1.0 BACKGROUND

1.1 Introduction

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

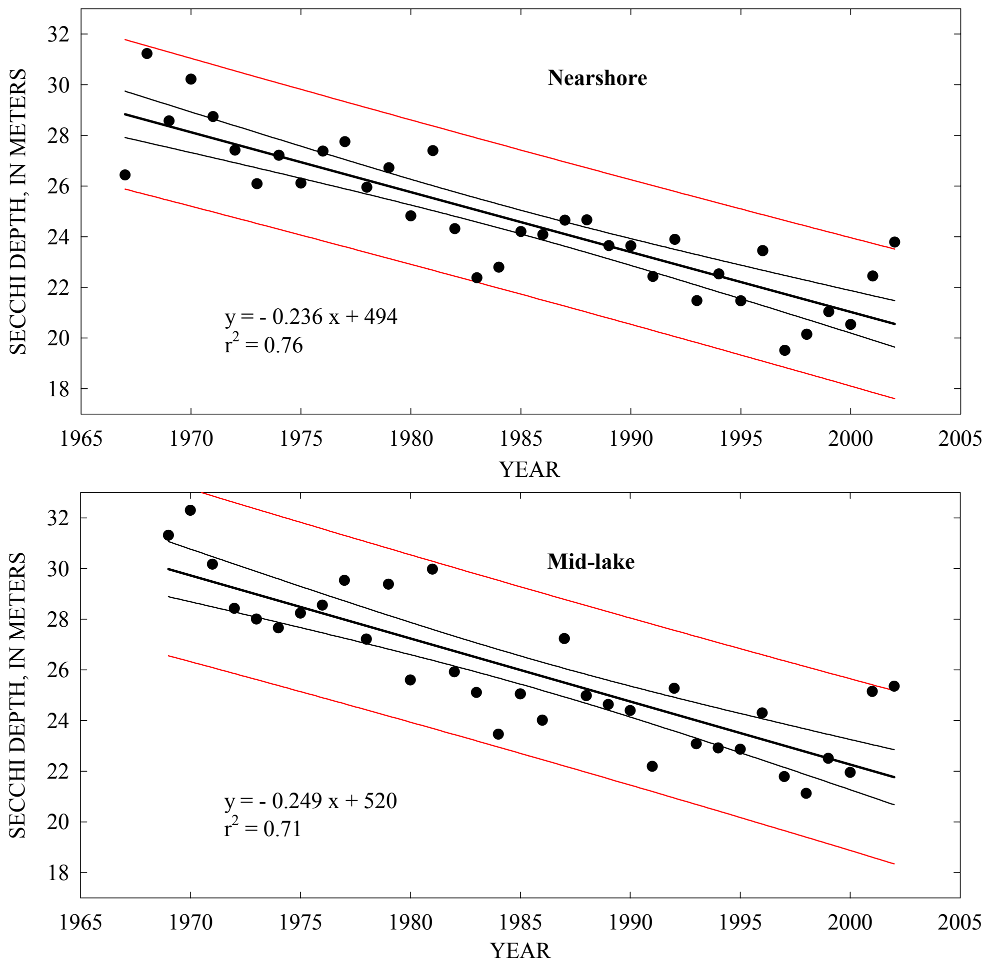

Figure 1-1. Trend of decreasing water clarity in Lake Tahoe as measured by secchi-depth for nearshore (top) and mid-lake stations (bottom). Raw data from Tahoe Research Group (TRG); Red lines denote 95% prediction limits.

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

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

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

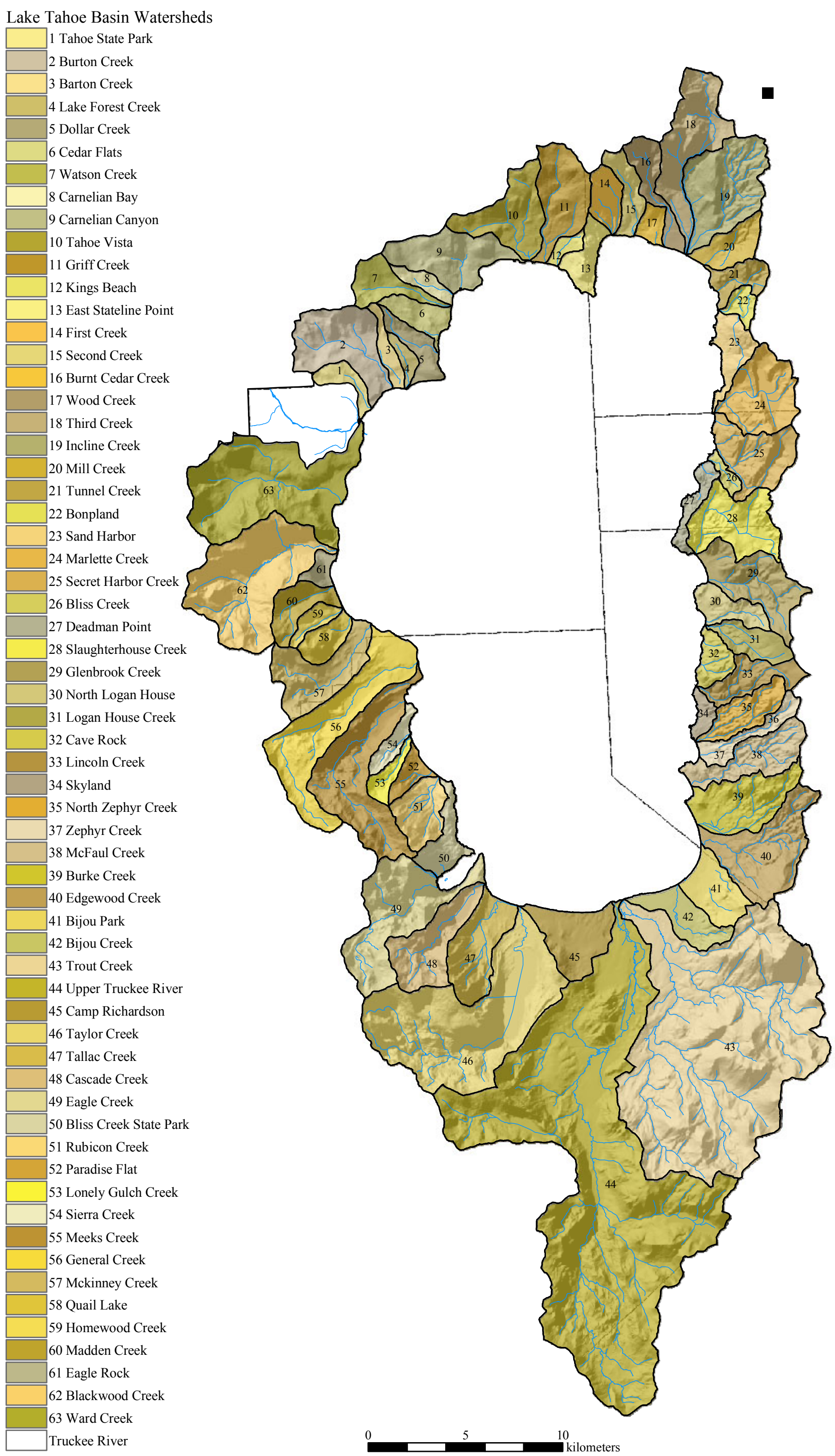

Figure 1-2. Map of Lake Tahoe Basin showing the 63 watersheds draining to the lake. Map obtained from the Tahoe Research Group (TRG).

1.2 Purpose and Scope of Investigation

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

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

1.3 Acknowledgments

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

The great majority of the funding for this research was provided by the U.S. Army Corps of Engineers (CoE), Sacramento District, where Phillip Brozek and his assistant Mellissa Kiefer provided straightforward management and oversight of the work. David Biedenharn, CoE, Coastal and Hydraulics Laboratory, Engineer Research and Development Center (ERDC) also provided funding out of the Regional Sediment Management Project. Agricultural Research Service discretionary research funds were also provided by NSL to support this effort. We owe a great debt to Ronnie Heath, ERDC, for recommending our research group to the Sacramento District to undertake this project.

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

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

1.4 <u>Overview of Research Approach</u>

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

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

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

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

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

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

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

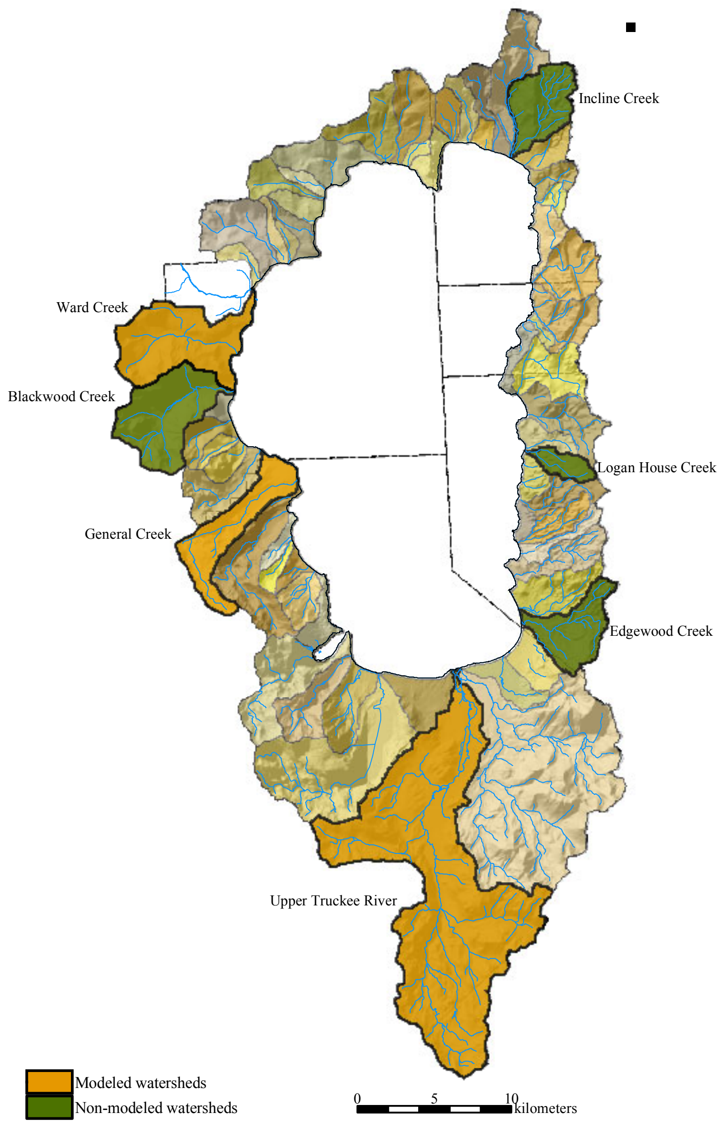

Figure 1-3. Map of the Lake Tahoe Basin showing the seven intensely studied watersheds. Numerical simulations were conducted on General and Ward Creeks, and the Upper Truckee River.

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

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

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

1.5 General Description of Basin Characteristics

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

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

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

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

1.6 Characteristics of the Intensely Studied Streams

1.6.1 Blackwood Creek

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

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

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

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

1.6.2 Edgewood Creek

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

The Edgewood creek watershed covers 17.3 km^2 on the southeast side of the Lake Tahoe Basin (Figure 1-3). Over 90% of the watershed is underlain by granitic bedrock. The remainder consists of glacial outwash and lacustrine deposits near the mouth (Hill, 1987). The average annual precipitation is about 584 mm (Hill, 1987). Above Highway 50, the watershed is well forested with second growth conifers. Below Highway 50, the stream flows through the Edgewood Golf course, where grass and sparse forest are the primary cover.

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

1.6.3 General Creek

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

The General Creek watershed covers 19.3 km^2 (Hill, 1987) on the west central side of the Lake Tahoe basin (Figure 1-3). The total relief of the stream, per topographic map, (Homewood 7.5 minute quadrangle) is 500 m over 13.6 km of valley length. The main channel flows in two distinct valleys. The upper valley, with a northwestern aspect and low gradient, was glacially scoured leaving many rounded and plucked granitic bedrock exposures in the valley. The lower valley contains depositional glacial features such as moraines and tills.

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

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

1.6.4 Incline Creek

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

The Incline Creek watershed drains 19 km^2 on the northeast side of the Lake Tahoe Basin (Figure 1-3). The valley has a southwestern aspect. The total relief of the stream is 750 m over 7.9 km of valley length (Entrex, 2001). Geologically, the upper watershed is composed of Cretaceous granodiorites and Tertiary andesites. The surficial geology of the lower watershed consists of Quaternary glacial outwash, alluvium, and lakeshore sediments (Entrix, 2001).

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

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

1.6.5 Logan House Creek

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

The Logan House Creek watershed covers 5.4 km^2 located on the east central side of Lake Tahoe (Hill, 1987) (Figure 1-3). The valley has a western aspect and the total relief of the stream channel, per topographic map, (Glenbrook 7.5 minute quadrangle) is 750 m over 5 km of valley length. A major tributary joins the main channel approximately 700 m above the mouth. Geologically, the watershed is underlain with decomposing granodiorite over the lower 70%, while the upper 30% is underlain with undifferentiated metamorphics (Hill, 1987). Precipitation averages 635 mm per year over the entire watershed (Hill, 1987) with the majority being snowfall. Upland vegetation consists of firs, while riparian vegetation consists of aspen, alder, willow, dogwood, and grasses.

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

1.6.6 Upper Truckee River

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

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

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

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

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

1.6.7 Ward Creek

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

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

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

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