Figure 22- Contribution of fine (<0.063 mm) sediment from streambanks compared to all other sources within a given watershed.

Three types of fine-sediment loadings estimates have been provided for each of the 63 contributing watersheds in both tabular and graphical form:

1. Average, annual fine-sediment (<0.063 mm) loadings in tonnes per year (T/y);
2. Average, annual fine-sediment (<0.020 mm) loadings in number of particles per year (*n*/y); and
3. Average, annual fine-sediment (<0.063 mm) loadings in T/y from streambank erosion.

Fine-sediment (<0.063) loadings (in T/y) for each un-monitored watershed were based on extrapolating relations between distributions of a combined-stability index and measured fine yields (T/y/km^2) within each basin quadrant. The greatest contributors happened to be those with measured data, not requiring extrapolation. In descending order they are: Upper Truckee River (1010 T/y), Blackwood Creek (846 T/y), Trout Creek (462 T/y) and Ward Creek (412 T/y). Summing the values from all 63 contributing watersheds provided an average, annual estimate of fine-sediment (<0.063 mm) loadings to the lake of 5,206 T/y.

Fine-sediment (<0.063 mm) loadings in tonnes per year had to be converted to loadings expressed number of particles per year finer than 0.020 mm for use in the lake-clarity model. This was accomplished using data from Rabidoux (2005) by establishing relations between total suspended-sediment concentration (in mg/l) and the concentration of the 5-20 μm fraction in number per milliliter. Resulting data were converted to mean-daily and then annual values using suspended-sediment rating relations from Simon *et al*., (2003). A total of 7.79E+19 particles in the 5-20 μm fraction were calculated to enter Lake Tahoe in an average year with the Upper Truckee River accounting for almost 25% of the total. Contributions from Blackwood, Ward, Trout, and Third Creeks account for another 23% of these very fine particles. Thus, these five streams making up about 40% of the basin area, account for almost 50% of all fine-sediment loadings to the lake.

Contributions of fine sediment from streambank erosion was estimated by developing empirical relations between measured or simulated bank-erosion rates (adjusted for the content of silt and clay in the bank material) with a field-based measure of the extent of bank instability along given reaches and streams. Measured, unit values of fine sediment (<0.063 mm) erosion rates ranged from 12.2 m^3/y/km for Blackwood Creek to 0.002 m^3/y/km for Logan House Creek. Multiplying by the length of main channels in the watershed produced estimates of fine-sediment streambank erosion for each of the watersheds in tonnes per year. Summing the values for all of the 63 contributing watersheds provided an average, annual fine-sediment loading from streambank erosion of 1,305 T/y. This represents about 25% of the average, annual fine-sediment load delivered to the lake from all sources. The two largest contributors, the Upper Truckee River (639 T/y) and Blackwood Creek (431 T/y), account for slightly more than 80% of all fines emanating from streambanks, representing about 20% of fine sediment delivered to Lake Tahoe from all sources.

Extrapolations of fine-sediment loadings to the un-monitored watersheds are based on documented empirical relations yet contain a significant amount of uncertainty. Except for those values derived directly from measured data, reported results should be considered as estimates.

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