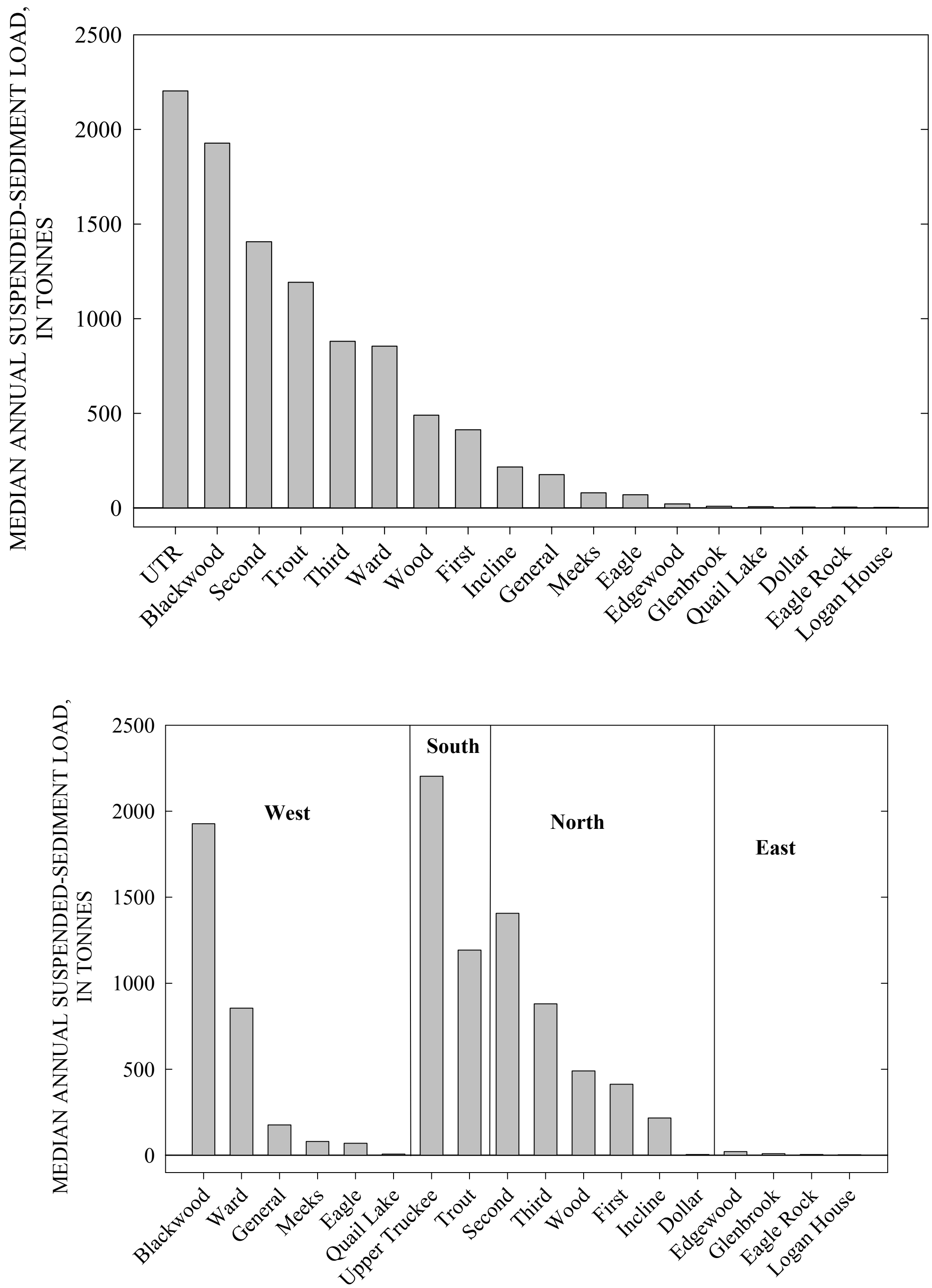


Figure 3-3. Median annual suspended-sediment loads for the 18 index stations sorted in descending order (upper) and, separated by basin quadrant (lower).

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.

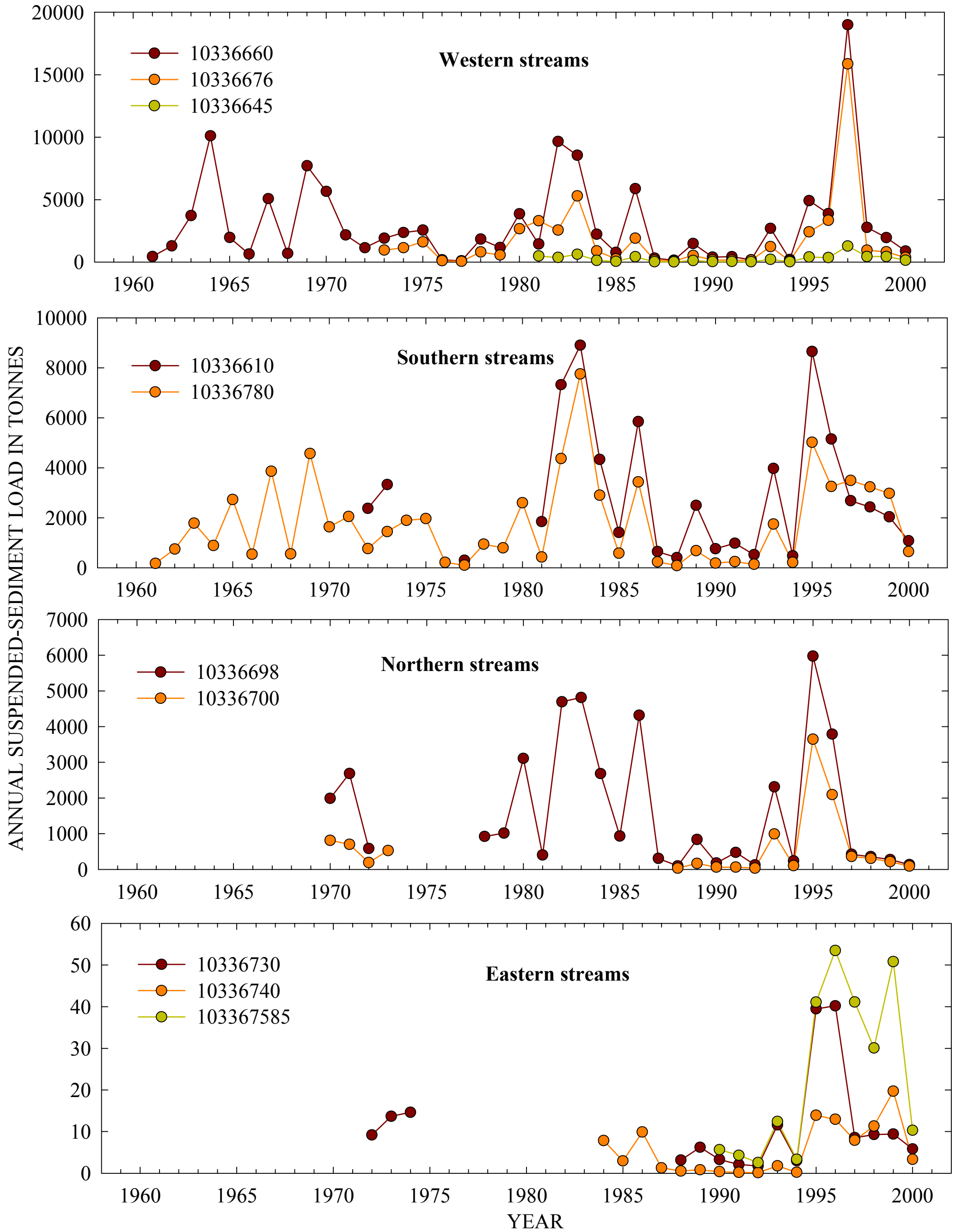


Figure 3-4. Temporal variability in total annual suspended-sediment loads for ten selected index stations in the four basin quadrants.

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

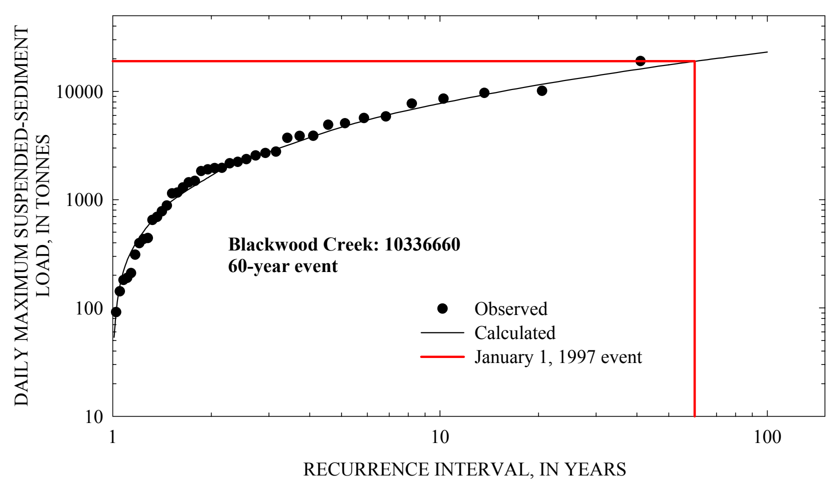
Stream	Station	Quadrant	Max Daily Flow (m^3/s)	Instantaneous Peak (m^3/s)	Recurrence Interval (y)	Flow rank
UTR	10336610	S	89.2	155	55.9	1
Incline	10336700	N	3.17	5.07	49.9	2
Glenbrook	10336730	E	2.41	4.08	37.7	3
Ward	10336676	W	39.4	71.6	35.0	4
Blackwood	10336660	W	56.6	83.2	32.7	5
UTR	10336580	S	32.0	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).



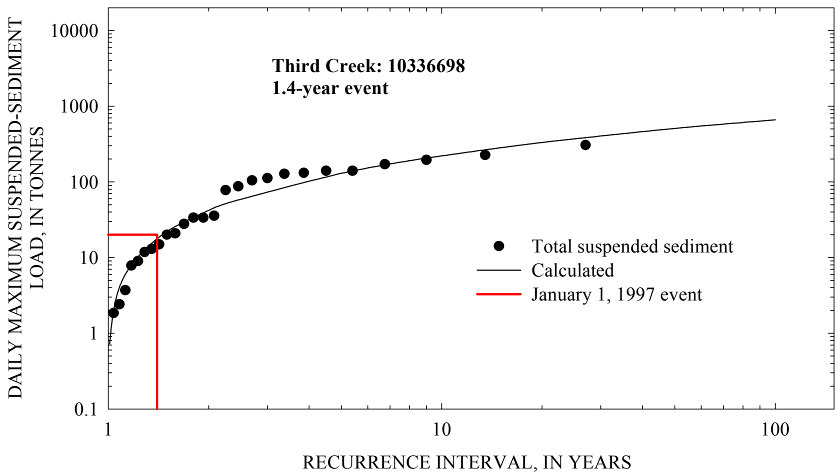


Figure 3-5. Magnitude-frequency analysis of annual, maximum-daily suspended-sediment loads for index stations on Blackwood Creek (10336660) and Incline Creek (10336700), showing widely varying return periods for the January 1, 1997 event.

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.

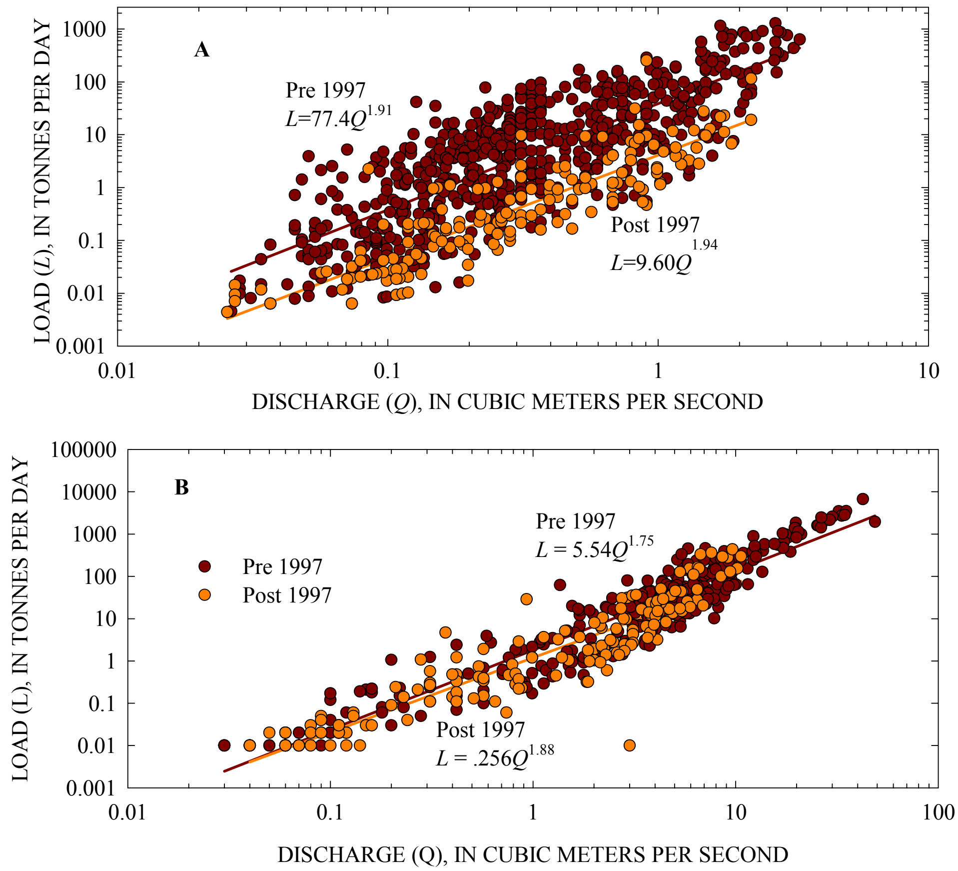


Figure 3-6. Examples of pre- and post-1997 suspended-sediment transport ratings for index station on Third Creek (10336698) showing flushing effect of January 1997 runoff event (A), and for Blackwood Creek (10336660) showing no discernable affect.

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	10336693	N	45.9	<.0001	decreasing
Incline	10336695	N	50.8	<.0001	decreasing
Third	10336698	N	272	<.0001	decreasing
Third	10336695	N	28.6	<.0001	decreasing

Third	103366958	N	27.5	<.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.

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)

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).