6.0 GIS ANALYSIS OF EROSION POTENTIAL FROM UPLAND AREAS

6.1 Introduction

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

6.2 Data Availability and Preparation

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

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

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

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

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

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

6.2.1 Soil-erodibility factor (*k*-factor)

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

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

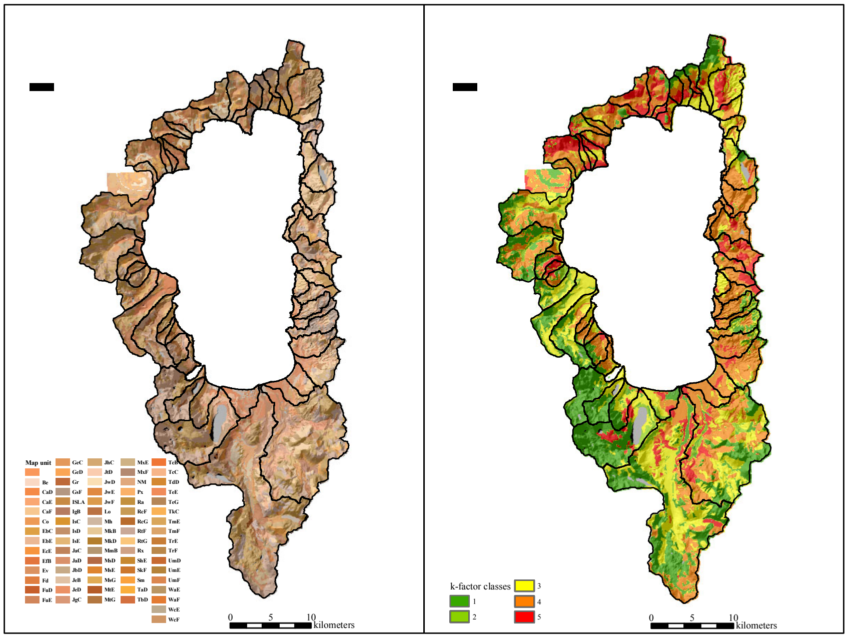

Figure 6-1. Distribution of soils categories (left) and assigned class values for soil-erodibility (*k*-factor) (right).

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

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

6.2.2 Landuse

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

Table 6-2. Landuse/landcover classification levels (LULC).

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

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

Table 6-3. Landuse/landcover erodibility potential.

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

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

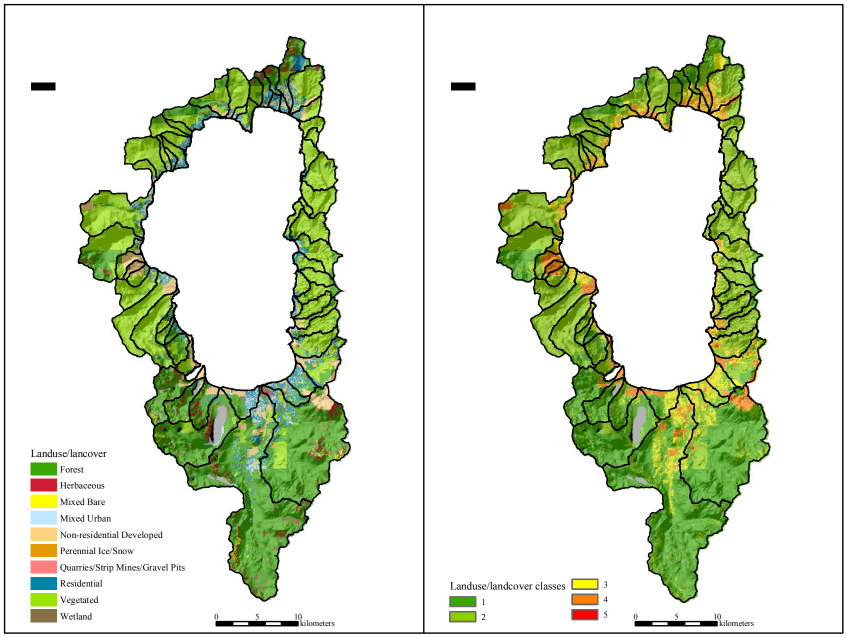

Figure 6-3. Distribution of landuse/landcover (left) and assigned class values for potential erodibility based on the characteristics shown in Table 6-3 (right).

6.2.3 Paved and Unpaved Roads, Trails and Streams

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

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

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

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

6.2.4 Surficial Geology

Data on the surficial geology of the Lake Tahoe Basin included a digital geologic map of the basin. This digital map, represented by a vector layer, contained detailed descriptions of geology grouped into four main rock types: volcanic, glacial, granitic and alluvial. The erodibility value assigned to each of these simple geologic types are listed in Table 6-5 while the spatial distribution is shown in Figure 6-4.

Table 6-5. Geology-erodibility classes.

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

Granites, granodiorites and metamorphics predominate in most of the east, southeast and parts of the southwest slopes of the basin and have been assigned the lowest erodibility index. Glacial terrains that cover the northwest and part of the south of the basin along the Upper Truckee River Watershed have an intermediate erodibility index. Alluvium, mostly concentrated at the lowlands and outlets of most watersheds principally in the south where they cover an extensive area, the northwest and the north parts of the lake were assigned a higher erodibility potential. Volcanic breccia mostly present in the slopes of Ward, Blackwood, the southernmost tip of Upper Truckee River watersheds and several other watersheds in the north and northeast parts of the basin were assigned the highest erodibility index. This determination was based on suspended-sediment yields from headwater areas of Ward Creek (10336670) that contain unvegetated slopes of this material, and because it has been suggested that they are an important contributor of sediment in Ward and Blackwood watersheds (Stubblefield, 2002).

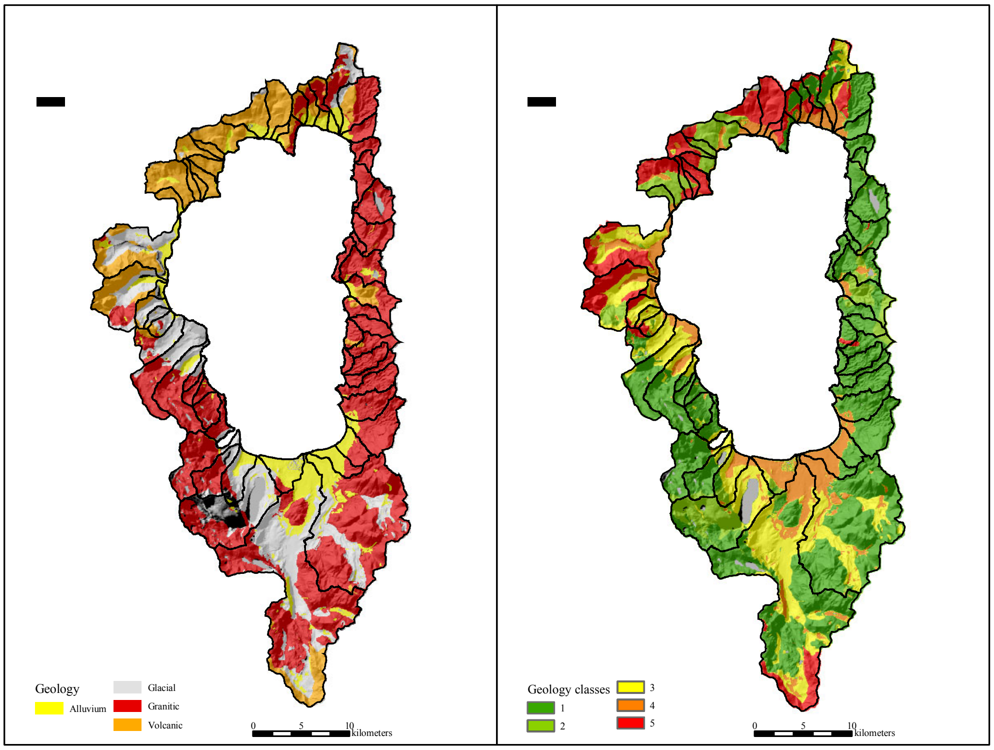

Figure 6-4. Distribution of surficial geology (left) and assigned class values for potential erodibility based on the characteristics shown in Table 6-5 (right).

6.2.5 Slope Steepness

A raster layer that represents topography in the Lake Tahoe Basin was created from a 10 by 10 m resolution USGS digital elevation model (DEM). The units of the digital elevation model showed elevation in feet and were converted to meters to be consistent with the technical literature and the use of metric units in this study. The new metric DEM was used to produce the slope raster used in the analysis (Figure 6-5). Values of elevation of the new raster varied from approximately 1875 to 3320m. Slope was derived from the DEM with angles that ranged from 0 to 72.5 degrees (Table 6-6).

Table 6-6. Slope classes for the Lake Tahoe Basin.

Slope intervals (degrees)	Assigned slope erodibility class
0-14.5	1
14.5-29.0	2
29.0-43.5	3
43.5-58.0	4
58.0-72.5	5

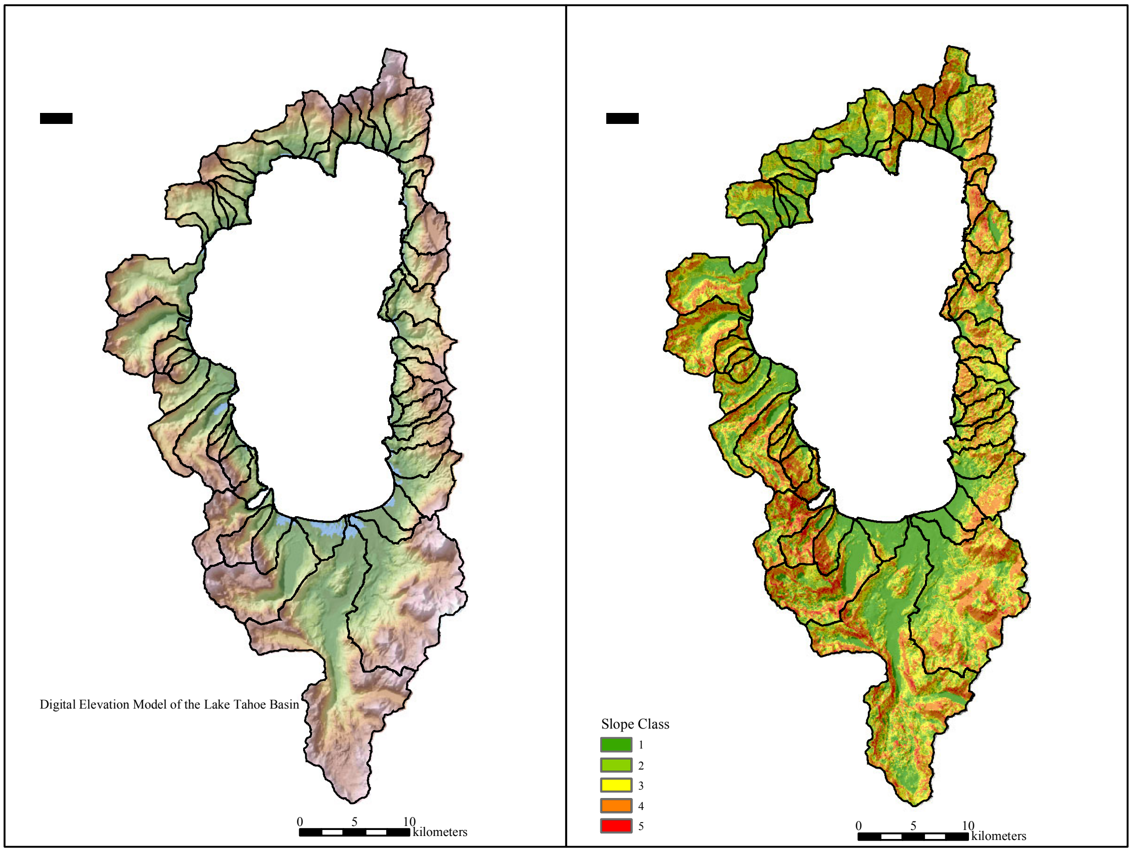

Figure 6-5. The digital elevation model (left) used to derive the slope-steepness layer (right) for the Lake Tahoe Basin.

6.2.6 Mean-annual precipitation

Basinwide data on precipitation characteristics was not readily available, as this study was to use data based on a simulation model being developed concurrently by others. To overcome this obstacle, mean-annual precipitation was screen-digitized from an isopluvial paper map created by Sierra Hydrotech (Sierra Hydrotech, 1986). A point- vector layer was created representing the isopluvial lines (Figure 6-6). Precipitation lines vary from 17 to 80 inches per year in intervals of 3, 5 and 10 inches per year. After all points of an isopluvial line were digitized, the corresponding precipitation value was assigned (Table 6-7). Then, the precipitation layer was completed and a raster representing precipitation was created after conversion of the data to millimeters (Figure 6-6).

Table 6-7. Mean-annual precipitation classes in the Lake Tahoe Basin.

Mean-annual precipitation isopluvial lines	Mean-annual precipitation intervals	Mean-annual precipitation class
17	2-17.6	1
20, 25, 30	33.2	2
35, 40	48.8	3
50, 60	64.4	4
70, 80	80	5

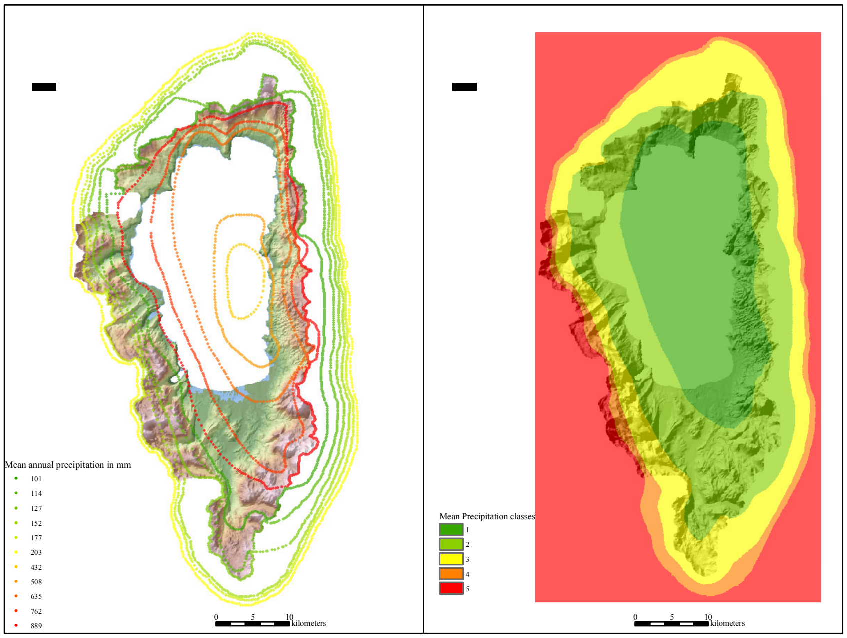

Figure 6-6. Isopluvial lines representing mean-annual precipitation for the Lake Tahoe Basin. Original data digitized from hard copy of Sierra Hydrotech (1986).

6.3 Merging Data Classes: Upland Erosion-Potential Map

Classed data from each of the five parameters were summed for each 10 by 10 m raster providing an upland-erosion potential value for every 100m^2 area of the entire basin. The sum of the minimum values of erosion potential was 5, and the maximum 25. The graphic result of the sum of raster layers was a map showing areas of varying degrees of upland-erosion potential (Figure 6-7). This map was reclassified and converted to a 1 to 5 scale. Finally, the raster layer was converted to a feature, or vector layer to determine the areas of each of the erosion-potential classes within a given watershed or upstream of a given gaging station. This conversion was made to determine the area that each individual class (1, low erosion potential to 5, high erosion potential) occupied over the entire basin and within each individual watershed. The highest upland-erosion potentials are colored in red with the next highest in orange and yellow, respectively and can be used to identify potentially critical areas (Figure 6-7). Two of the densest concentrations of the high erosion-potential index are in the Homewood and Madden Creek watersheds on the western side of the lake.

The two highest erosion classes were used subsequently to test relations with gaged suspended-sediment loads from index stations. The percent of each watershed area covered in these latter two classes are shown in Table 6-8 ranked from highest percentage to lowest.

Figure 6-7. Map of upland-erosion potential for the Lake Tahoe Basin obtained by summing the classed values of each of the five selected parameters and reclassifying at a scale of 1 to 5. Areas colored in red and orange represent zones of high upland-erosion potential.

6.3.1 Basinwide distribution

The map of upland-erosion potential (Figure 6-7) provides insights into differences in upland–erosion potential across the Lake Tahoe Basin. Some of these, such as the generally green areas (lowest classes) in the eastern quadrant were to be expected as this represents the dry side of the lake where suspended-sediment yields are low. Similar areas, such as in the southwest part of the basin are consistent with the generally low suspended-sediment yields emanating from these watersheds (and documented in Chapter 3. Areas of high upland-erosion potential are concentrated in the northwest parts of the basin, particularly in headwaters areas of Burton, Ward and Blackwood Creeks, as well as in the Homewood and Madden Creek watersheds. Sizeable high erosion-potential areas are also depicted in Third Creek and several other northern quadrant streams.

6.3.2 Determination of Areas Covered By Erosion Classes

Conversion of erosion-class data to areas simplified subsequent analysis between upland-erosion potential and suspended-sediment transport rates calculated from measured flow and sediment-concentration data. Areas occupied by each erosion-potential class were determined within individual watersheds and above gaging stations. Initially, the raster was converted to a vector layer using the convert raster to feature function. This conversion created polygons representing erodibility classes for the entire basin. Secondly, this new vector layer was intersected with the watershed outline layer creating a new set of polygons representing erodibility classes separated by watershed. The areas of each erosion class within a given watershed were added to determine whether the total area calculated by the ArcView zonal-statistics analysis corresponded to the actual area of the watershed. Table 6-8 lists the 63 watersheds draining Lake Tahoe in decreasing order of the percentage of their basin area covered by high erosion classes 4 and 5 (orange and red areas; Figure 6-7).

Table 6-8. Percentage of the area of each watershed draining to Lake Tahoe covered by the two highest upland-erosion potential classes (percentage of red plus orange areas in Figure 6-7).

Watershed	Percent class 4	Percent class 5	Percent of two highest classes
HOMEWOOD CREEK	68.3	4.34	72.7
KINGS BEACH	67.7	0.00	67.7
DOLLAR CREEK	65.5	0.57	66.1
GRIFF CREEK	57.2	0.07	57.2
BARTON CREEK	44.8	5.98	50.7
EAGLE ROCK	47.3	0.00	47.3
BURTON CREEK	43.5	3.29	46.8
MADDEN CREEK	43.4	2.79	46.2
WARD CREEK	40.1	2.82	43.0
LAKE FOREST CREEK	42.0	0.00	42.0

EAST STATELINE POINT	38.0	0.00	38.0
WATSON	37.5	0.38	37.9
TAHOE VISTA	37.4	0.07	37.5
SECOND CREEK	26.7	0.52	27.2
BLACKWOOD CREEK	26.3	0.92	27.2
QUAIL LAKE CREEK	26.0	0.93	26.9
BURNT CEDAR CREEK	25.7	0.45	26.2
FIRST CREEK	23.0	0.00	23.0
CEDAR FLATS	22.5	0.00	22.5
INCLINE CREEK	18.7	0.91	19.7
CAMP RICHARDSON	11.6	0.00	11.6
BIJOU CREEK	8.4	0.00	8.4
CARNELIAN CANYON	7.9	0.00	7.9
UPPER TRUCKEE RIVER	7.9	0.00019	7.9
MKINNEY CREEK	6.7	0.08	6.8
CAVE ROCK	6.1	0.39	6.5
WOOD CREEK	5.1	0.03	5.1
CARNELIAN BAY CREEK	4.6	0.00	4.6
TALLAC CREEK	4.6	0.00	4.6
GENERAL CREEK	3.7	0.00	3.7
BLISS STATE PARK	3.6	0.04	3.6
THIRD CREEK	3.6	0.00	3.6
EAGLE CREEK	3.4	0.02	3.4
LINCOLN CREEK	3.3	0.00	3.3
BIJOU PARK	2.8	0.00	2.8
GLENBROOK CREEK	2.5	0.00	2.5
TAHOE STATE PARK	2.5	0.00	2.5
SIERRA CREEK	2.3	0.00	2.3
PARADISE FLAT	2.1	0.00	2.1
SECRET HARBOR CREEK	2.0	0.00	2.0
CASCADE CREEK	1.5	0.00	1.5
RUBICON CREEK	1.4	0.00	1.4
EDGEWOOD CREEK	1.2	0.00	1.2
TAYLOR CREEK	1.1	0.00098	1.1
MEEKS	1.1	0.00	1.1
TROUT CREEK	0.7	0.00	0.7
SLAUGHTER HOUSE	0.3	0.00	0.3
MARLETTE CREEK	0.2	0.00	0.2
LONELY GULCH CREEK	0.1	0.00	0.1
BURKE CREEK	0.1	0.00	0.1
NORTH LOGAN HOUSE CREEK	0.1	0.00	0.1

MILL CREEK	0.0	0.00	0.0
BLISS CREEK	0.0	0.00	0.0
BONPLAND	0.0	0.00	0.0
DEADMAN POINT	0.0	0.00	0.0
LOGAN HOUSE CREEK	0.0	0.00	0.0
MCFAUL CREEK	0.0	0.00	0.0
NORTH ZEPHYR CREEK	0.0	0.00	0.0
SAND HARBOR	0.0	0.00	0.0
SKYLAND	0.0	0.00	0.0
TRUCKEE RIVER	0.0	0.00	0.0
TUNNEL CREEK	0.0	0.00	0.0
ZEPHYR CREEK	0.0	0.00	0.0

6.3.3 Results

Interpretation of data describing the upland-erosion potential index centers on comparing suspended-sediment transport data calculated at gaging stations with the percentage of high-erosion potential classes (percentage of red areas plus orange areas in Figure 6-7) in each basin or upstream of each gaging station. Similar regression characteristics wrere obtained when working with several variables representing annual suspended-sediment transport rates such as load (T/y), yield (T/km^2), and concentration (g/m^3) for both index stations and for areas above all gaging stations. In all cases, three stations plotted anomalously above the fitted regression: Blackwood Creek, Ward Creek and Third Creek, all having substantial contributions from channel sources. The most encouraging results were obtained using suspended-sediment transport data from all stations with median, annual data expressed as annual yields (Figure 6-8); $r^2 = 0.63$. It seems from the data in Figure 6-8 that there may be a threshold value or range of values above which the processes represented by the upland-erosion potential index effects downstream sediment-transport rates causing higher transport.

Readers should be cautioned that the relation depicted in Figure 6-8 should not be used for predictive purposes. Still, the basinwide map of the upland erosion-potential index is useful as a general guide to help identify areas that can produce significant quantities of suspended sediment to Lake Tahoe streams.

6.3.4 Limitations of Analysis

A potential problem with one of the underlying assumptions of the analysis in relating the upland-erosion potential index with gaged sediment-transport rates is that upland sources will make up an unknown proportion of downstream sediment loads with the remainder emanating from channel sources. Thus, watersheds with high channel-erosion rates relative to upland contributions may not regress well with an upland-erosion index even if the index is accurately defining upland-erosion potential. Appropriately representing landuse/landcover over the time period of sampling at each downstream gaging station poses additional uncertainty because of land surface changes over the period, particularly in the northern quadrant of the basin. Finally, because the mean- annual precipitation layer had the coarsest resolution, 20 by 20 m, the final raster layer had that resolution.

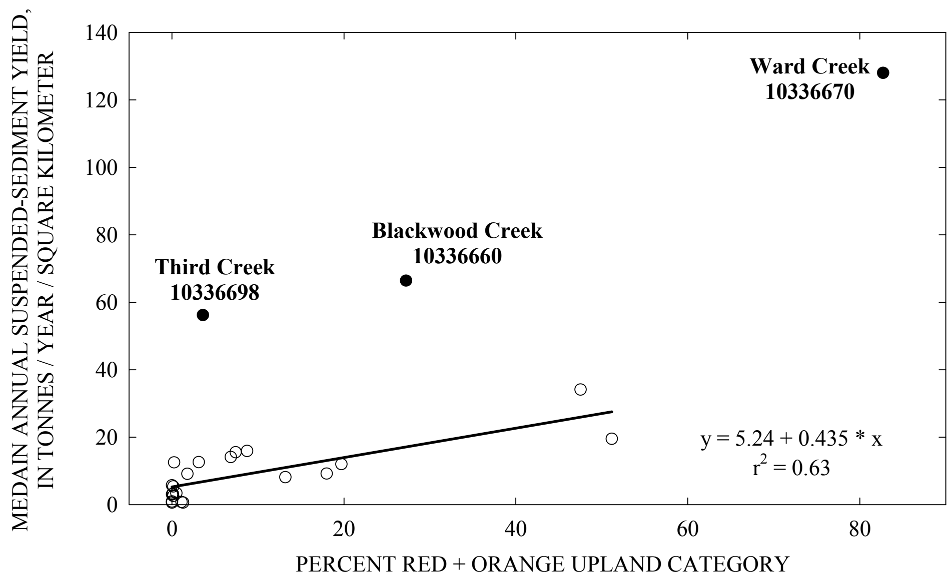

Figure 6-8. Relation between high upland-erosion potential and median, annual suspended-sediment yield.