4.0 CHANNEL EROSION AND BASIN GEOMORPHOLOGY

4.1 Introduction

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

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

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

4.2 Direct Comparison of Measured Cross Sections

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

4.2.1 Availability of Data

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

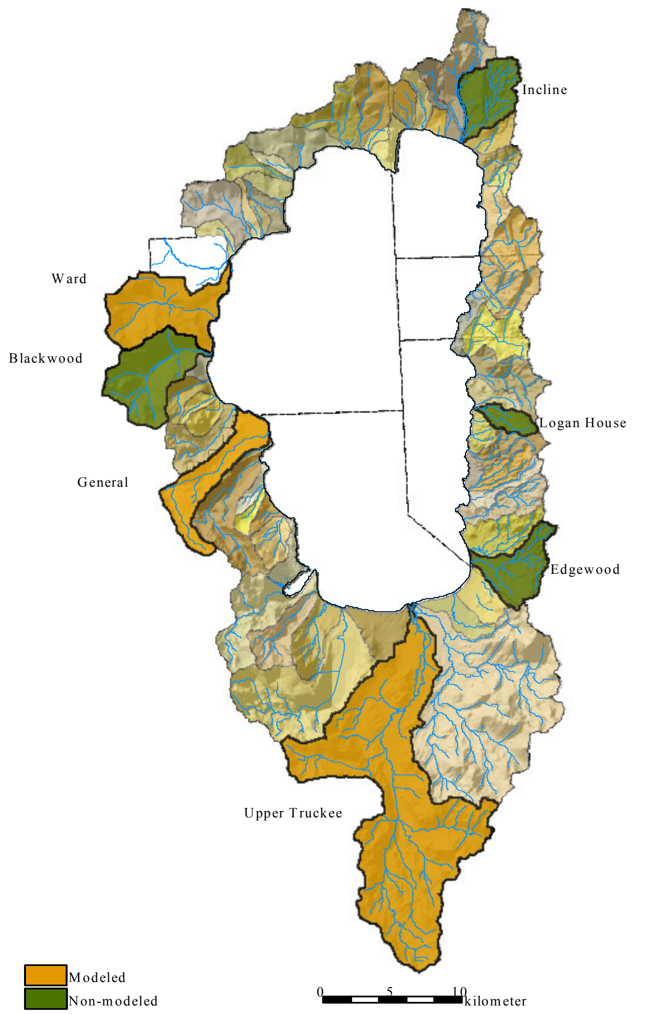


Figure 4-1. Denoted watersheds were the subject of detailed surveying and geomorphic assessments.

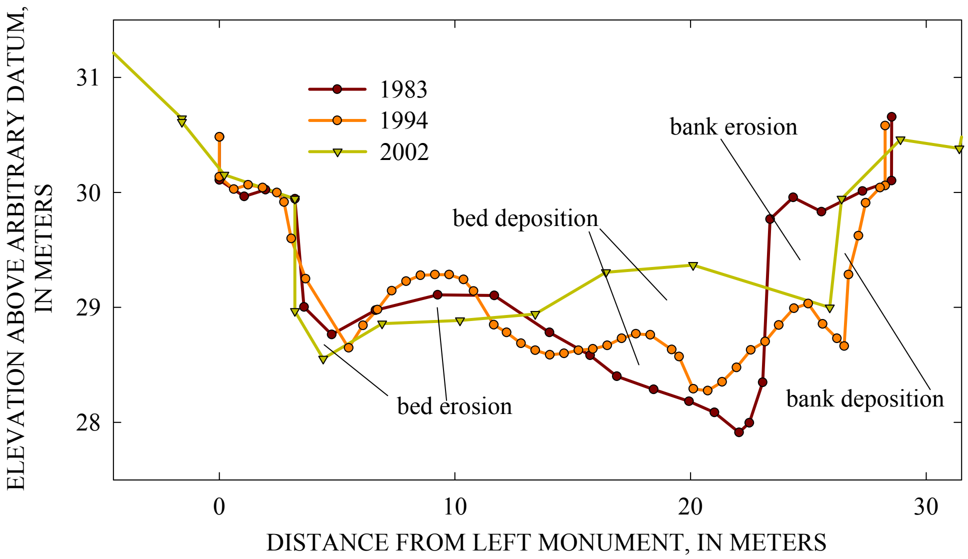
Table 4-1. Summary of historical cross-section data available for this study.

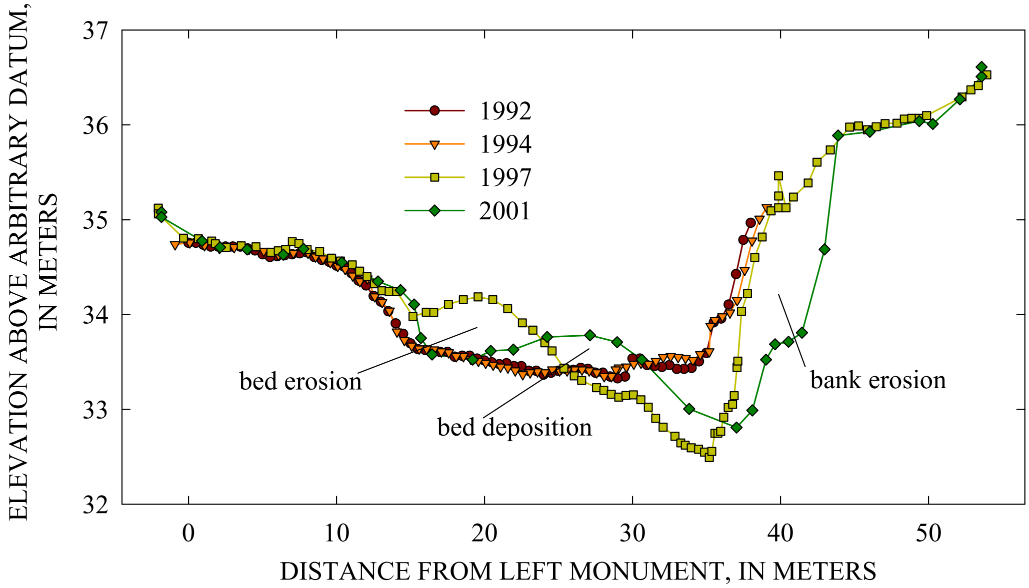
Stream	Date of first survey used	Number of sections matched	Total matched length (km)	Source of historical data
Blackwood	1983	17	8.3	USGS[1]
Edgewood	1983	23	5.6	USGS[1]
General	1983	12	8.5	USGS[1]
Logan House	1984	10	3.3	USGS[1]
Upper Truckee	1992	24	2.9	Calif. Parks[2]

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

4.2.2 Calculation of Volumes Eroded or Deposited

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





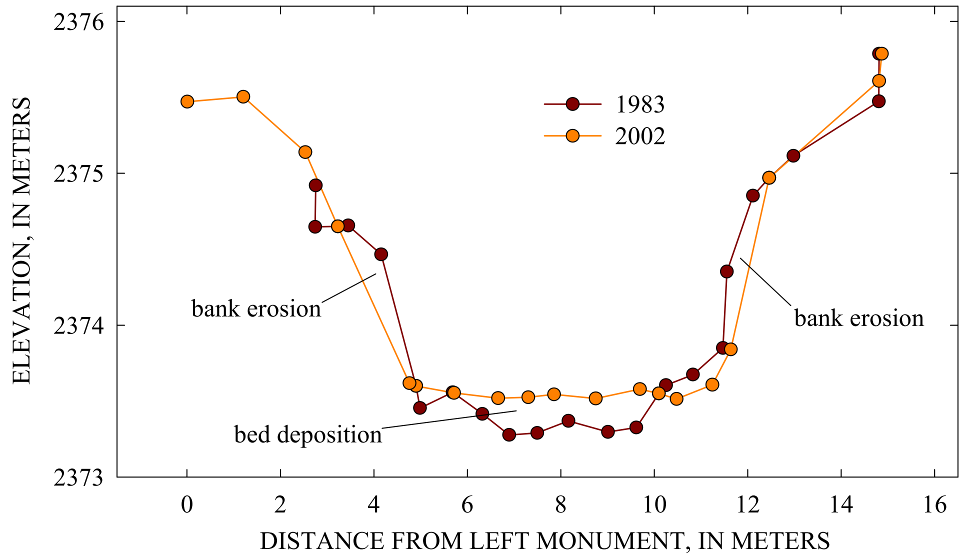


Figure 4-2. Examples of overlain surveys from Blackwood Creek, Upper Truckee River and General Creek.

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

4.3.1 Evaluation of Continuous Stream Lengths (Stream Walks)

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

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

4.3.2 Rapid Geomorphic Assessments (RGAs)

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

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

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

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

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

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

4.4 Combined Stability Index

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

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

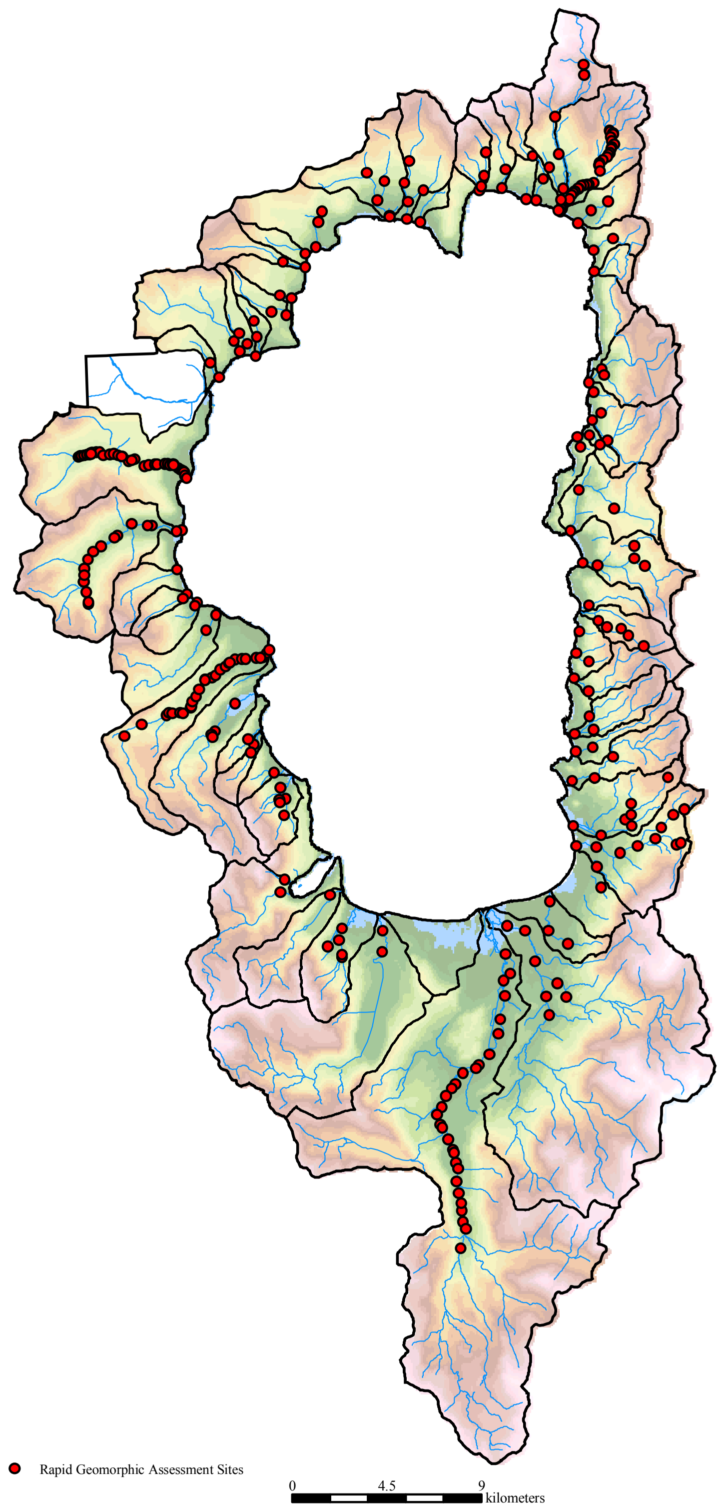


Figure 4-3. Map showing locations of the 304 rapid geomorphic assessments (RGAs) conducted in the Lake Tahoe Basin between September and November, 2002.

COMBINED-STABILITY RANKING SCHEME

Station #__________________ **Station Description**____________________________________

Date _____________ **Crew** _______________ **Samples Taken**_________________________

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

1. Primary bed material ____

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

2. Bed/bank protection ____

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

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

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

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

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

5. Streambank erosion (Each bank) ____ ____

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

6. Streambank instability (Percent of each bank failing) ____ ____

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

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

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

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

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

9. Stage of channel evolution ____

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

10. Condition of adjacent side slope (circle) ____

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

11. Percent of slope (length) contributing sediment ____ ____ ____

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

12. Severity of side-slope erosion ____

None	Low	Moderate	High
0	0.5	1.5	2

TOTAL ____

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

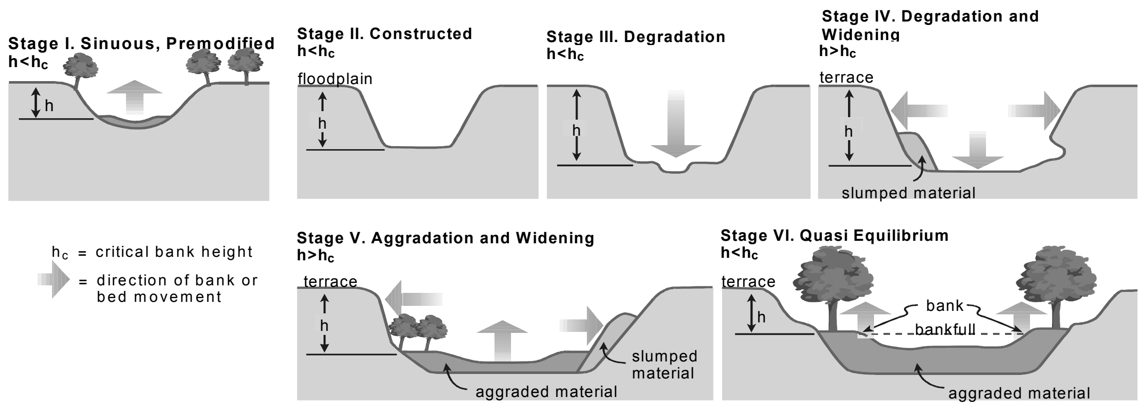


Figure 4-5. Six stages of channel evolution from Simon and Hupp (1986) and Simon (1989) identifying Stages IV and V as those dominated by bank widening.

4.5 <u>Channel Changes With Time: Rates and Volumes of Streambank Erosion</u>

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

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

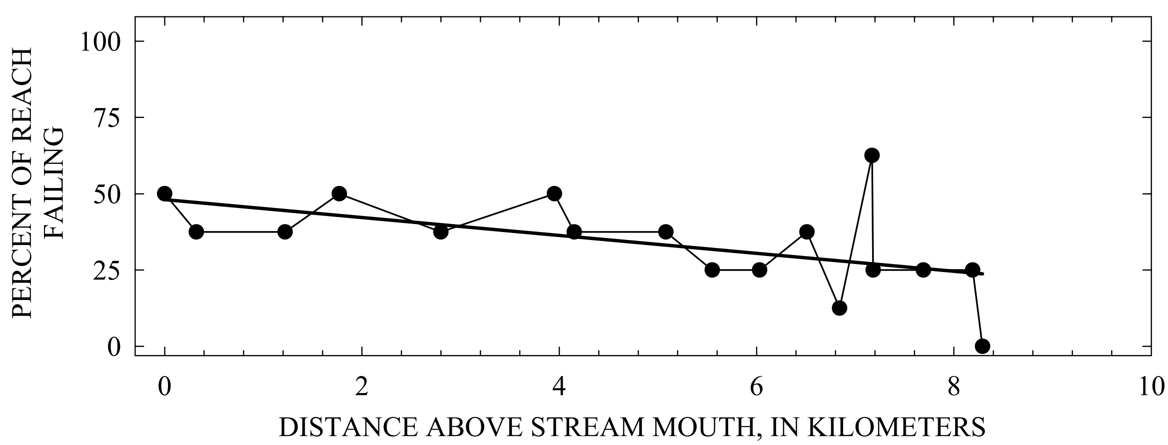
(1) except for the upstream-most site which is upstream of a headcut, 25-50% of the longitudinal extent of all assessed banks were unstable;
(2) there is a general trend of decreasing bank instability with distance upstream (Figure 4-6); and
(3) a knickpoint at about km 8.1 marks the headward advance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

Points 2 and 3 above are typical of streams responding to disturbance. Combined, all of the evidence from Blackwood Creek, including the exceptionally high suspended-sediment yields suggests that the consistently high sediment loadings are the result of not only the gravel mining operations downstream but also land surface disturbance over 100 years ago. We speculate that alluvial valley fills dating from the period of intense logging operations provides the source of much of the sediment eroding from channel banks along Blackwood Creek.

Compare Figure (4-6) for Blackwood Creek, with RGA results from Logan House Creek, where extremely low sediment yields and net bank deposition have been calculated from past and present surveys (Figure 4-6), and the importance of streambank erosion in delivering suspended sediment can be appreciated.

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

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



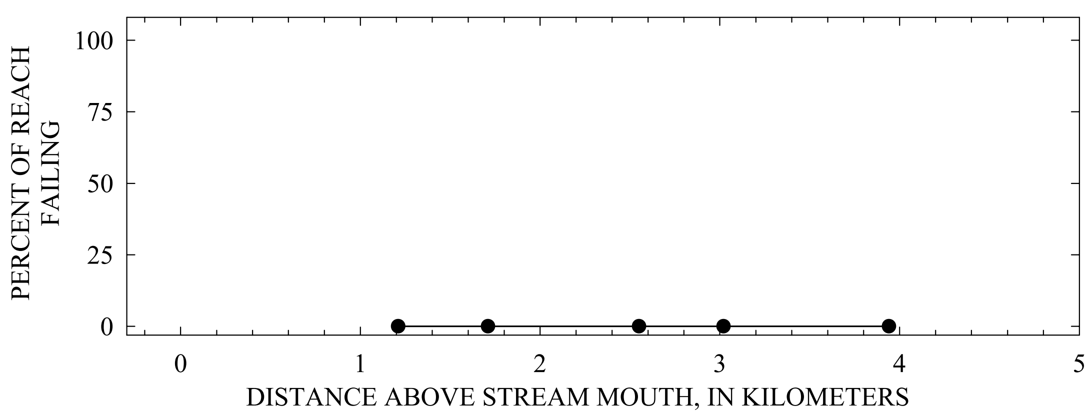


Figure 4-6. Percentage of left and right banks that are unstable along Blackwood Creek (upper) and along Logan House Creek (zero) (lower).

4.5.1 Upper Truckee River

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

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

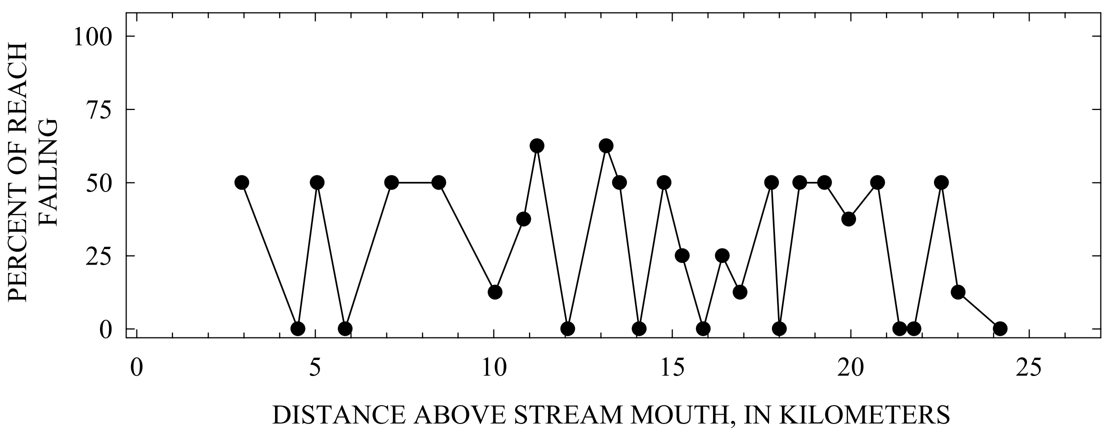


Figure 4.7. Percentage of left and right banks failing along the Upper Truckee River.

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

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

2.31 km). The downstream 73% of the reach runs through the Lake Tahoe Golf Course. Figure 4-8 illustrates the four channel centerlines.

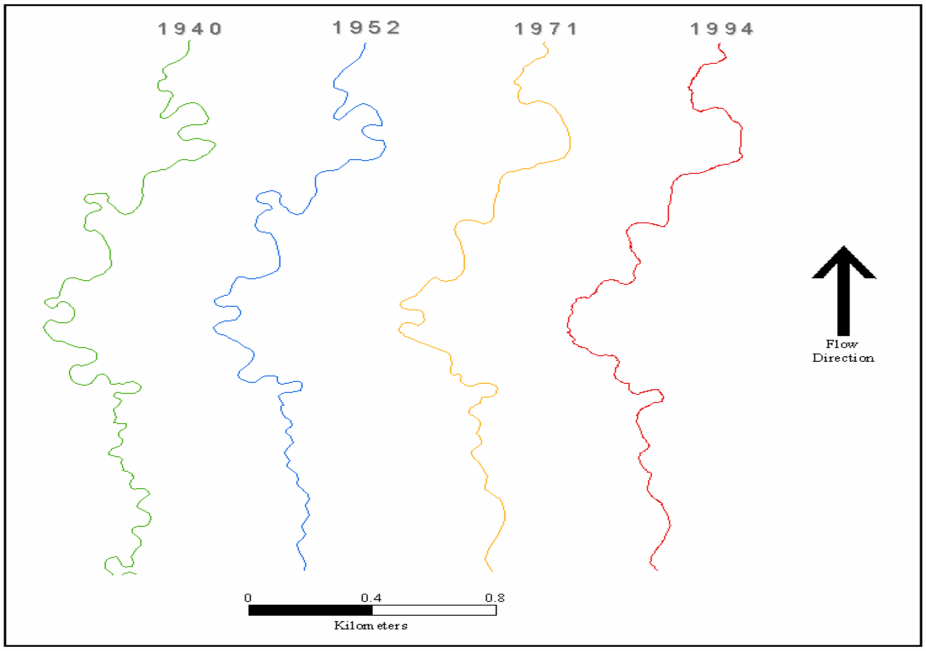


Figure 4-8. Successive centerlines of the Upper Truckee River, 1941 – 1994.

4.5.3 Analysis of Channel Lengths and Channel Activity

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

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

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

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

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

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

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

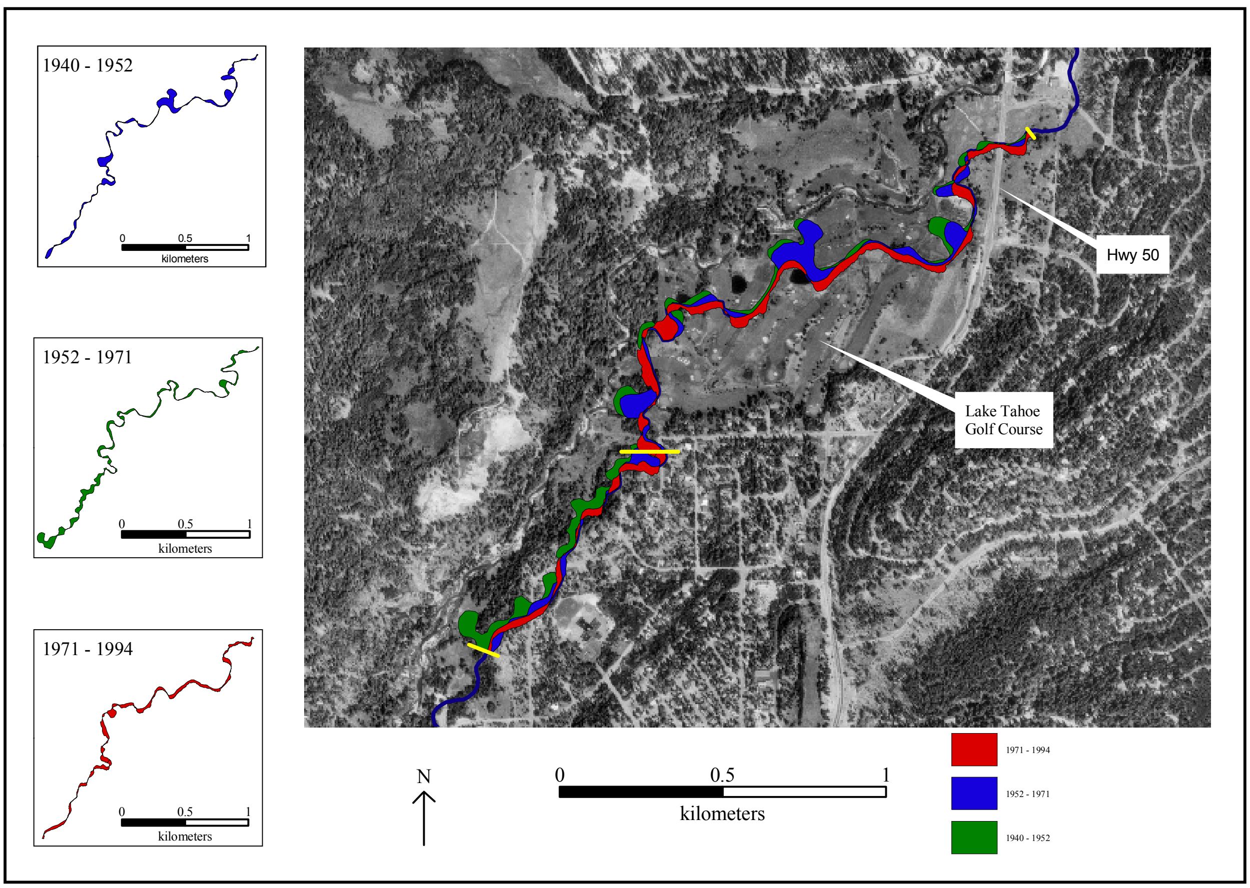


Figure 4-9. Map of polygons resulting from analysis of time-series channel centerlines along a reach of the Upper Truckee River.

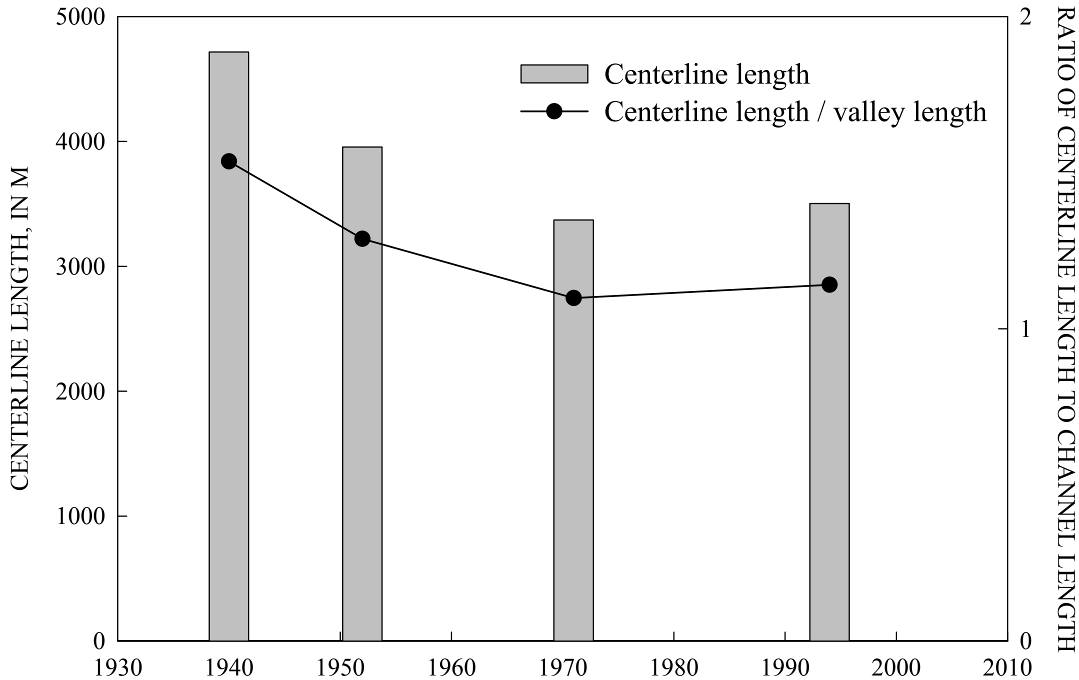


Figure 4-10. Upper Truckee River channel length results, 1941 – 1994.

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

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

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

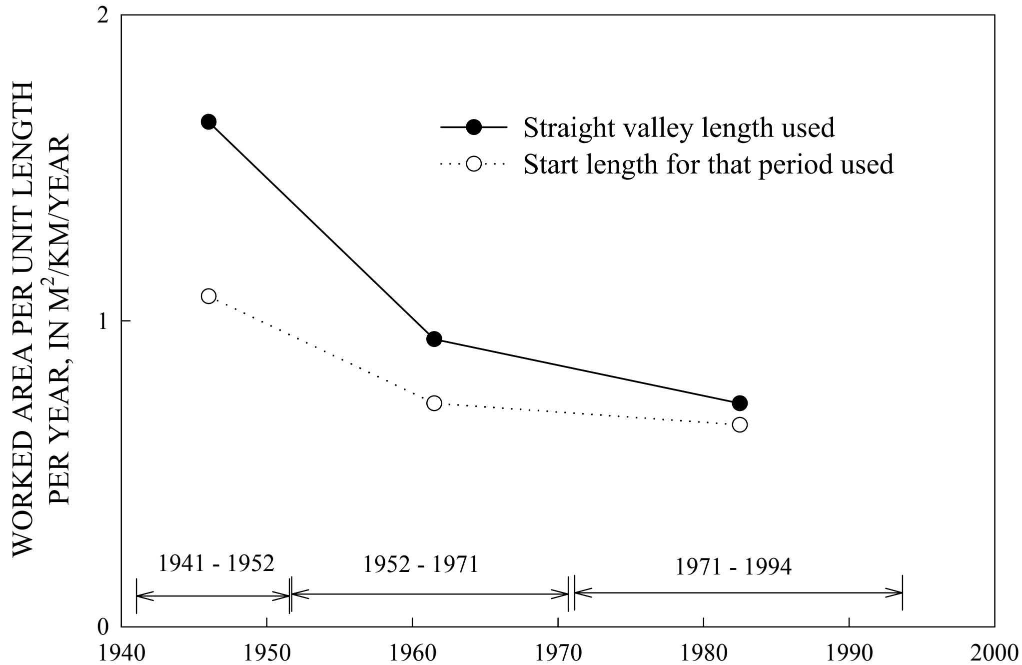


Figure 4-11. Upper Truckee River channel-activity results, 1941 – 1994.

4.5.4 Sub-Reach Channel Activity Results

Comparison between reaches adjacent to and upstream of the golf course show decreasing channel activity with time. Figure 4-13 contains graphs summarizing results of analysis of the golf course reach and remaining upstream reach and Table 4-6 tabulates this information.

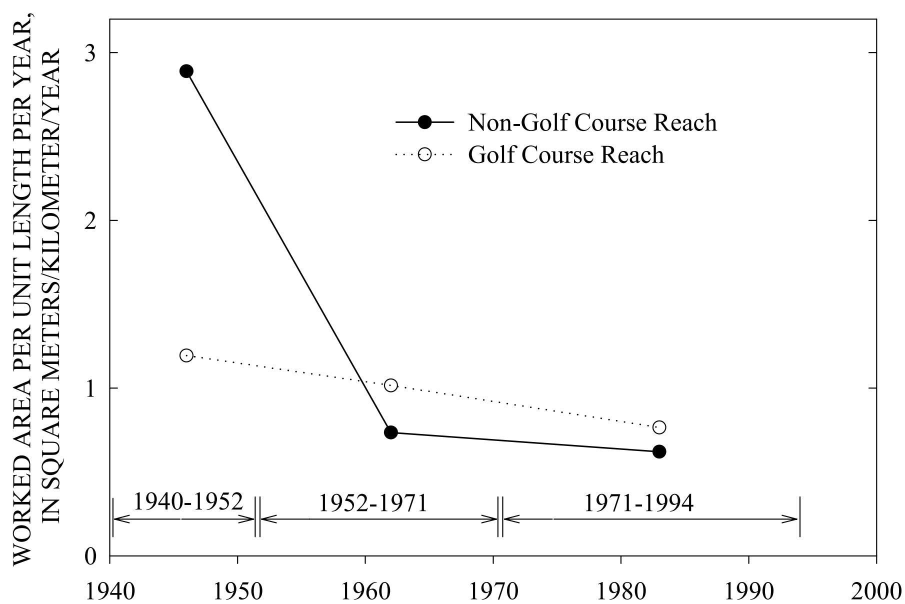


Figure 4-12. Channel activity for golf course and upstream sub-reaches, using valley length.

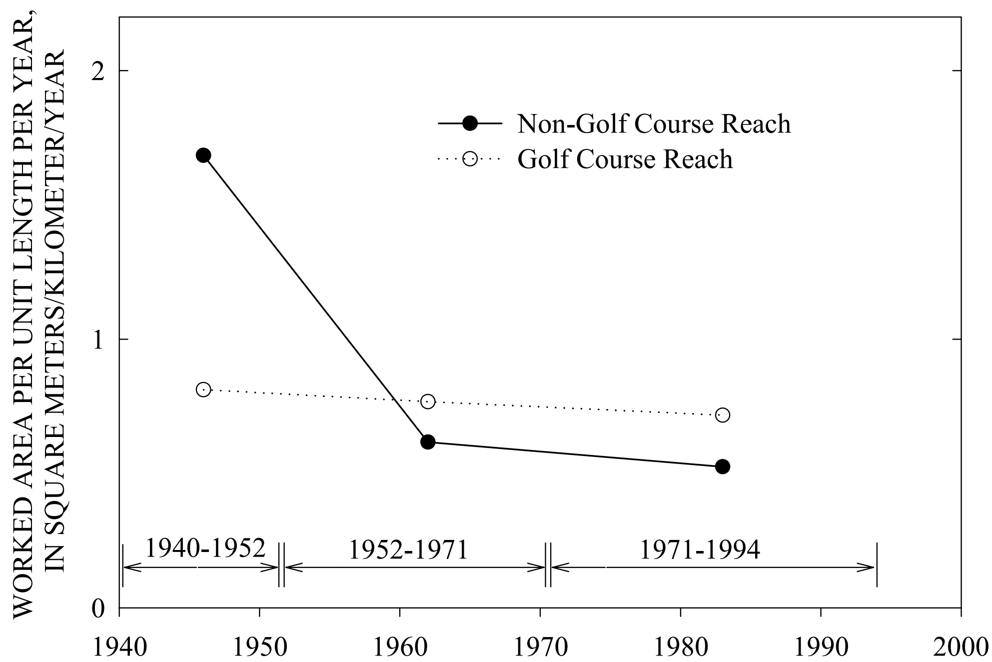


Figure 4-13. Channel activity for golf course and upstream sub-reaches, using centerline start length.

Table 4-6. Channel Activity in upstream and golf course sections of the Upper Truckee River.

Period	Reach	Worked area (m^2)	Worked Area/Valley Length per Time Interval (m^2/km/y)	Worked Area per (Start) Length per Time Interval (m^2/y/km)
1940-52	Upstream of Golf Course	28700	2.89	1.68
1952-71	Upstream of Golf Course	11600	0.735	0.617
1971-94	Upstream of Golf Course	11800	0.620	0.525
1940-52	Golf Course	32100	1.19	0.812
1952-71	Golf Course	43220	1.02	0.767
1971-94	Golf Course	39400	0.765	0.717

The first period of the reach upstream of the golf course possessed the largest active area value. The active area of the golf course reach is also comparatively high during this period. Between 1952 and 1971, and 1971 and 1994, the reach upstream of the golf course showed slightly lower activity values than the reach in the golf course. This may be attributable to the construction of a sheet-pile grade control structure in the upstream reach which serves to arrest further channel incision. Still, activity rates for both reaches show a decline over the 53-year time period, further supporting the view that sediment loads from the Upper Truckee River are decreasing.

4.6 Ground Reconnaissance: Results of RGAs and Stream Walks

4.6.1 Upper Truckee River

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

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

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

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

Erosion hotspot	Hotspot Location (UTM)		Source of Fine Sediment	Relative erosion magnitude
	Easting	Northing		
1	760870	4312260	1.5 m high sloughed silt bank	moderate
2	760920	4312250	1.5 m high sloughed silt bank	moderate
Hwy 50 bridge				
3	760970	4312230	1.5 m high sloughed silt bank	high
4	761070	4312226	1.5 m high sloughed silt bank	high
5	761110	4312230	1.5 m high sloughed silt bank	high
6	761155	4312223	1.5 m high sloughed silt bank	high
7	761256	4312156	1.5 m high sloughed silt bank	high
8	761371	4311919	1.5 m high sloughed silt bank	high
9	761503	4311704	1.5 m high sloughed silt bank	high
10	761468	4311521	1.5 m high sloughed silt bank	high

11	761441	4311376	5 m high escarpment below dam	moderate
Dam				
12	761304	4311214	6 m high escarpment	moderate
13	761219	4311170	6 m high escarpment	high
14	761133	4311094	4 m high escarpment	high
15	761020	4310981	1.2 m high undercut bank of silt/sand	moderate
16	760960	4310835	1.2 m high undercut bank of silt/sand	moderate
17	761029	4310789	1.2 m high undercut bank of silt/sand	moderate
			channelized and rip-rapped	negligible
18	760940	4309060	6 m high escarpment	moderate
19	760924	4308810	1.5 m high sloughed silt bank	moderate
20	760871	4308448	1.5 m high sloughed silt bank	moderate
21	760732	4308262	1.5 m high sloughed silt bank	moderate
22	760641	4308068	2.0 m high sloughed silt bank	moderate
Hwy 50/89 bridge				
23	759662	4306745	3 m high slumped bank	moderate
24	759376	4306658	2 m high slumped bank	moderate
25	758927	4306417	2 m high eroding bank	moderate
26	758910	4306450	1.5 m high eroding bank	moderate
27	758672	4306417	2 m high eroding bank	moderate
28	758694	4306026	2.3 m high scalloped R bank	moderate
End of golf course				
29	758523	4305851	2.5 m high eroding R bank	moderate
30	758062	4303989	3 m high eroding bank affected by LWD	major
31	758579	4303011	eroding L bank	low
32	758685	4302967	LWD jam causing bank scour	moderate
33	758642	4302801	1.5 m high eroding silt/fine sand bank	moderate
34	758800	4302180	1.5 m high slumped L bank	moderate
35	758805	4302080	1.5 m high slumped L bank	moderate
36	758776	4301770	1.5 m high sloughed silt overlying sand bank	moderate
37	758775	4301618	1.5 m high sloughed silt overlying sand bank	moderate
38	758864	4300887	3 m high slumped bank	moderate
39	758936	4300508	2 m high eroding bank	moderate
Portal Road bridge				

40	758975	4300020	1.5 m high eroding L bank	low
41	759073	4299718	1.5 m high undercut/slumped L bank	low
42	759072	4299677	5 m high escarpment	moderate
43	759078	4299581	2 m high slumped bank	moderate
USGS Stream Gage: 10336580				

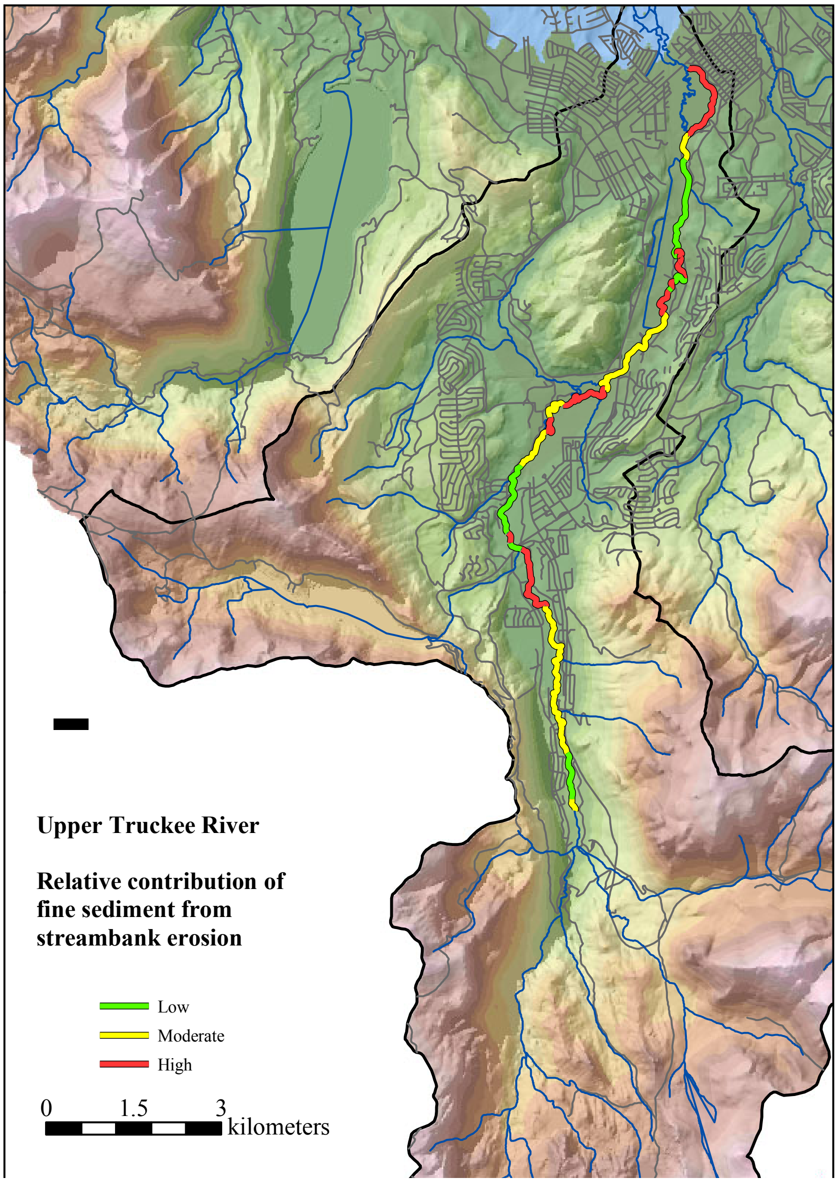


Figure 4-14. Map of the relative contribution of fine sediment from streambank erosion for the Upper Truckee River main stem.

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

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

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

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

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

The stream crossing a moraine marks the intersection of the Upper Truckee River and Highway 50 above Meyers the beginning of the alternating meadow/moraine reach. The channel contains boulders up to 5 m in diameter immediately upstream of the bridge. The 0.5 km upstream contains sporadic locations of high bank erosion, where boulders have eroded out of the till, but do not defend the banks from high flows (hotspots 30 to 32, Table 4-7). The banks at these locations tend to be high, 3 to 4 m, and the boulders also serve to catch large woody debris which exacerbates local scour. Transitioning from the upper end of the moraine to the meadow reach, bank heights become lower and the channel is predominantly bedded with gravel with fewer boulders.

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

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

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

Summary

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

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

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

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

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

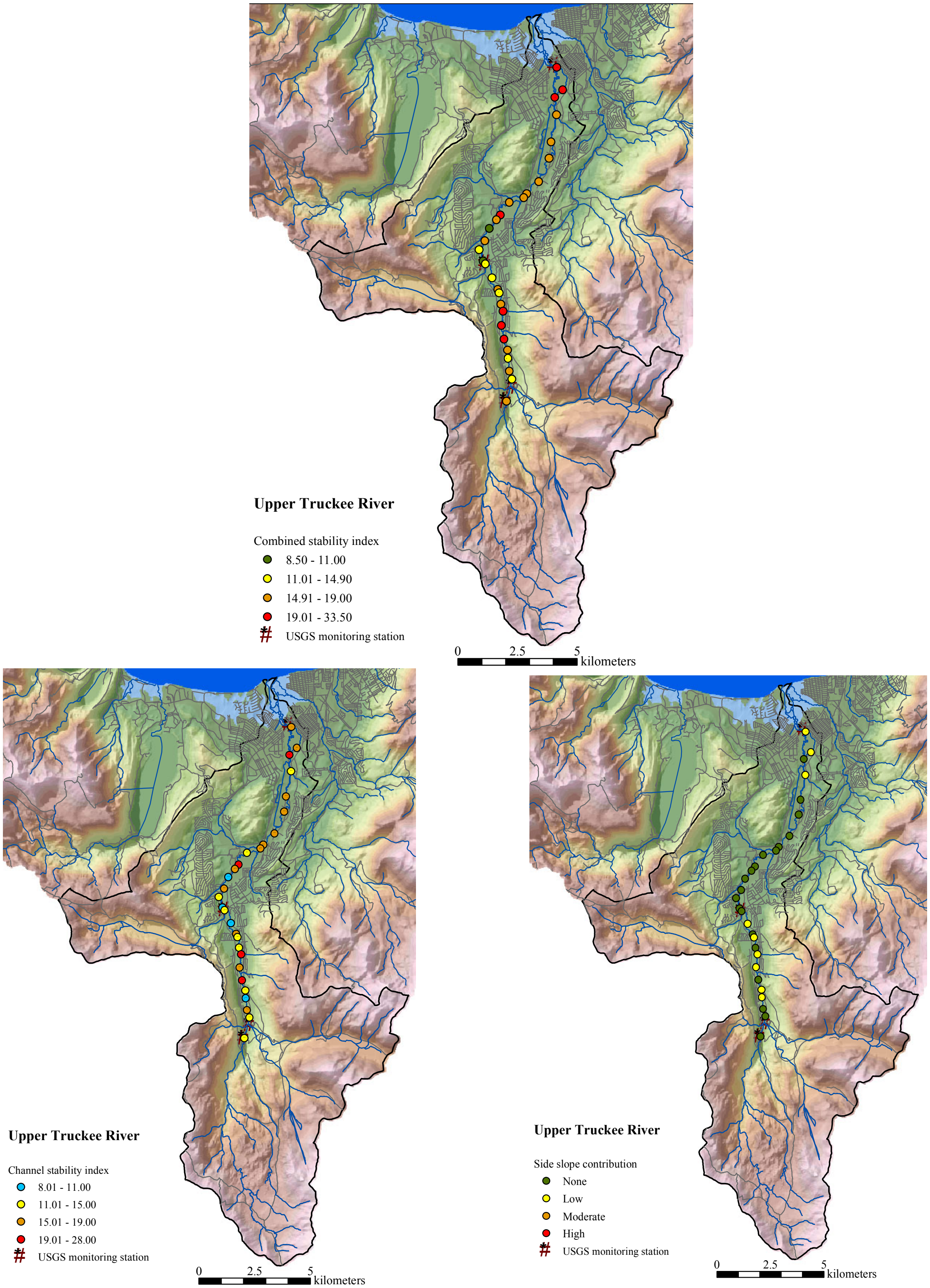


Figure 4-18. Results of rapid geomorphic assessments of the Upper Truckee River showing the relative contributions of channel- and side-slope indexes to the combined stability index, and critical erosion areas.

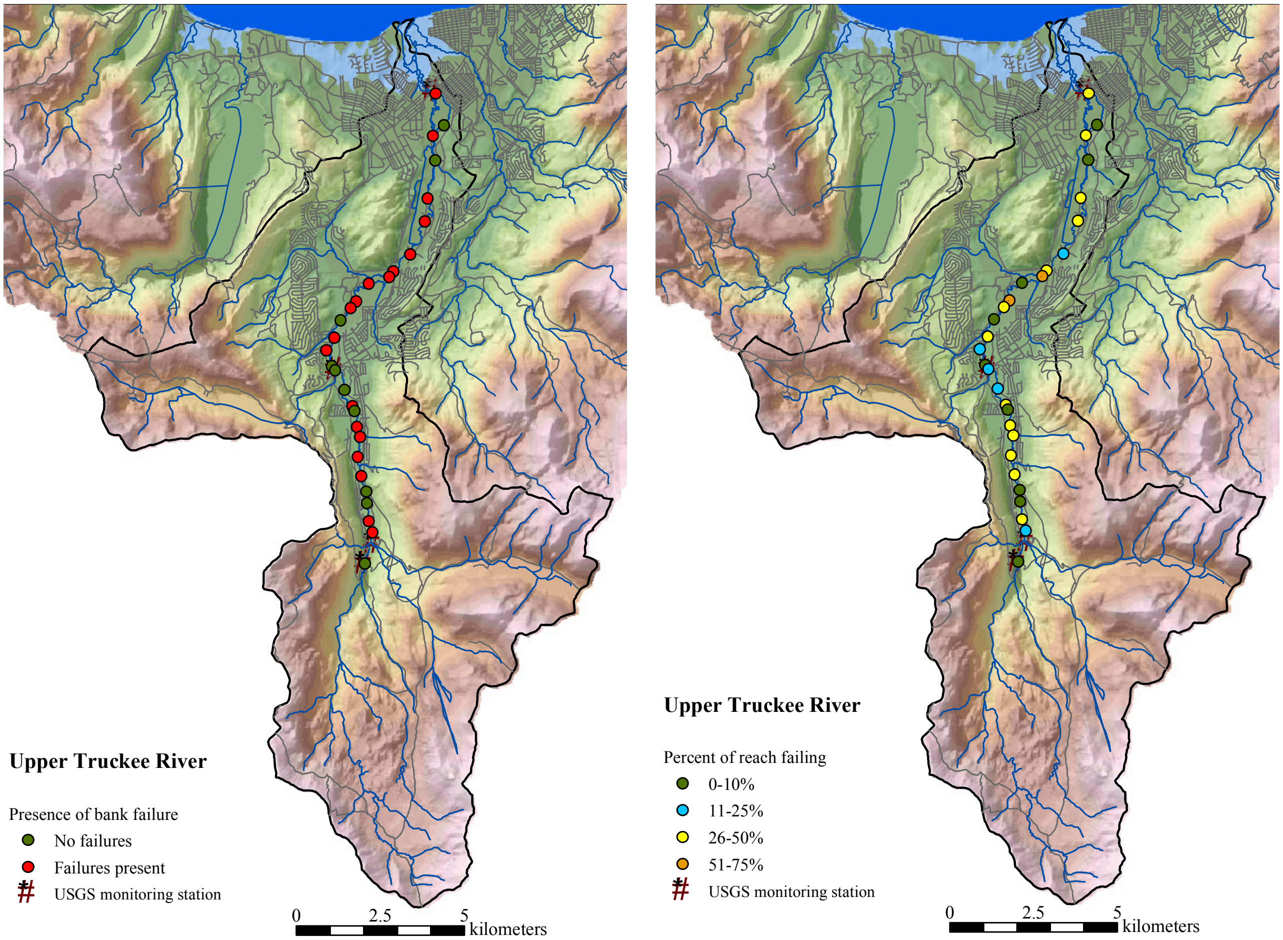


Figure 4-19. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along the Upper Truckee River.

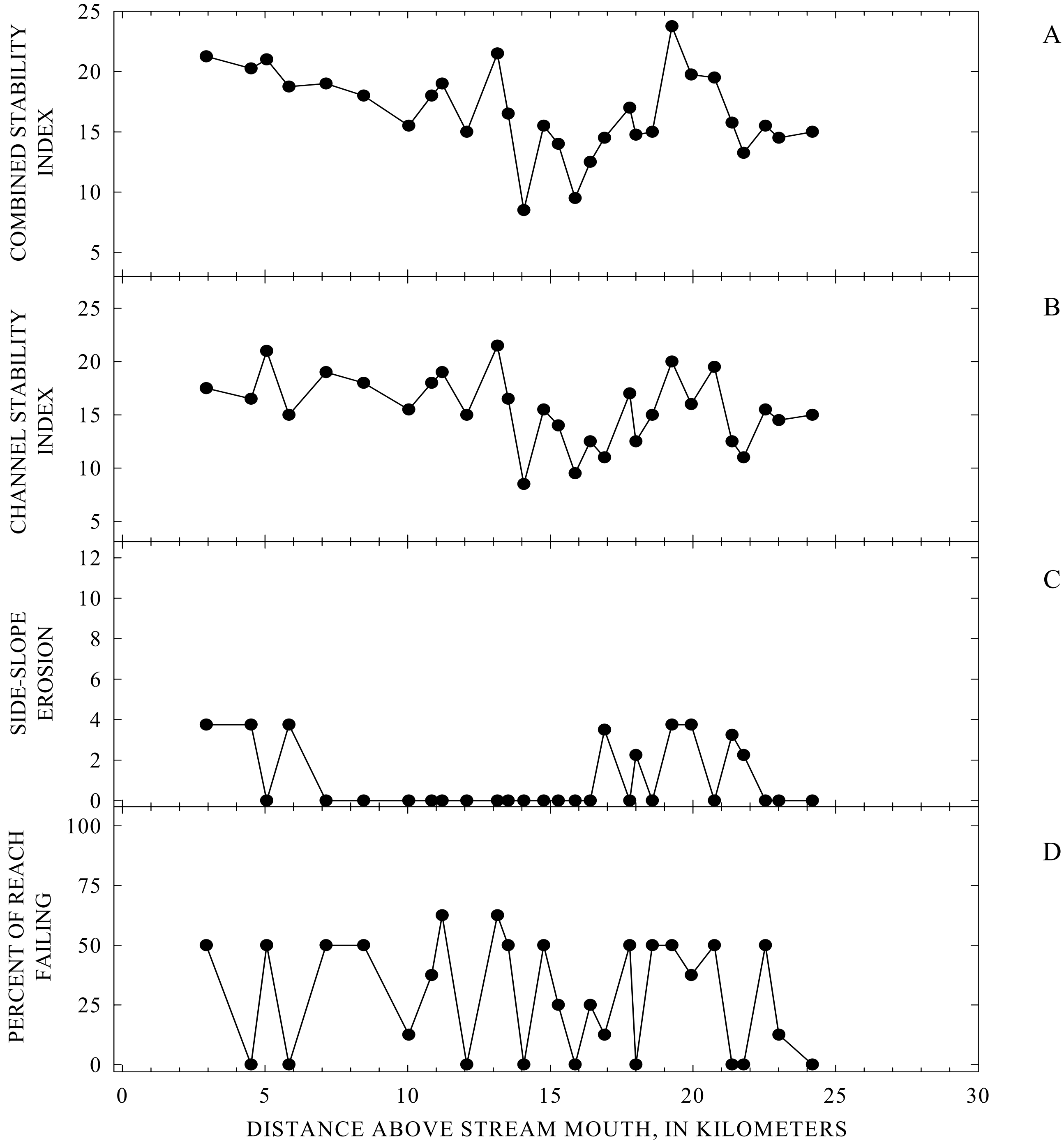


Figure 4-20. Results of RGAs conducted along the Upper Truckee River showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank bank failures.

4.6.2 Blackwood Creek

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

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

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

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

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

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

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

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

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

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

Summary

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

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

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

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

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

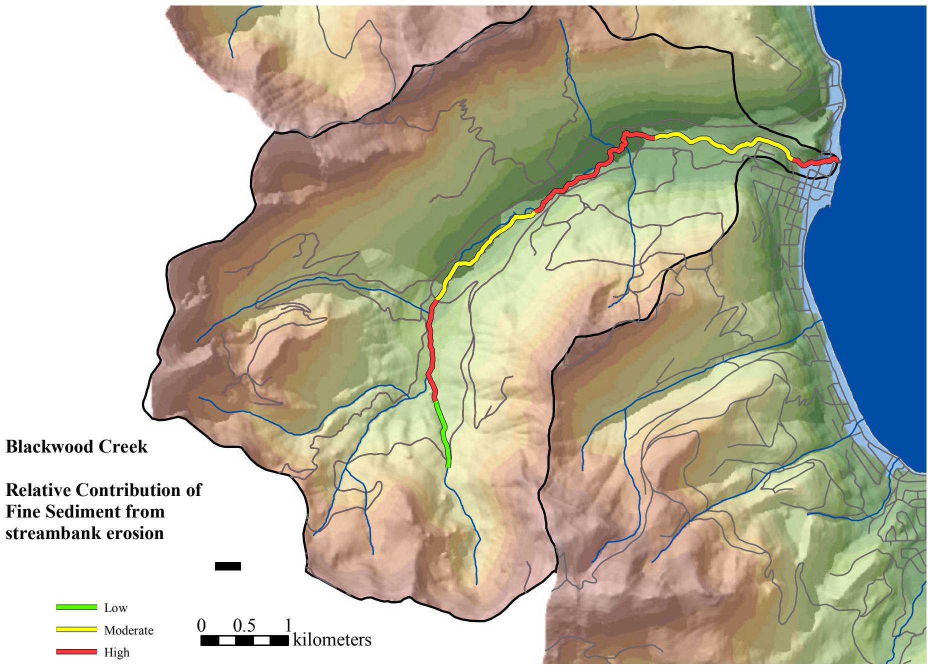


Figure 4-23. Map of the relative contribution of fine sediment from streambank erosion for Blackwood Creek.

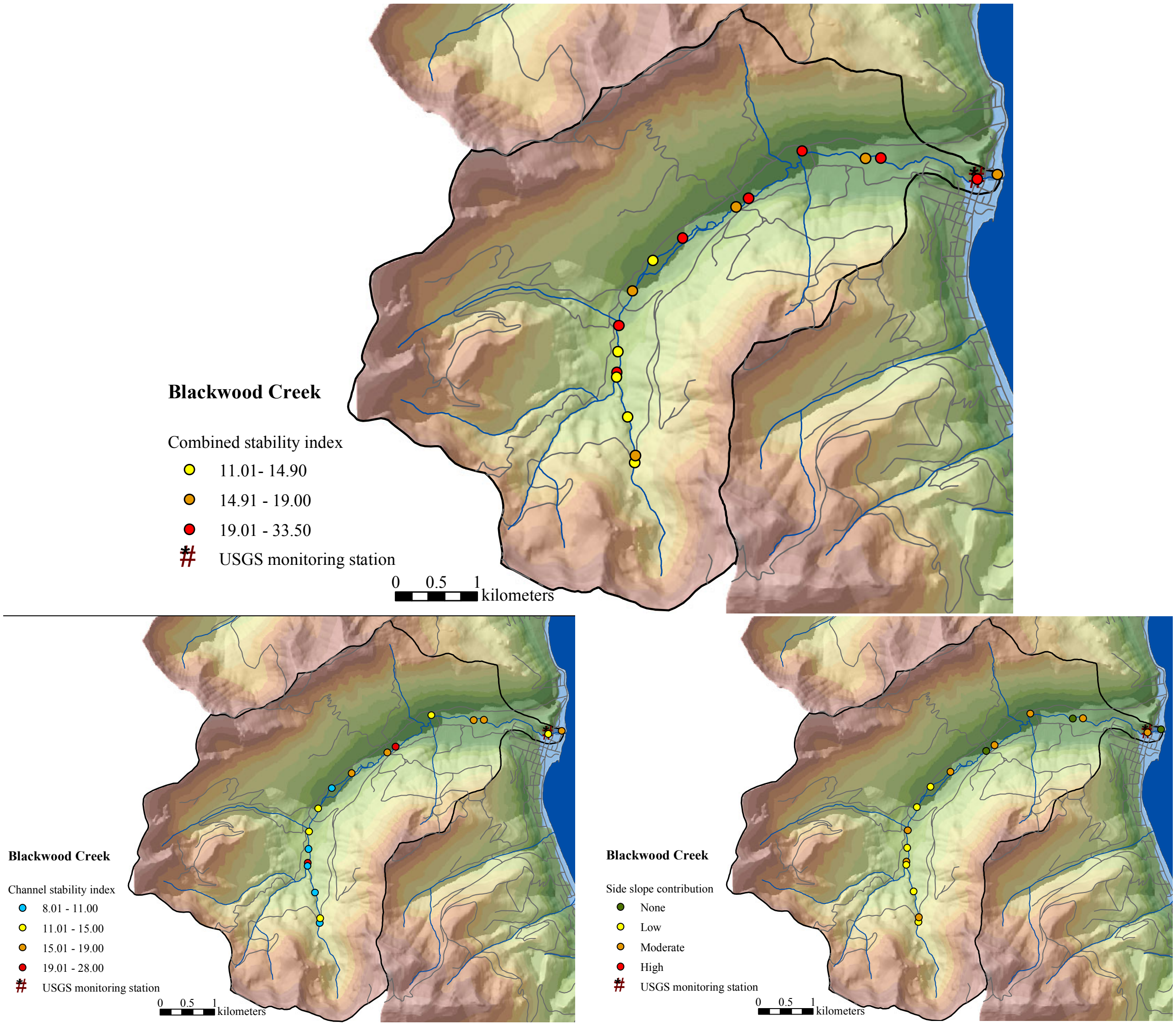


Figure 4-24. Results of rapid geomorphic assessments of Blackwood Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

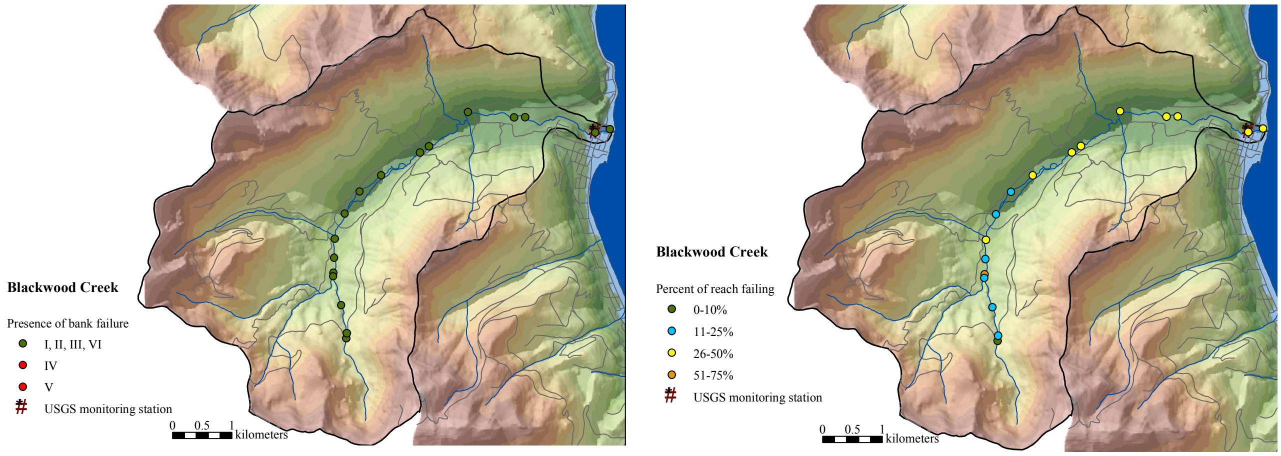


Figure 4-25. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along Blackwood Creek.

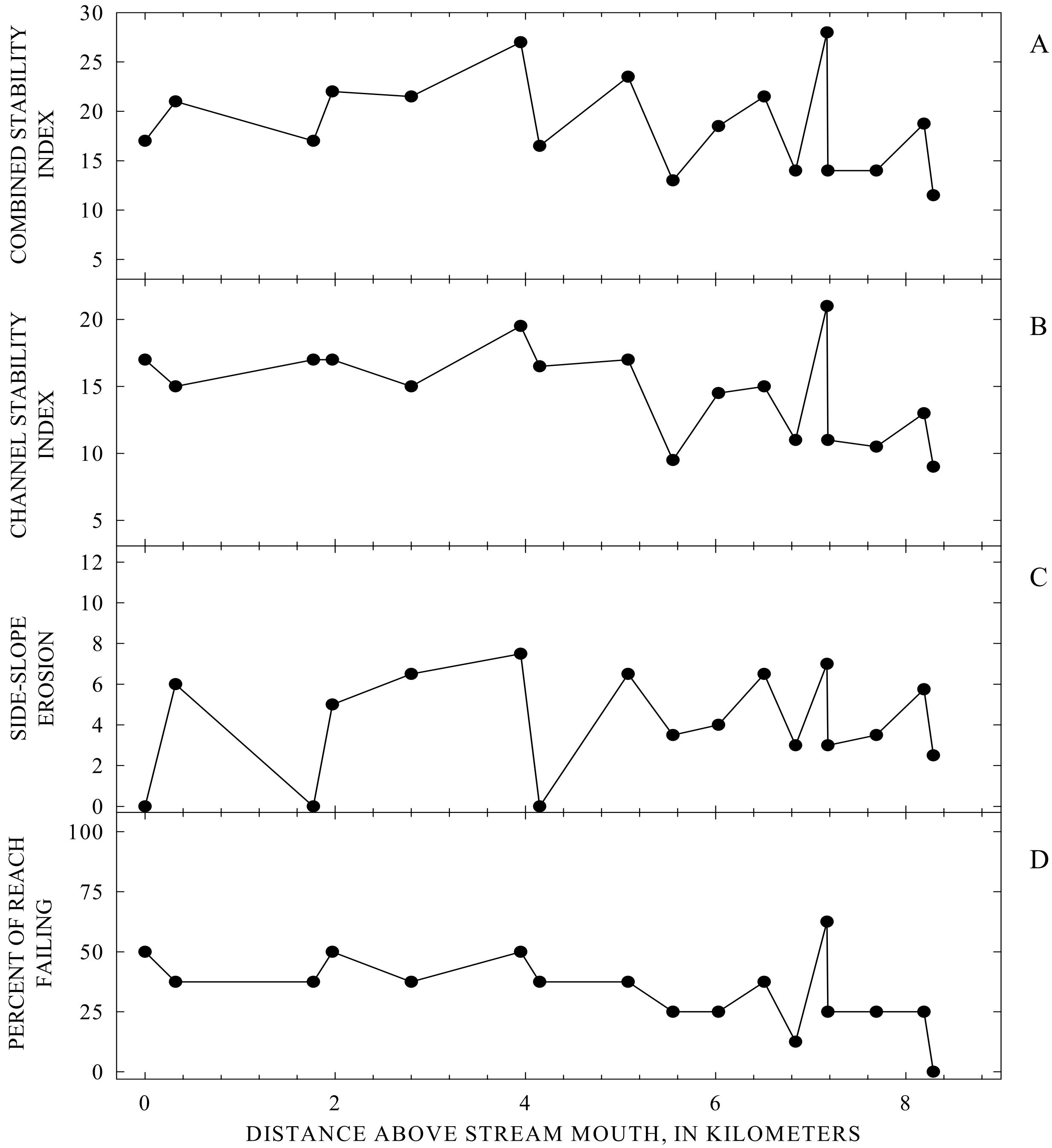


Figure 4-26. Results of RGAs conducted along Blackwood Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

4.6.3 Ward Creek

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

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

Erosion hotspot	Hotspot location (UTM)		Source of fine sediment	Relative erosion magnitude
	Easting	Northing		
1	745862	4334956	2.3 m high failing R bank	moderate
2	745816	4335040	2.6 m high failing R bank	moderate
3	745643	4335227	6 m high failing R bank	high
4	745117	4335472	2 m high failing R bank	moderate
5	744784	4335534	12 m high failing R bank	high
6	744545	4335515	1.5 m high failing R bank	moderate
7	744215	4335462	7 m high failing R bank	high
8	744064	4335444	4 m high failing R bank	high
9	743707	4335478	7 m high failing R bank	high
10	743666	4335517	4 m high failing R bank	high
11	743481	4335671	reworking fluvial deposits	low
12	743283	4335672	15 m high failing bank	high
13	743202	4335667	1.7 m high failing bank of reworked fluvial deposits	moderate
14	743139	4335718	1.7 m high failing bank of reworked fluvial deposits	high

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

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

The glacial till/beaver meadow reach spans 3.1 km from the exit of the canyon until the confluence near the USGS stream gage approximately 4.7 km above the mouth meadow (Hotspots 9 to 34, Table 4-9). This reach channel meanders through a flat valley several hundred meters wide. The channel has mixed forms: cobble/boulder runs, cobble/gravel pool riffles, braided gravel/cobbles, and beaver ponds. Banks in the middle of the valley range from 0.5 to 2.0 m-high, however they become 4 to 12 m-high escarpments where the stream cuts into the valley walls. Stable reaches consist of banks less than 0.5 m-high composed of gravel with dogwood and alder growing to the water's edge. Stable reaches can also be braided with poorly vegetated cobble bars. It is assumed that the cobble bars formed during the January 1997 flood. Unstable reaches have 0.5 to 1.5 m-high vertical banks composed of organic rich silt (old beaver pond deposits). These banks are typically being undercut with frequent sloughing of the upper grass root-bound layer. They are considered to have low to moderate fine-sediment erosion potential depending on the length of the exposed bank (Figure 4-27). Areas considered to have high erosion potential are cut banks of beaver pond deposits higher than 1.5 m or escarpments where the stream is cutting into valley walls of glacial till. Overall, the glacial till/beaver meadow reach has a moderate amount of fine sediment available for erosion.

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

Summary

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

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

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

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

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

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

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

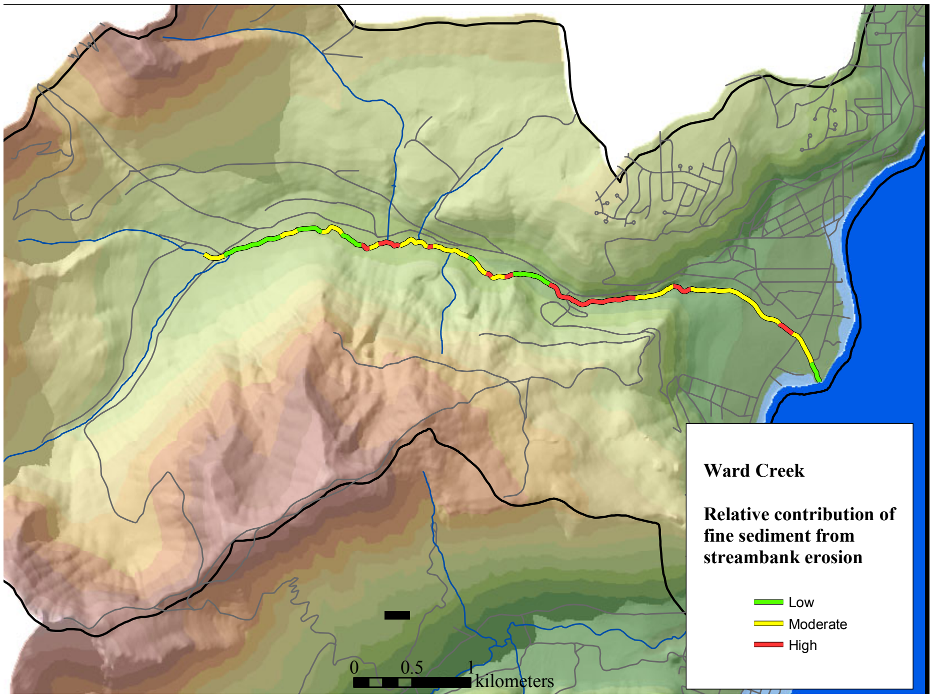


Figure 4-29. Map of the relative contribution of fine sediment from streambank erosion for Ward Creek.

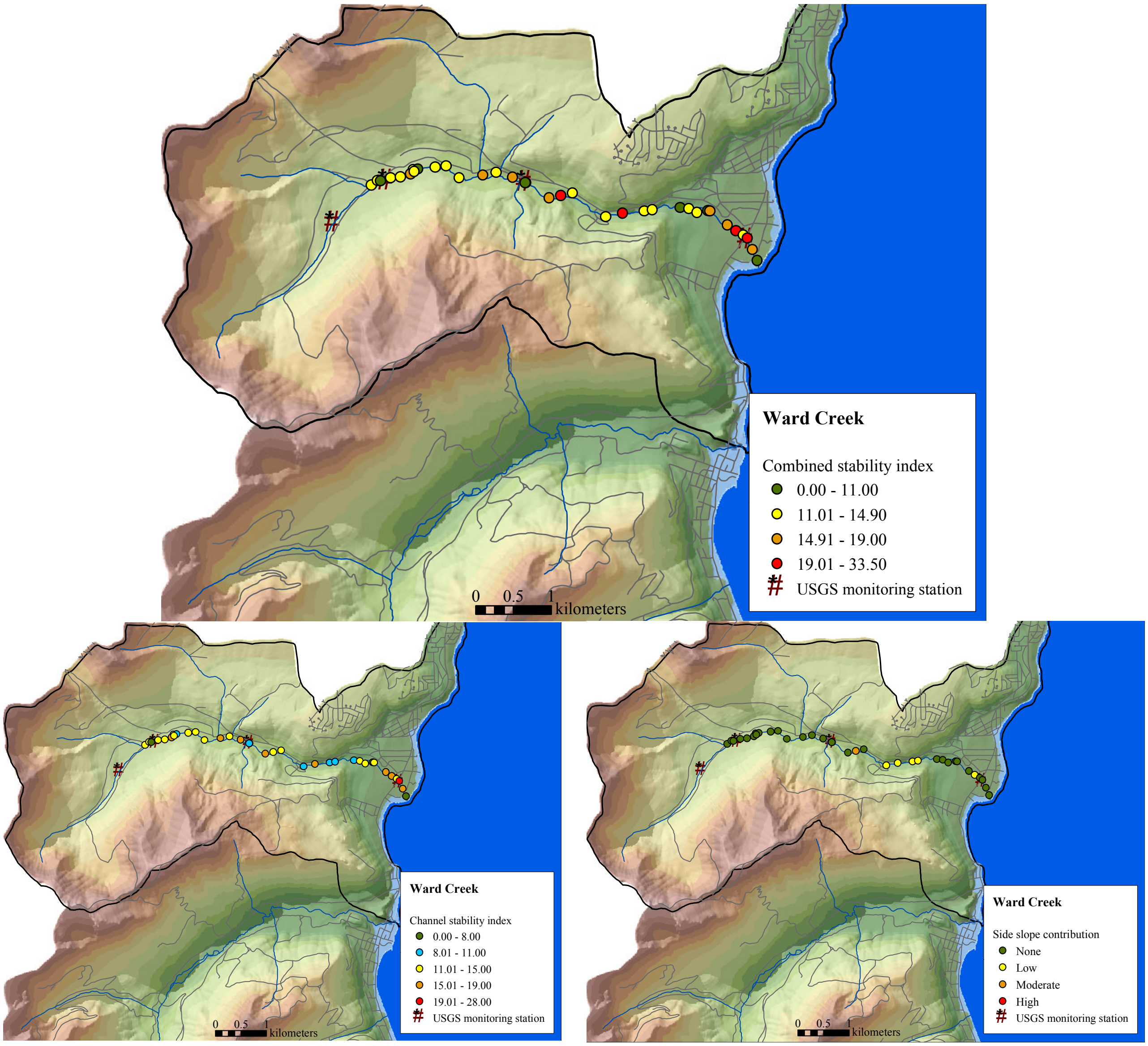


Figure 4-30. Results of rapid geomorphic assessments of Ward Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

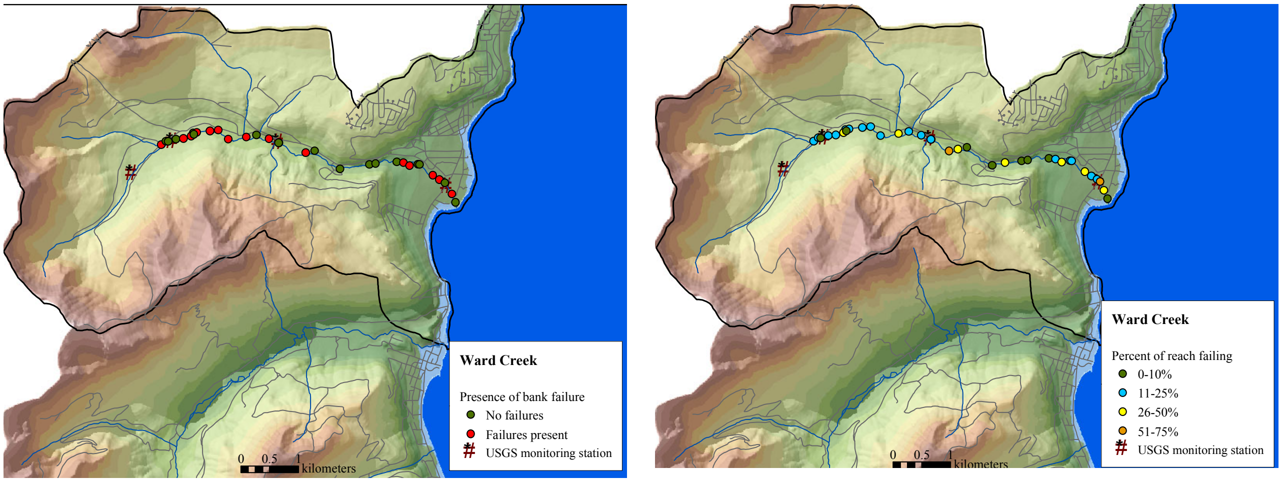


Figure 4-31. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along Ward Creek.

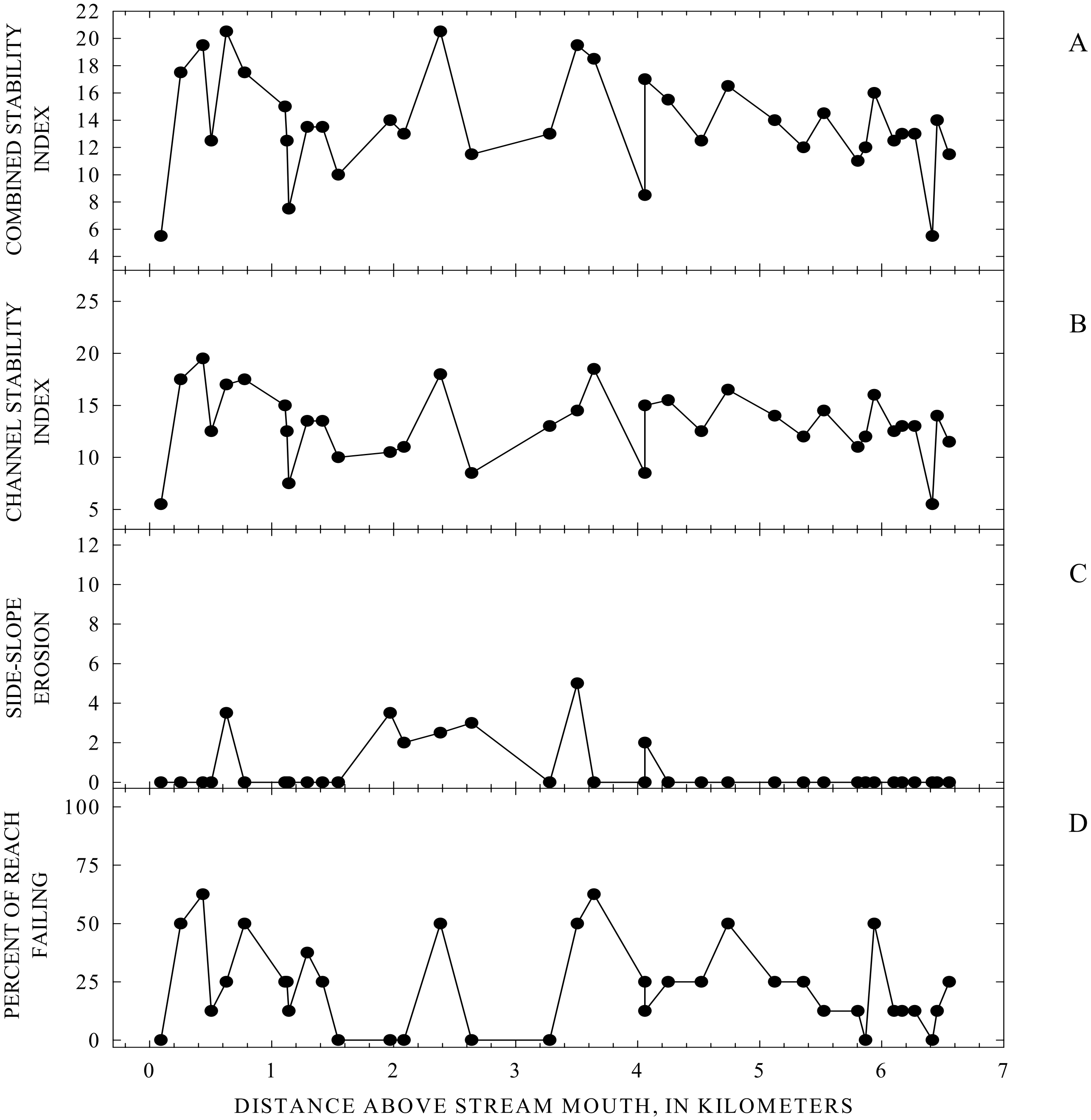


Figure 4-32. Results of RGAs conducted along Ward Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

4.6.4 General Creek

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

The delta reach encompasses the 0.7 km reach from the mouth to 100 m above Highway 89. Near the mouth, coarse sand is being deposited in 1.5 m high bars. Bank materials include fluvially deposited coarse sand, fluvially deposited silt/sand layers overlying gravel/cobble, and organic rich silt/clay lake deposits. Bank heights vary from 0.1 m in the pool of a beaver dam to about 1.0 m below the dam. Alders, dogwood, and grasses densely cover the banks. Bank erosion is greatest at two locations where large woody debris is causing bank scour. Erosion is also occurring through the undercutting of the silt/sand overlying gravel. The lake deposits are cohesive and appear to be a minor sediment contributor. The overall fine-sediment erosion potential of the reach is low (Hotspots 31 to 34, Table 4-10).

The incised-till reach spans 3.0 km from 100 m above Highway 89 to the furthest upstream U.S. Forest Service bridge. This reach is characterized by a meandering channel incised through a downstream thickening glacial till deposit (Figure 4-33). The result is a channel with 1 meter high floodplains between high till terraces. Escarpments form where the stream engages the terrace wall. Escarpments near the upper end of the reach are less than 3 m-high. Approaching the lower end of the reach, the escarpments reach to an estimated 20 m-high (Figure 4-33). All these escarpments are considered to be major sources of fine sediment. As they continue to erode, large trees become undercut and fall into the channel. The resulting large woody debris exacerbates erosion through scour by directing flows into the banks (Hotspots 16 to 30, Table 4-10).

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

The aggrading gravel-bed section begins above the upper bridge and ends 2.4 kilometers upstream or about 0.3 km below the confluence of General Creek and the tributary from Lost Lake. The reach is split into upper and lower halves where it crosses a moraine by a short boulder riddled steep gradient reach. The downstream half is characterized by low banks well vegetated by alder and dogwood. The riparian zone in the lower half of the reach is well shaded by pines. The undergrowth is comprised of ferns and other plants requiring low-sunlight. The forest thins in the upper part of the reach leaving banks exposed to the sun. Dense alder and dogwood form a canopy over the channel. Grasses and annual vegetation cover portions of the flood plains. The channel has aggraded a gravel and cobble bed into a braided channel along the upper quarter the section. The channel is actively widening through undercutting its banks. Banks are typically less than 1.5 meters high and are composed of fluvially deposited silt/sands overlying coarse sand and gravel. The banks in the moraine reach are well protected by boulders (Figure 4-34) therefore fine sediment production appears to be negligible along this reach (Between hotspots 12 and 13, Table 4-10). Overall the fine sediment erosion level appears to be moderate where the primary erosion processes are bank undercutting and large woody debris initiated scour (Hotspots 6 to 15, Table 4-10).

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

Erosion hotspot	Hotspot location (UTM)		Source of fine sediment	Relative erosion magnitude
	Easting	Northing		
1	742970	4322627	failing RB	moderate
2	743197	4322926	steep upland slope connected to channel	low
3	743282	4322916	steep upland slope connected to channel	low
4	743921	4323169	steep upland slope connected to channel	low
5	744241	4323216	LWD directs flow into bank	moderate
6	745249	4323685	reworking fluvial deposits	moderate
7	745619	4323681	reworking fluvial deposits	moderate
8	745629	4323739	reworking fluvial deposits	moderate
9	745700	4323704	undercutting bank	moderate
10	745754	4323657	LWD directs flow into bank	high
11	745844	4323719	reworking fluvial deposits	moderate
12	745847	4323738	LWD directs flow into bank	high
13	746343	4324405	undercutting bank	low
14	746465	4324516	2 m high failing bank	moderate
15	746522	4324617	undercutting bank RB	low
16	746795	4325174	2 m high failing RB	moderate
17	746822	4325269	4 m high failing RB	high

18	746883	4325295	undercutting RB	low
19	747003	4325339	3 m high failing RB	moderate
20	747124	4325348	2 m high failing RB	high
21	747351	4325529	2 m high failing RB	moderate
22	747419	4325686	2 m high failing LB	moderate
23	747546	4325803	7 m high failing R andLB	high
24	747663	4325847	reworking fluvial deposits	moderate
25	747815	4325894	8 m high failing RB	high
26	748066	4326128	5 m high failing RB	high
27	748351	4326221	1 m high failing RB	moderate
28	748671	4326305	LWD directs flow into bank	moderate
29	748772	4326278	20 m high failing bank	high
30	748895	4326329	20 m high failing bank	high
31	749609	4326427	undercutting LB	low
32	749770	4326559	LWD directs flow into bank	low
33	749829	4326641	undercutting RB	low
34	749831	4326678	failing LB	low

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

The boulder step-pool section begins about 0.3 km below the confluence of General Creek and the tributary from Lost Lake and runs 1.5 km to a trail crossing which marks the boundary into the canyon section. The boulder step-pool section is characterized by a steep gradient, bed and bank material varying in size from gravel to 3 m in diameter, dense dogwood and alder on the banks, and upland slopes attached to the channel without a floodplain. The overall fine sediment erosion potential from the banks is considered negligible due to the lack of fines available (Hotspots 6 to 1, Table 4-10).

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

Summary

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

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

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

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

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

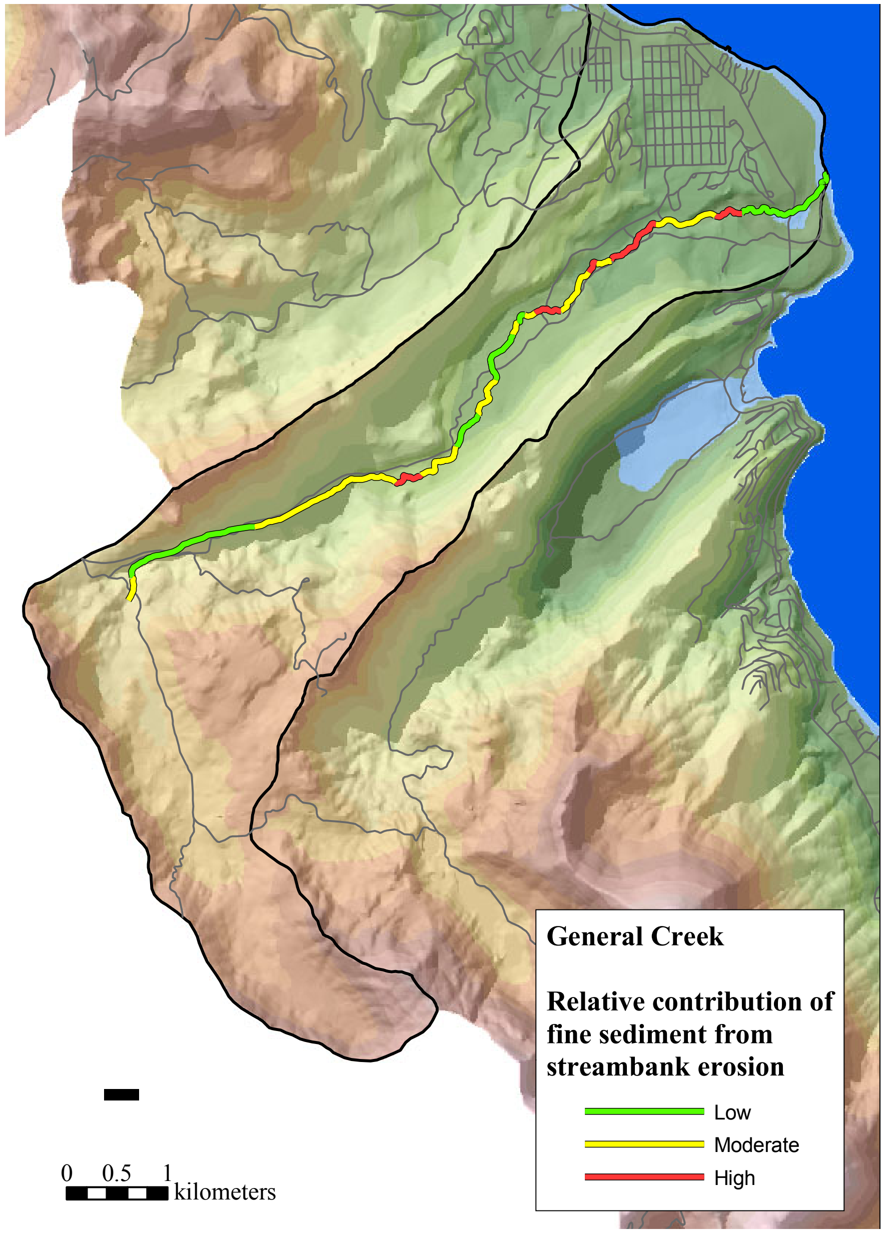


Figure 4-35. Map of the relative contribution of fine sediment from streambank erosion for General Creek.

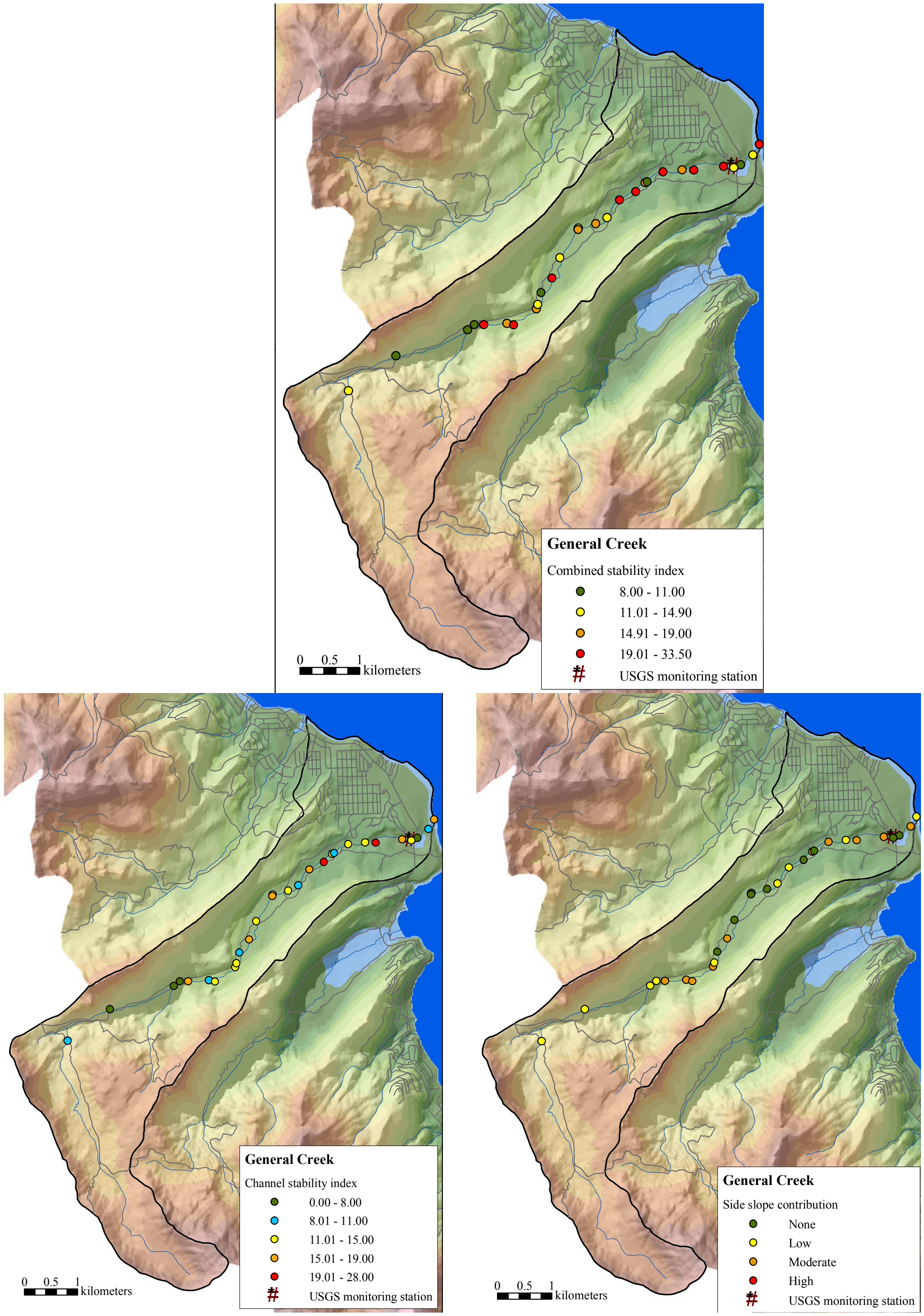


Figure 4-36. Results of rapid geomorphic assessments of General Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

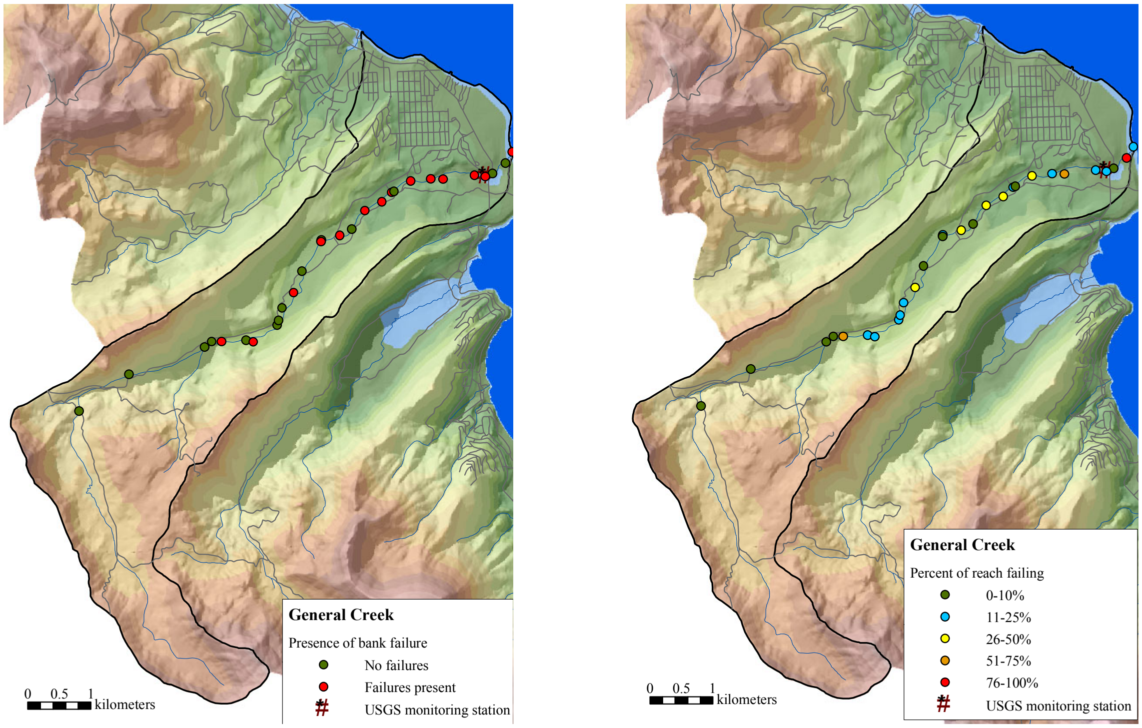


Figure 4-37. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along General Creek.

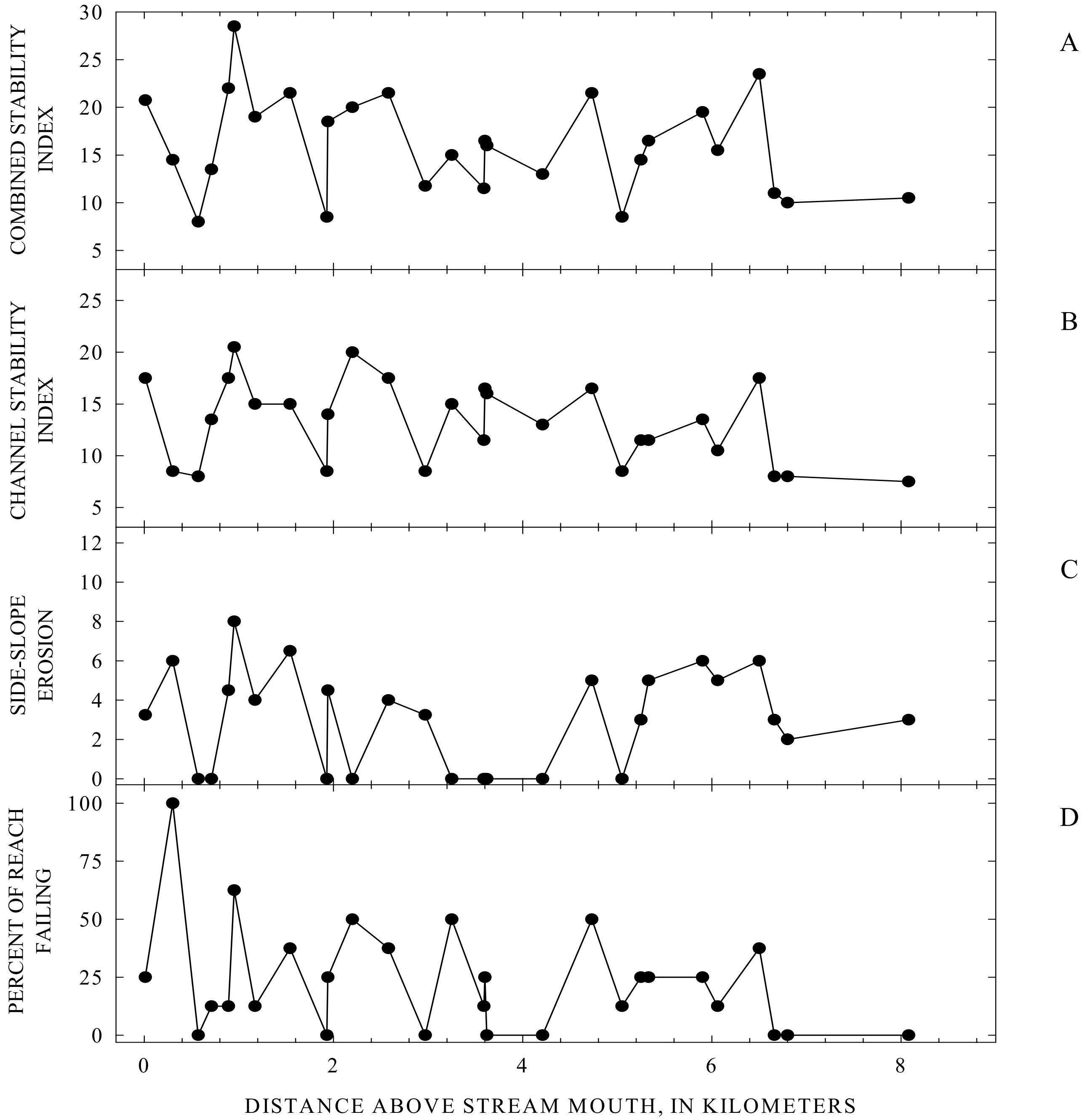


Figure 4-38. Results of RGAs conducted along General Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

4.6.5 Incline Creek

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

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

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

Table 4-11. Summary of reconnaissance-level evaluation of areas of streambank instability and delivery of fine-grained sediments along Incline Creek.

Erosion hotspot	Hotspot location (UTM)		Source of fine sediment	Relative erosion magnitude
	Easting	Northing		
1	766104	4351381	undercut banks	low
2	766142	4351303	bank scour at foot of boulder steps	low
3	766154	4351289	undercut banks	low
4	766176	4351263	undercut banks, bed slightly incised	low
5	766200	4351272	1 m high fill bank scoured at high flows	low
6	766236	4351236	veg removed from L bank and 1 m high banks eroding	moderate
7	766237	4351186	1 m high undercut and slumping banks	moderate
8	766221	4351143	0.5 m high eroding banks	moderate
9	766217	4351138	veg removed from L bank	moderate
10	766155	4351071	undercut L bank	low
11	766148	4350962	disintegrating granite bank	low
12	766212	4350879	disintegrating granite bank	low

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

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

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

Summary

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

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

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

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

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

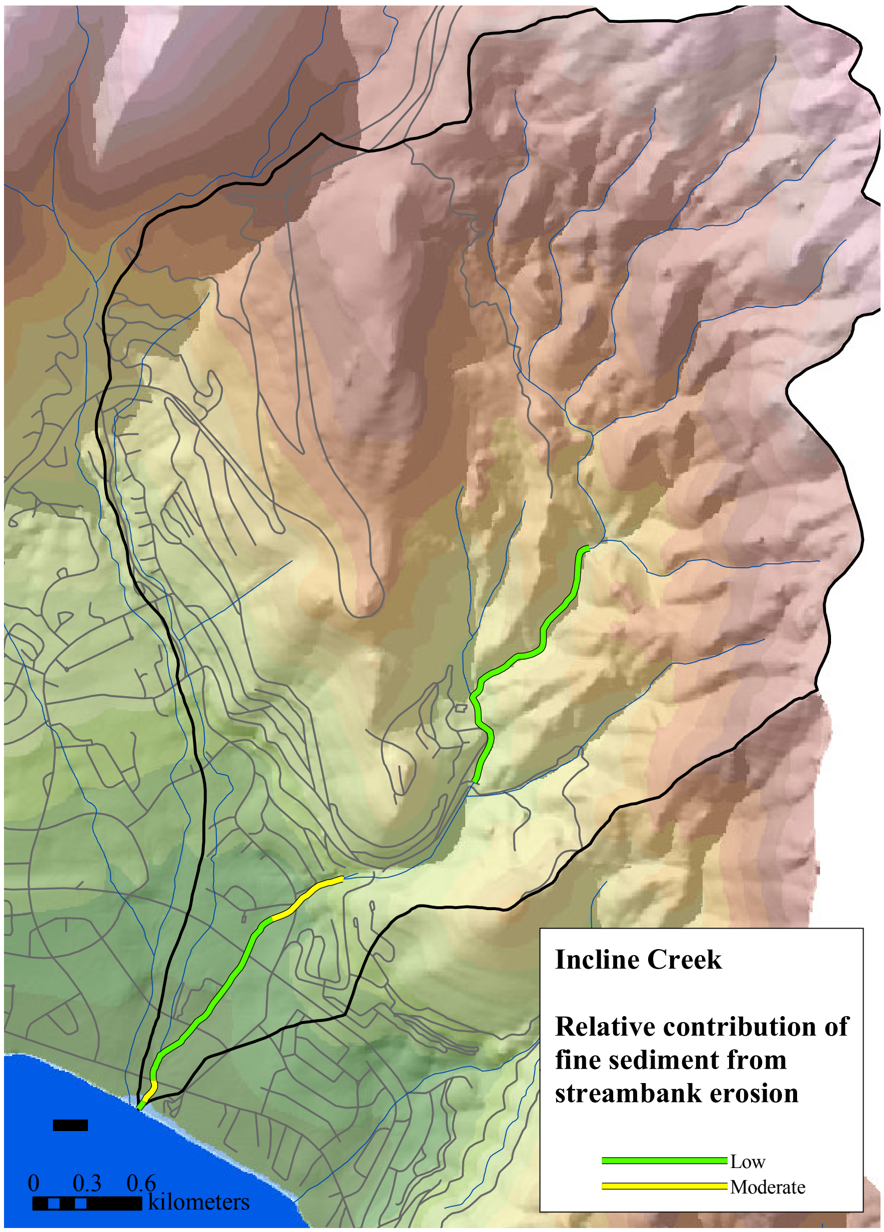


Figure 4-41. Map of the relative contribution of fine sediment from streambank erosion for Incline Creek.

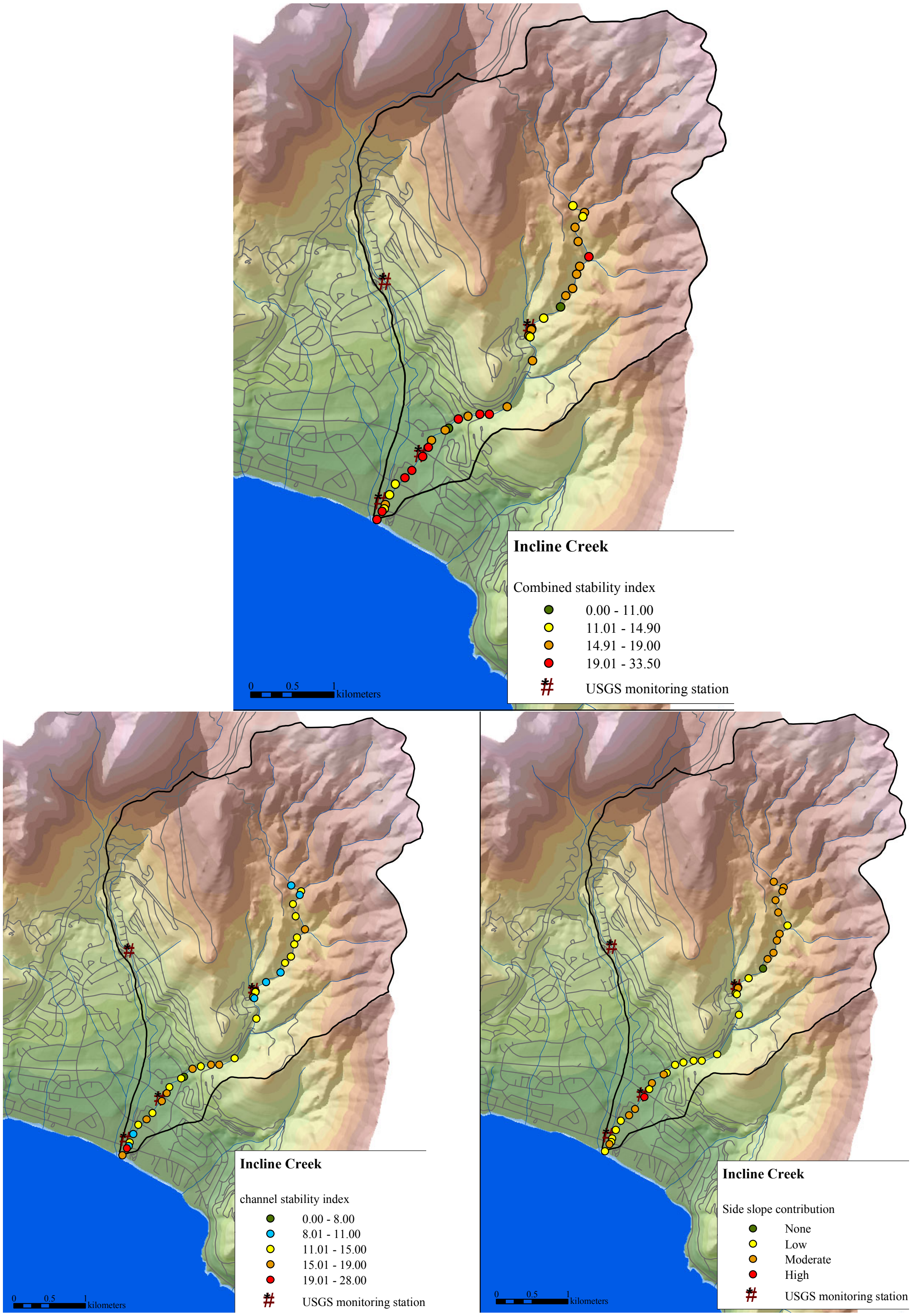


Figure 4-42. Results of rapid geomorphic assessments of Incline Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

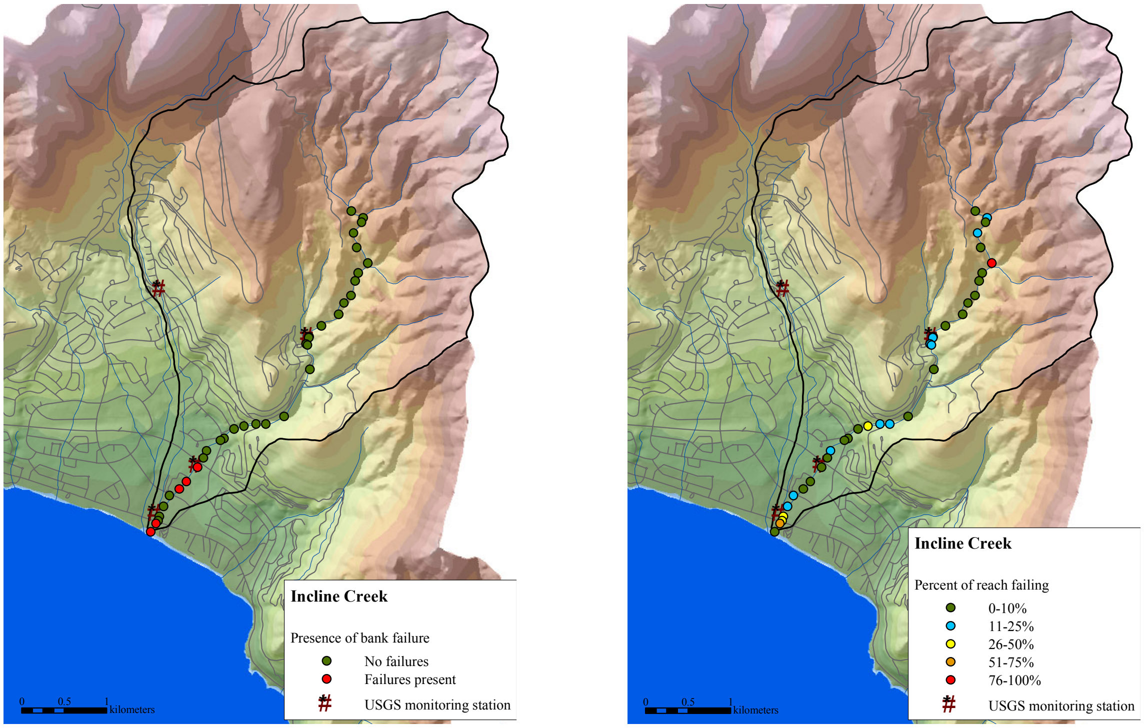


Figure 4-43. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along Incline Creek.

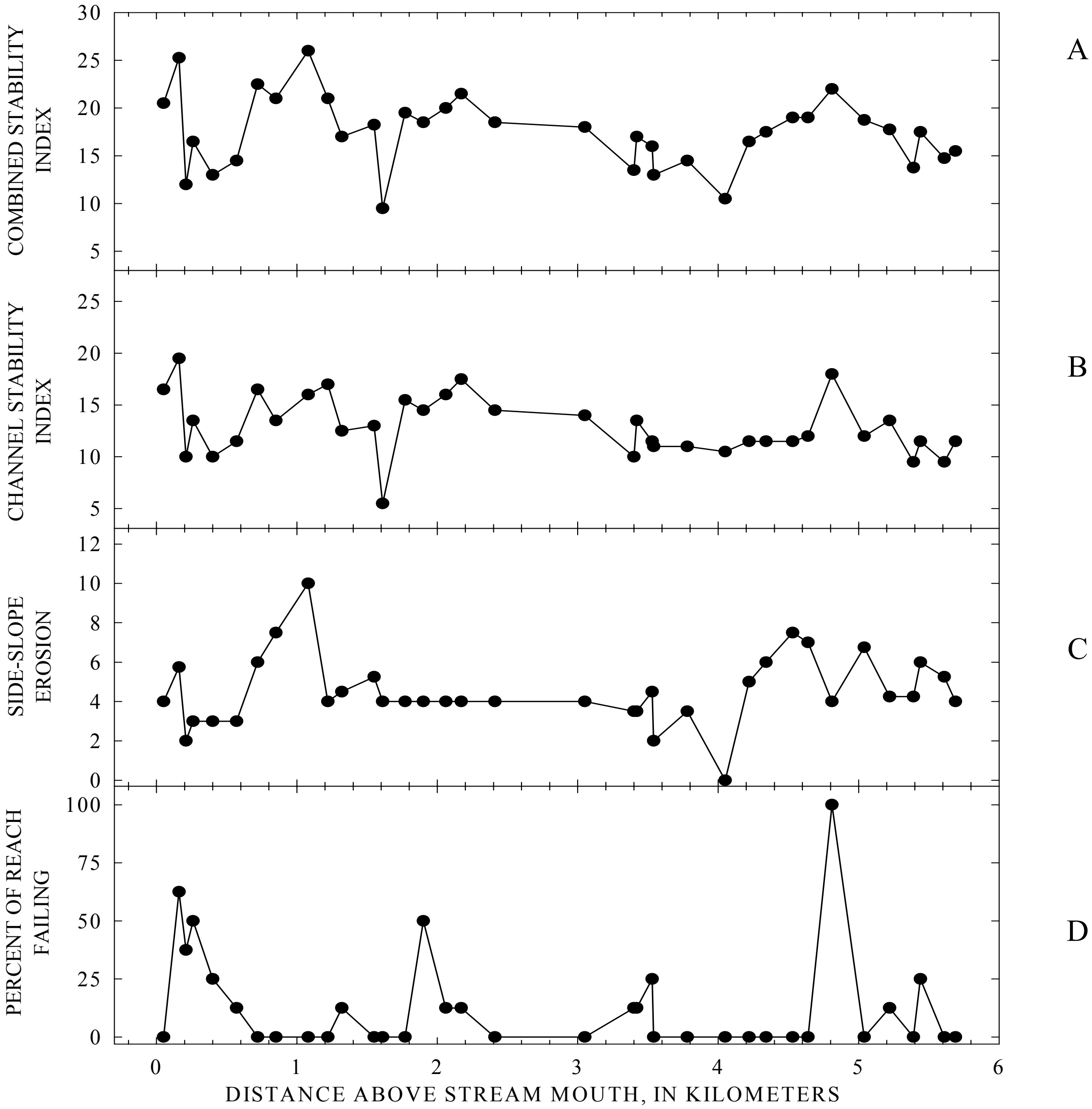


Figure 4-44. Results of RGAs conducted along Incline Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

4.6.6 Logan House Creek

The assessed portion of Logan House Creek covers 4.0 km and consists of three major reaches: an upper meadow reach, a colluvial valley, and a neighborhood reach (Figure 4-45). The upper meadow reach encompasses the first 1.5 km below the upper Forest Service road crossing. The channel crosses a gently cupped valley densely covered with aspen, willows and grass. Progressing downstream, the vegetation transitions into a pine forest with dense cover of alder, aspen, and grass in the riparian zone. Bank heights are less than 0.5 m, and vegetation on the bank edge is rooted all the way to the bank toes and prevents virtually any stream bank erosion from taking place.

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

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

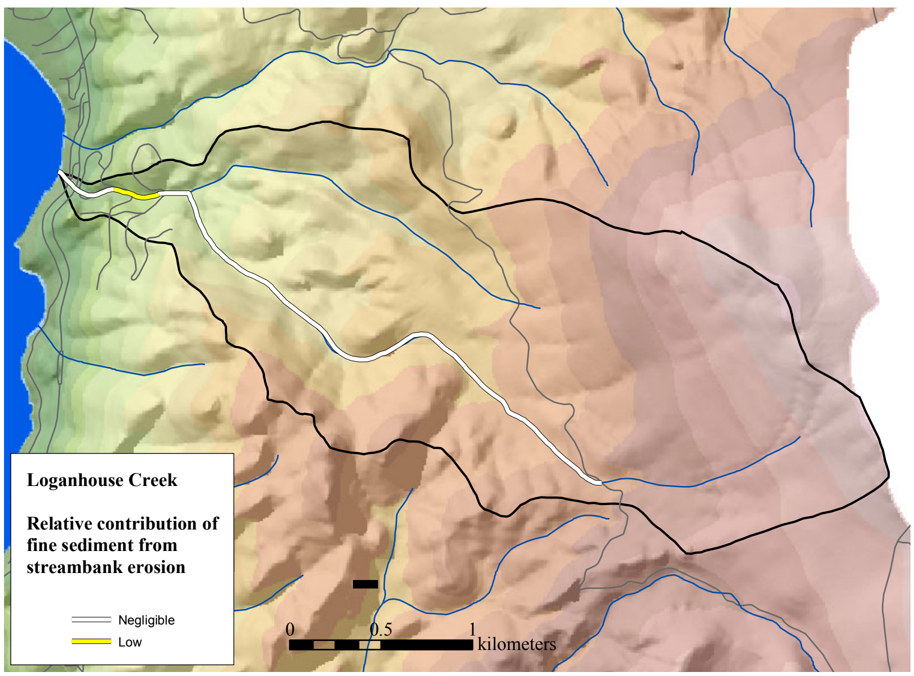


Figure 4-45. Map of the relative contribution of fine sediment from streambank erosion for Logan House Creek.

Summary

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

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

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

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

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

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

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

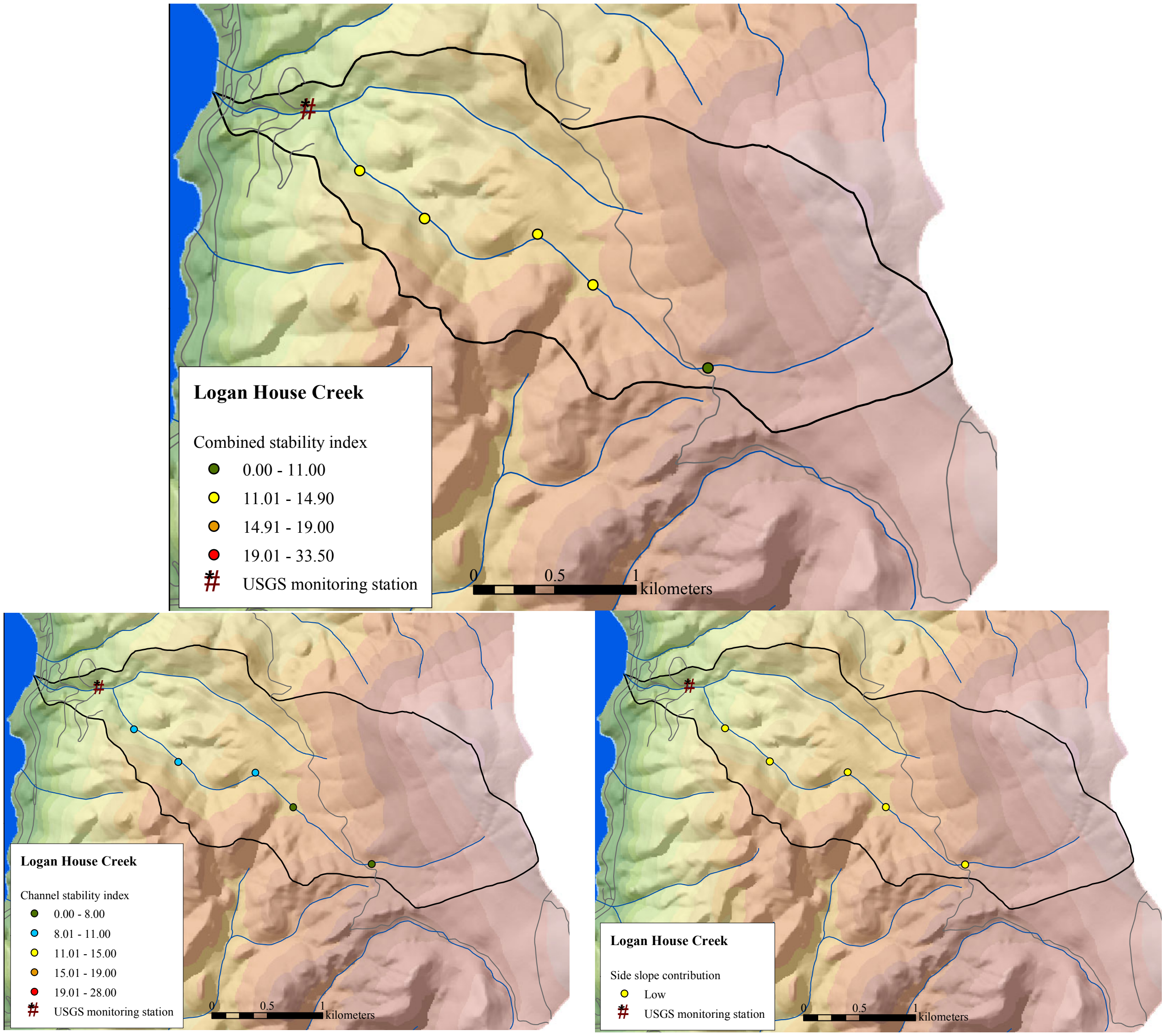


Figure 4-46. Results of rapid geomorphic assessments of Logan House Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

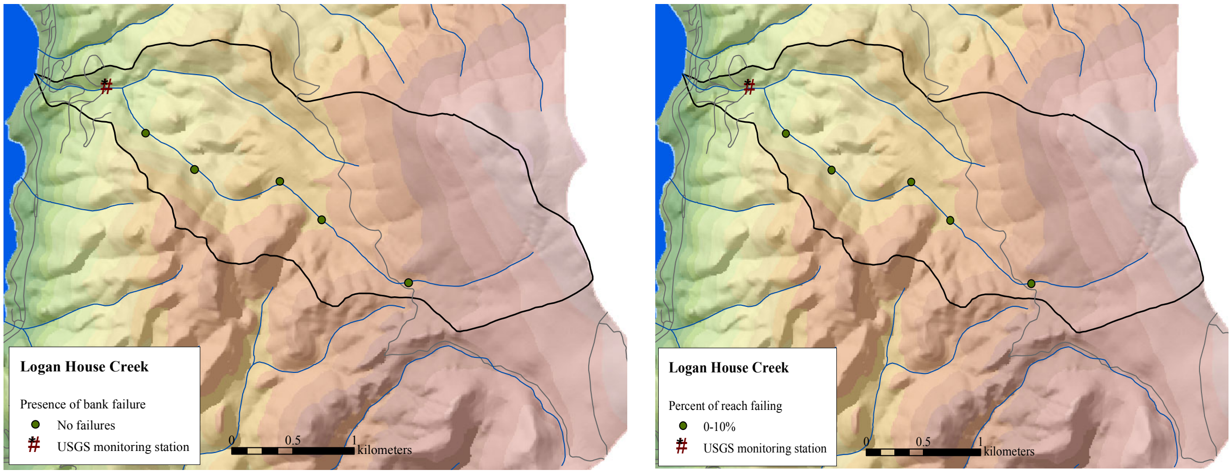


Figure 4-47. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along Logan House Creek.

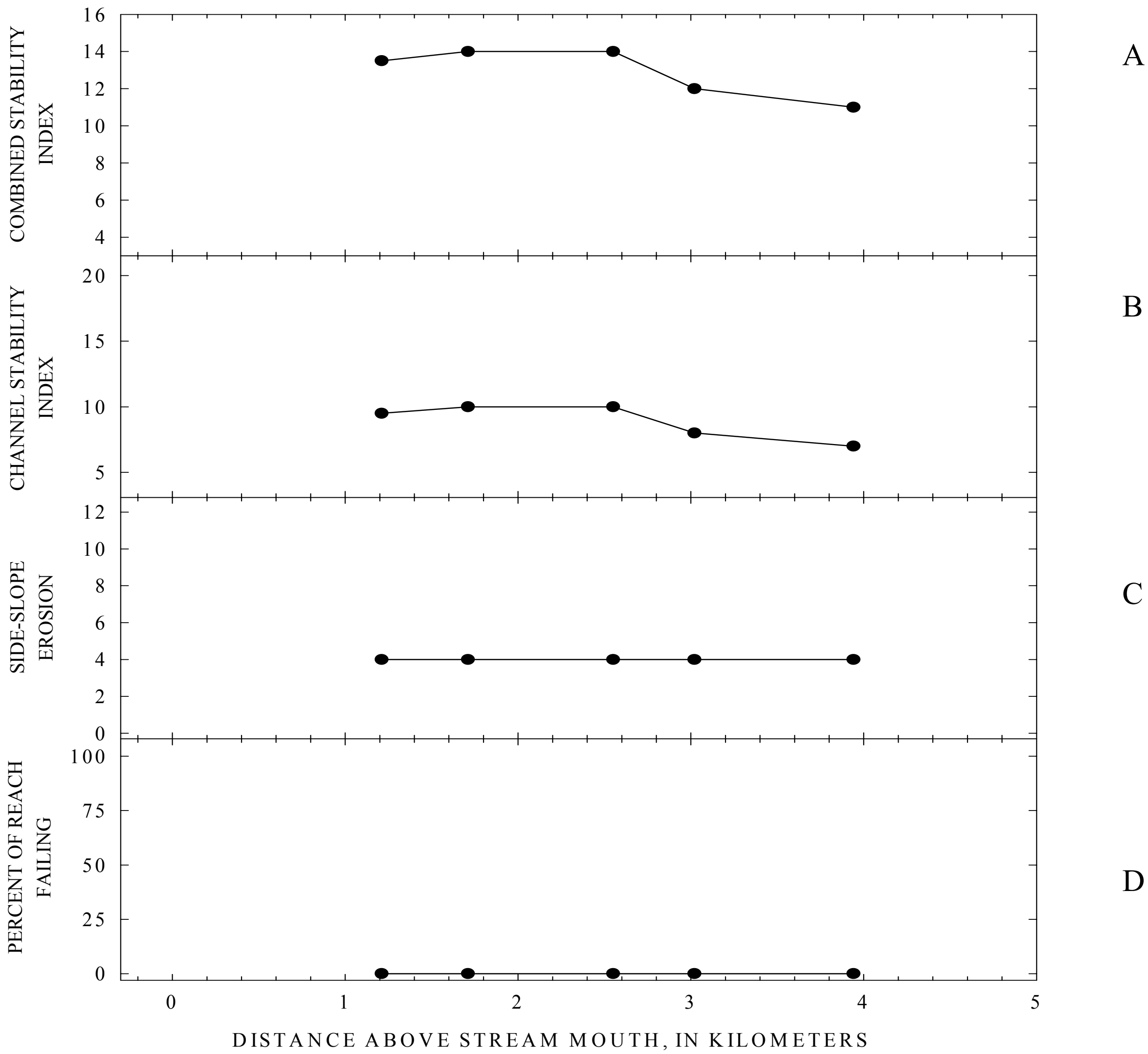


Figure 4-48. Results of RGAs conducted along Logan House Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

4.6.7 Edgewood Creek

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

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

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

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

Erosion hotspot	Hotspot location (UTM)		Source of fine sediment	Relative erosion magnitude
	Easting	Northing		
1	764449	4317360	None	low
2	765408	4317292	LWD induced scour	low
3	766549	4317041	0.7 m high failing banks	low
4	767358	4317353	0.5 m high eroding banks	low
5	768221	4317707		low

6	768513	4318230	Erosion on both banks	moderate
7	769064	4318842	Fines eroding from both banks	low
8	769227	4317449		low
9	769444	4317516		low
10	769594	4319113	Both banks eroding	moderate
11	769594	4319113	Left bank mass wasting	moderate
12	769594	4319113		low

Summary

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

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

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

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

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

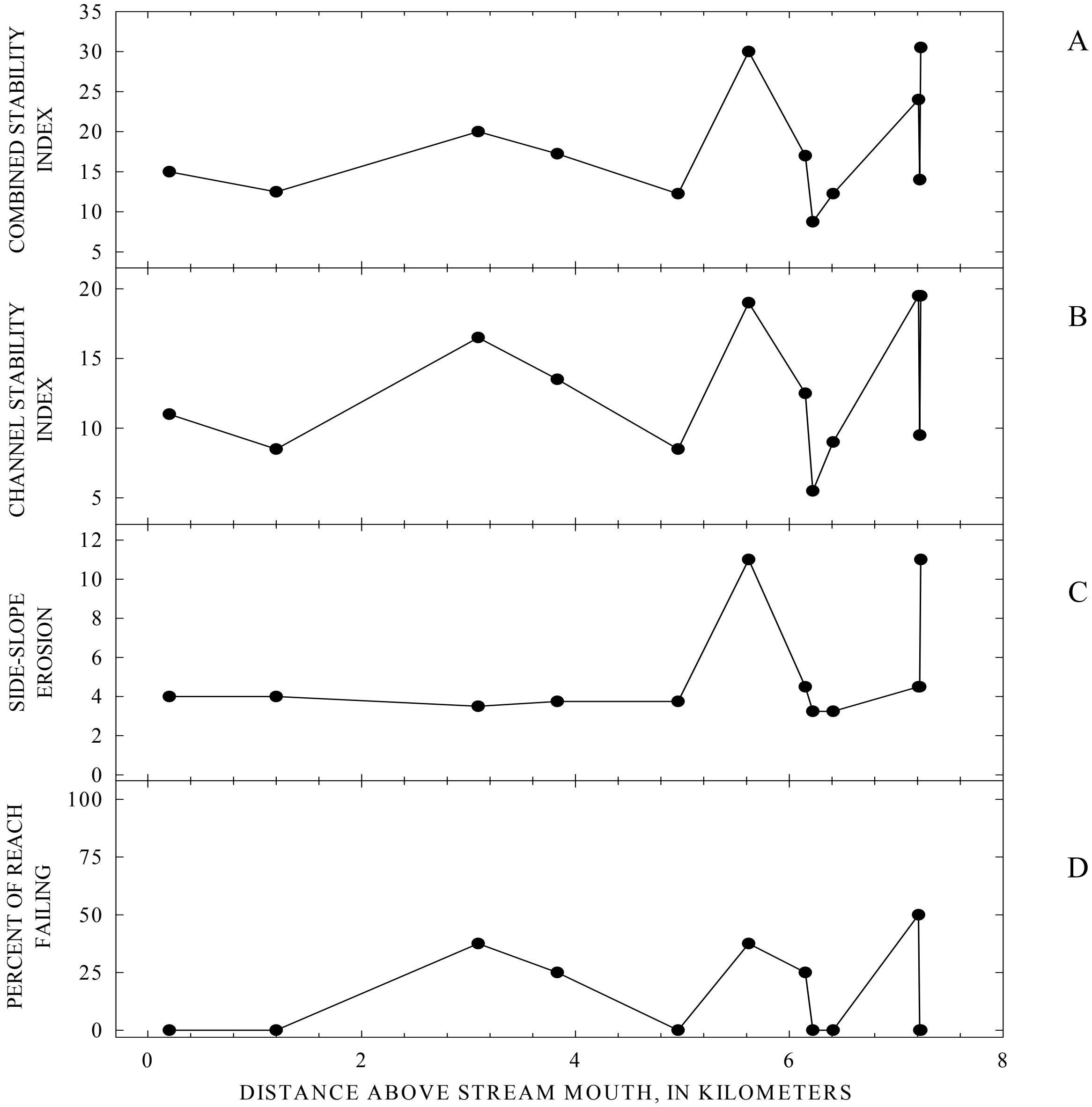


Figure 4-49. Results of RGAs conducted along Edgewood Creek showing the longitudinal distribution of the combined, channel and side-slope erosion indexes, and the percent of reaches undergoing streambank failures.

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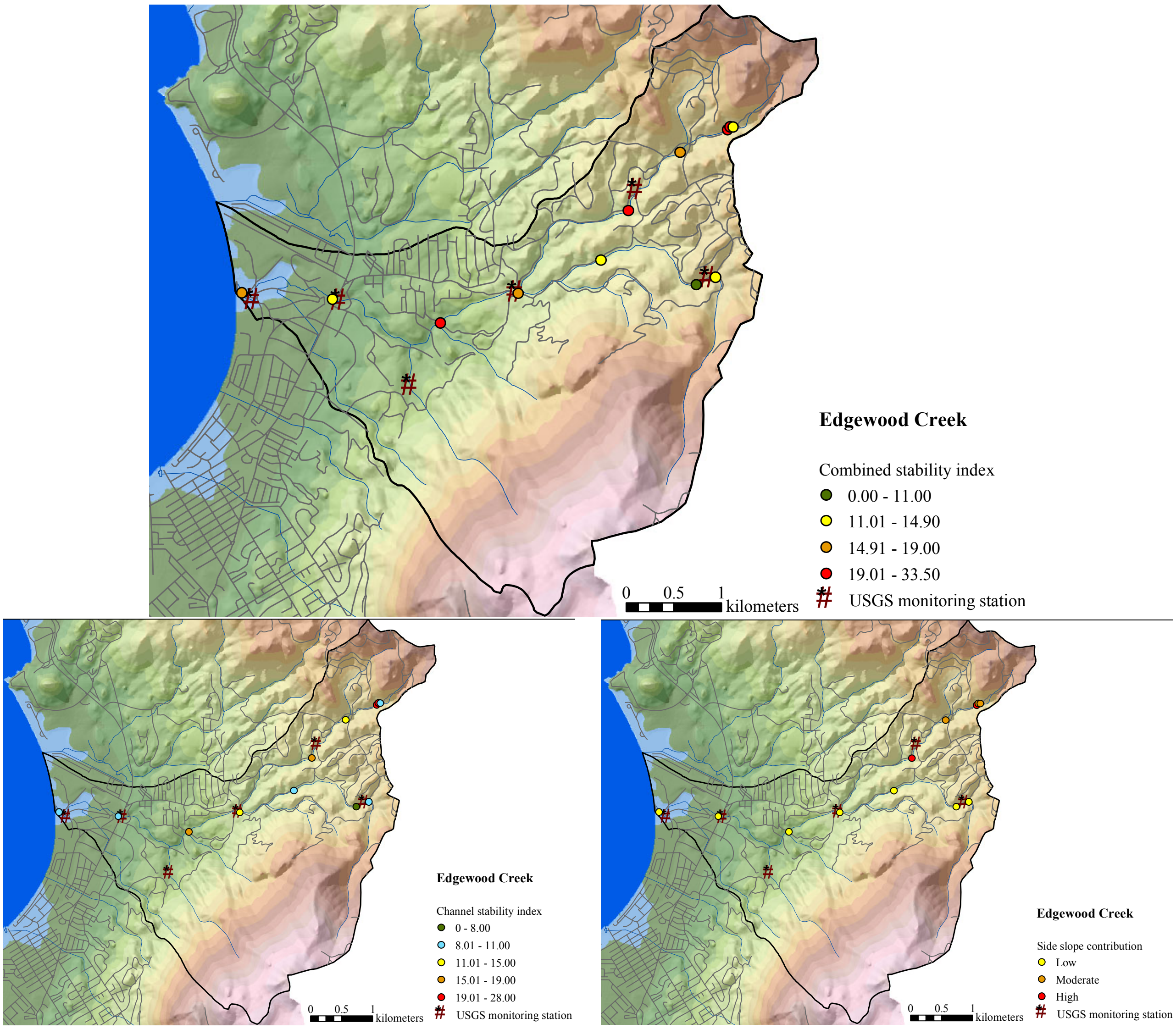

Figure 4-50. Results of rapid geomorphic assessments of Edgewood Creek showing the relative contributions of channel- and side-slope indexes to the combined stability index and critical erosion areas.

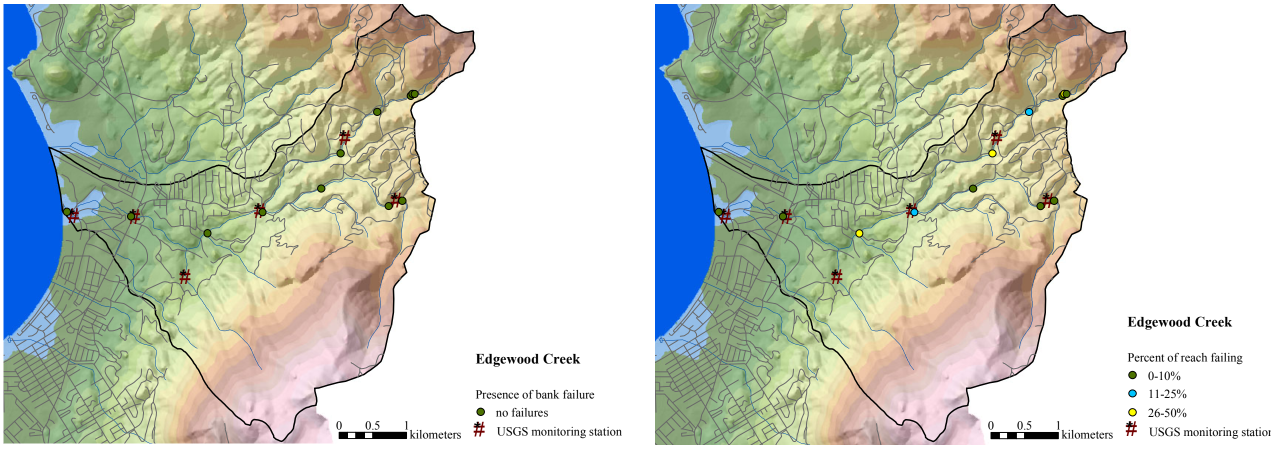

Figure 4-51. Presence or absence of bank failures and the percent of the longitudinal extent of left and right banks undergoing active mass-wasting processes along Edgewood Creek.

4.7 Basin-Wide Evaluations of Channel Conditions

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

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

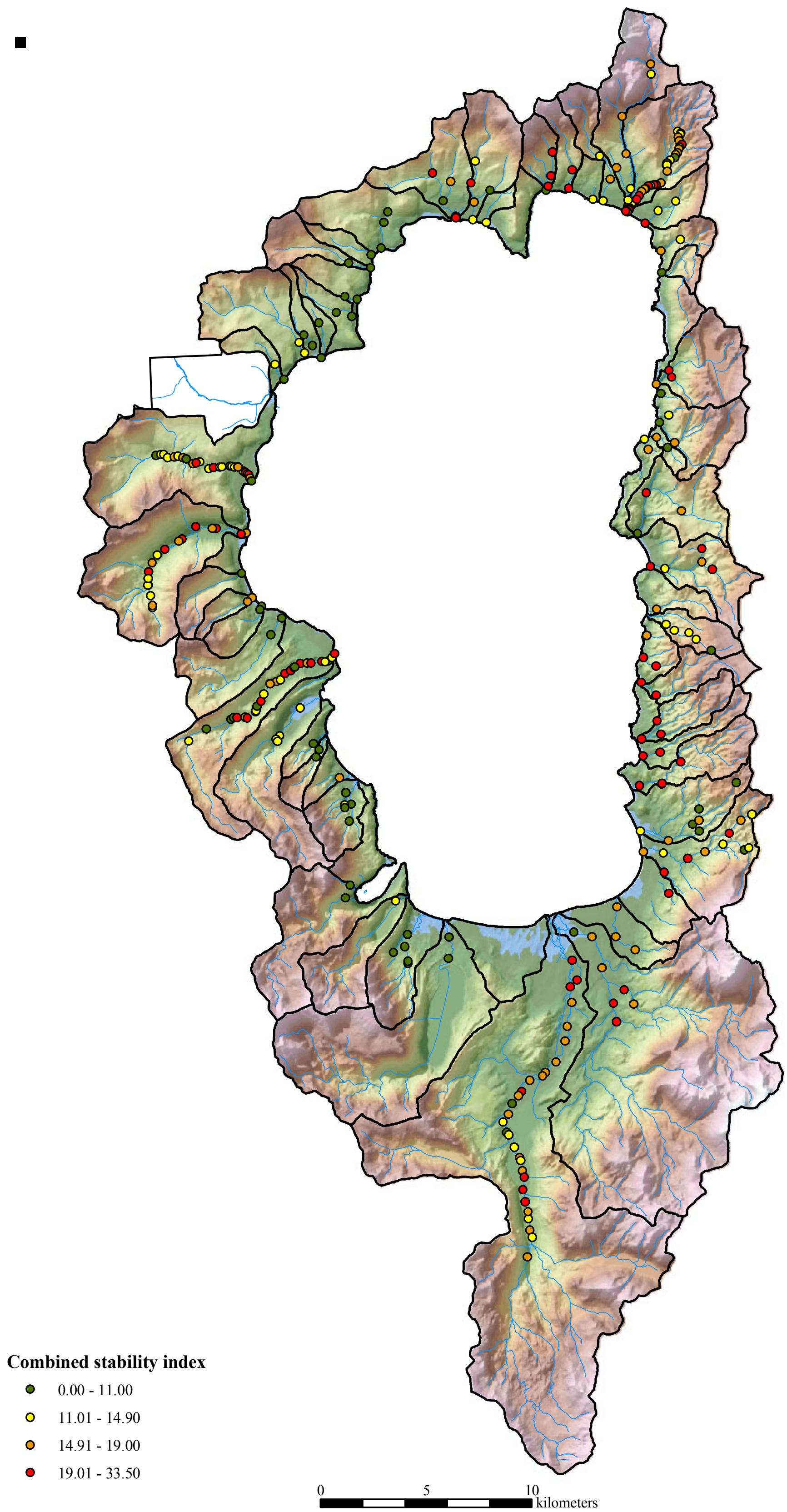

Figure 4-52. Spatial distribution of combined stability index for 304 sites.

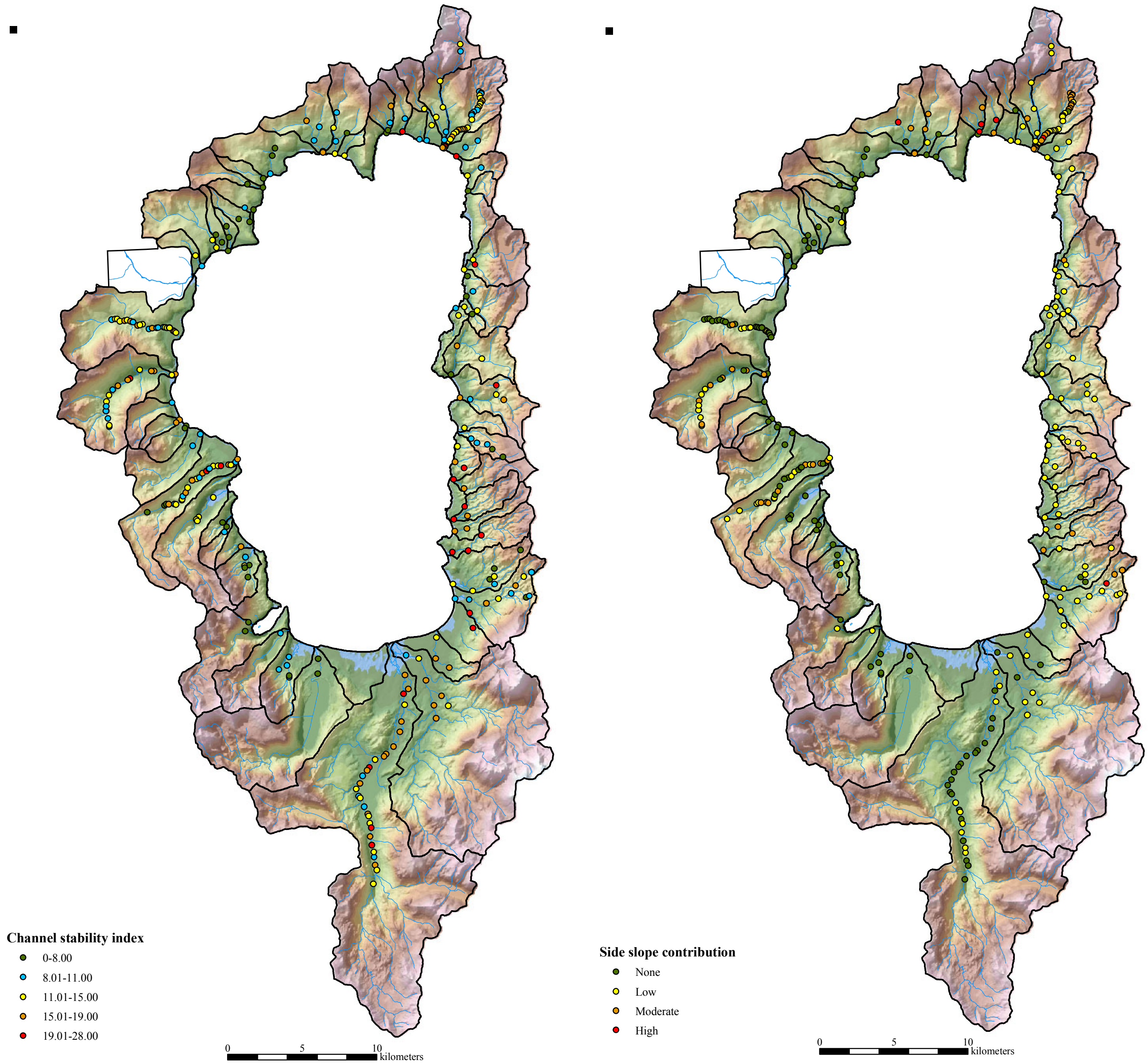

Figure 4-53. Channel-stability (left) and side-slope erosion indexes (right) used to distinguish relative contributions of sediment.

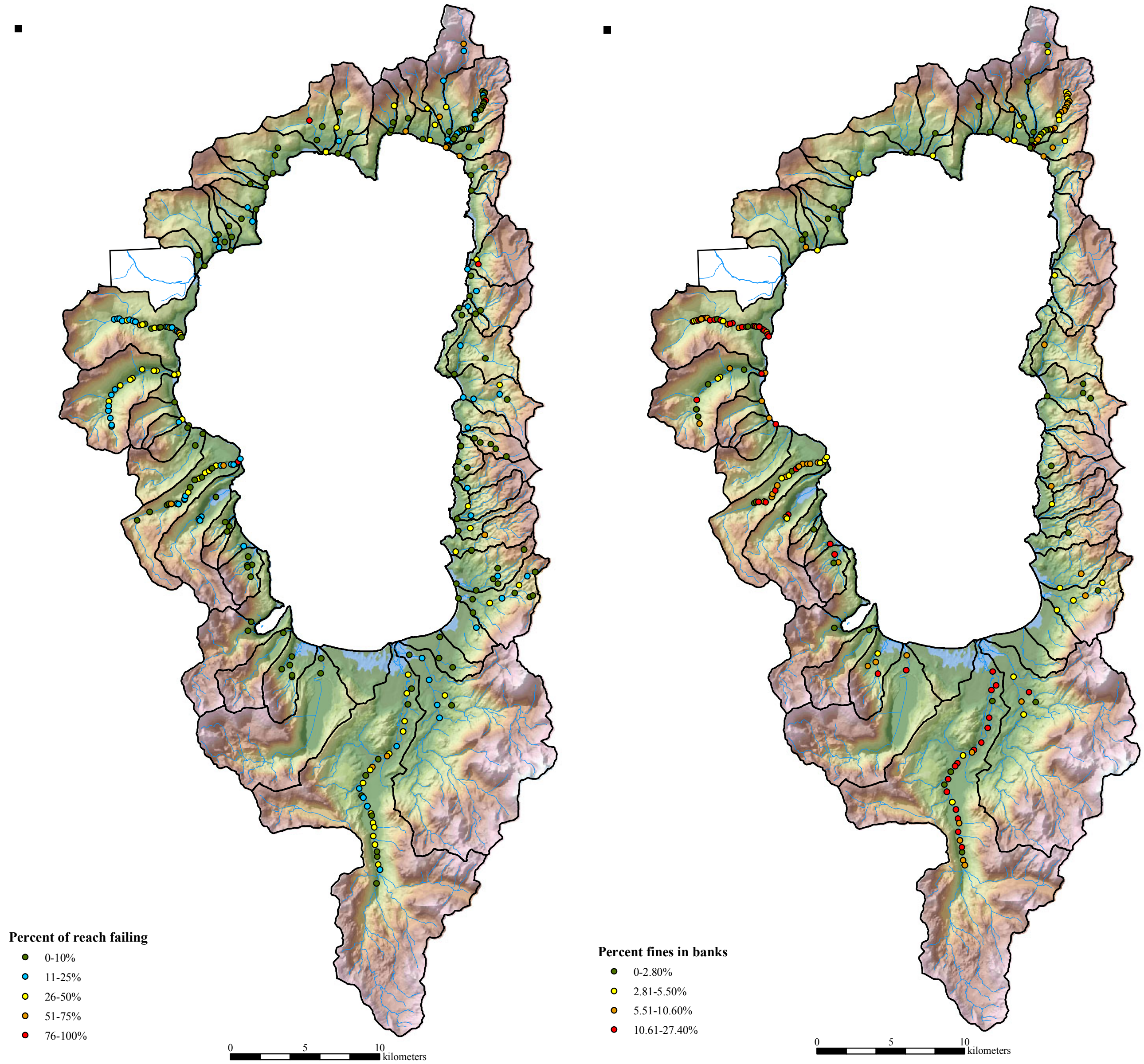

Figure 4-54. Percent of left and right banks that are failing (left), and the relative fine-grained (silt plus clay) content in the streambanks (right) to be used collectively as a measure of fine-sediment contributions from eroding streambanks.

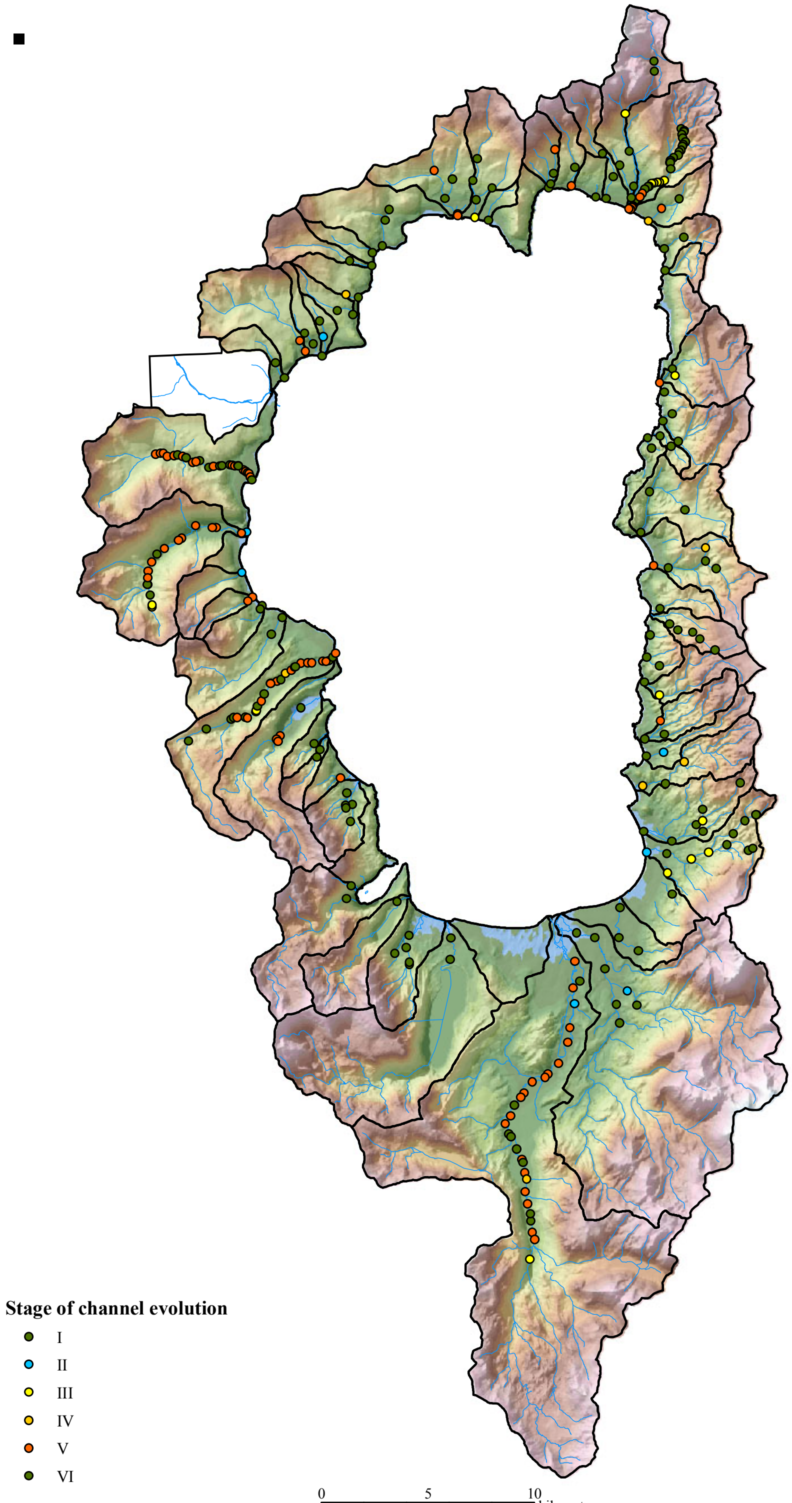

Figure 4-55. Spatial distribution of stages of channel evolution. Stages I and VI are indicative of stability; stages IV and V are indicative of degradation and widening, and aggradation and widening, respectively.