LAKE TAHOE BASIN FRAMEWORK STUDY
GROUNDWATER EVALUATION
LAKE TAHOE BASIN, CALIFORNIA AND NEVADA

1.0 INTRODUCTION

1.1 Scope of Project

The U.S. Army Corps of Engineers has completed a Lake Tahoe Basin Framework Study Groundwater Evaluation with results and conclusion presented herein. The goals of this evaluation were to:

- Estimate nutrient loading (phosphorus and nitrogen) to Lake Tahoe via groundwater,
- Determine known and potential nutrient sources, and
- Recommend potential nutrient reduction alternatives.

This information will be used to determine potential projects that could aid in reducing the nutrient loading to the lake from groundwater. The Tahoe Regional Planning Agency (TRPA) may use this information to meet its management goals. The Lahontan Regional Water Quality Board (LRWQCB) and Nevada Division of Environmental Protection (NDEP) plan to use the information from this evaluation in their development of Total Maximum Daily Loads (TMDLs) for Lake Tahoe. This evaluation broadens the understanding of nutrient cycling in the basin, and provides refined estimates of nutrient contributions to the lake through the groundwater system that are a component of the eutrophication processes reducing lake clarity.

This Groundwater Evaluation is a portion of the Lake Tahoe Framework Implementation Report that Congress directed the U.S. Army Corps of Engineers (Corps) to complete. The Framework Report will present alternatives for improvement of environmental quality at Lake Tahoe by enhanced implementation of projects. Basin Stakeholders identified the effort presented in this Groundwater Evaluation as a critical missing element to presenting comprehensive alternatives for improvement of environmental quality. A summary of recommendations from the Groundwater Evaluation will be included in the report to Congress. This report is part of a large effort to assess sources of nutrients and sediment to Lake Tahoe as part of the Lake Tahoe TMDL Program. Most management strategies and implementation actions have been and continue to be focused on controlling nutrient and sediment loading into the lake. Future activities should consider giving priority to those areas with the greatest contribution to the various pollutant loading budgets. The information presented in this report can assist agencies and policy makers in identifying areas that should be considered higher priority in terms of groundwater nutrient contribution in the Lake Tahoe Basin.

1.2 Defining the Problem

Groundwater has been identified as a potentially important source of nutrient pollutants being discharged into Lake Tahoe. Some research on the effects of groundwater nutrient contributions on lake water quality has been conducted (e.g., Loeb 1987, Thodal 1997, Ramsing 2000), but further assessment is needed. Likely sources of nutrient contribution to the lake through groundwater are residual effluent from past sewage disposal sites, fertilizer application, sewage conveyance lines, and infiltration of urban storm water runoff.

A hydraulic gradient exists between the upland areas and Lake Tahoe. Groundwater flows downgradient until it is discharged by evapotranspiration, seepage to streams, springs, small lakes, and Lake Tahoe.

Increased eutrophication and algal growth due to an increase in nutrients, most notably phosphorus and nitrogen, has been cited as one of the causes of degradation in lake clarity in Lake Tahoe. The accelerated eutrophication can be measured by an increase in phytoplankton productivity in the lake, and can be directly attributed to increased urban development in the Lake Tahoe Basin. Long-term monitoring of Lake Tahoe shows that near-surface lake clarity (within 30 meters (100 ft.) of the surface) has declined significantly since 1968, due to both nitrogen and phosphorus loading which stimulates the growth of algae (Goldman 1988) and the loading of fine sediment particles from watershed erosion (Jassby et al. 1999). Groundwater is not considered a source of sediment loading. Due to the geochemistry at Lake Tahoe, it is unlikely that colloids would form in the sand dominated subsurface (Tyler 2003). Lake Tahoe is losing clarity at the rate of about 0.3 meters (1 foot) per year (Jassby et al. 2001). Previous studies have indicated that groundwater which discharges into Lake Tahoe contains concentrations of nutrients, such as nitrogen and phosphorus, greater than those found in lake water (Thodal 1997, Loeb 1975, 1987).

Given that dissolved nutrients are frequently found in higher concentrations in groundwater than in sub-alpine surface waters, it can be hypothesized that nutrient discharges to Lake Tahoe via groundwater may be significant despite low rates of flow (Ramsing 2000). Based on the most current nutrient budget for Lake Tahoe, Reuter et al. (2002) reported that nitrogen and phosphorus loading via groundwater accounts for approximately 15% and 9%, respectively, of the Lake Tahoe loading rate.

1.3 Site Background

1.3.1 Evaluation Focus

Lake clarity has been degrading in Lake Tahoe as documented over the last 30 years. This decrease in clarity has been attributed to accelerated eutrophication due to an increase in nutrients being discharged into the lake (Goldman 1988, Thodal 1997, Reuter et al. 2002). Efforts to determine the sources of nutrient and particulate pollutants have been ongoing for a number of years and are currently being organized as part of the TMDL program.

This evaluation consolidates and evaluates information about nutrient loading to Lake Tahoe by way of groundwater. It focuses on a re-evaluation of existing data and the compilation of new data generated since Thodal's study in 1997. The evaluation also focuses on identification of land use practices, both current and historic, that could be contributing to nutrient loading to the groundwater system. The results of this evaluation are presented in terms of total loading to Lake Tahoe and are also broken down into five regions based on political boundaries and major aquifer limits. These regions include South Lake Tahoe/Stateline, Incline Village, Tahoe Vista/Kings Beach, Tahoe City/West Shore and East Shore. This report represents the results of an in-depth review of existing reports and did not include any field work.

Thodal's (1997) groundwater study indicated that groundwater could be an important contributor of nutrients to Lake Tahoe. This report acts as an independent assessment of Thodal's analysis. The report differs from Thodal's in that it divides the basin into geographic regions, rather than assessing the groundwater loading using a basin-wide approach only. In addition, data that has been collected since the Thodal study by the USGS and other monitoring conducted by various stakeholders in the basin was used in this evaluation. Enough data was available to develop a groundwater flow model for the South Lake Tahoe area to obtain better estimates of groundwater discharge to Lake Tahoe. Multiple methods of developing nutrient concentrations were used to provide a more detailed analysis of the nutrient concentrations found in the basin. Another component that this groundwater evaluation added beyond previous studies in the basin is the potential affect of ambient nutrient concentrations. This is the first attempt to determine the percent of nutrients present in groundwater from ambient sources.

1.3.2 Location and Physiography

Lake Tahoe has a surface area of roughly 495 square kilometers (191 square miles) and is located in a fault-bound basin on the border of California and Nevada between the Sierra Nevada and Carson Mountain ranges (Crippen and Pavelka 1972, Boughton et al. 1997). The evaluation area is within the Lake Tahoe Basin Hydrographic Area, or Lake Tahoe Basin. The basin is approximately 816 square kilometers (315 square miles), excluding the lake. It has a legally defined maximum depth of 501 meters (1,645 ft), and an average depth of 313 meters (1,027 ft) (Thodal 1997, TRPA 1988). Sixty-three watersheds drain directly into Lake Tahoe. The basin is contained within portions of six counties including Placer, El Dorado, and Alpine Counties in California, and Douglas and Washoe Counties and the Carson City rural area in Nevada. (Figure 1-1)

1.3.3 Previous Investigations

Data from previous groundwater investigations and monitoring in the basin was obtained and used to develop an estimate of nutrient loading to Lake Tahoe via groundwater. This effort was based on the compilation and evaluation of existing knowledge of groundwater flow characteristics, geology, and existing groundwater and near-shore lake nutrient data for the Tahoe Basin.

Several reports were referenced in preparation for this evaluation. Some of these reports are discussed in further detail in portions of sections 3 – 8 of this study. McGauhey and others

(1963) investigated environmental and water-quality issues in the Lake Tahoe Basin; Crippen and Pavelka (1970) focused on water and other natural resources of the basin. Thodal (1997) studied the hydrogeology of the Lake Tahoe Basin, which included a groundwater monitoring program. The results for water years 1990-1992 show that groundwater contains concentrations of nutrients that are greater than those of lake water, and that groundwater does discharge into Lake Tahoe. Loeb and Goldman (1979) estimated the total groundwater flow from the Ward Valley watershed into Lake Tahoe from basic hydraulic principles. Later, Loeb and others (1987) participated in a program that studied the groundwater quality in three major aquifers within the Lake Tahoe Basin between 1985 and 1987. They concluded that groundwater was being polluted with nutrients, such as nitrate-nitrogen, as they moved toward Lake Tahoe through developed regions of the watershed. A Master's Thesis at the University of California, Davis by Woodling (1987) focused on the hydrogeologic aspects of groundwater and lake interactions in the southern portion of the Lake Tahoe Basin. Similarly, a Master's Thesis at the University of Nevada, Reno by Ramsing (2000) focused on measuring groundwater seepage into Lake Tahoe and estimating the nutrient transport from the Incline Creek watershed.

1.4 Geologic Setting

The Tahoe Basin is a structural basin situated between the Sierra Nevada Mountains to the west and the Carson Range to the east. The lake was formed by downward block faulting during uplift of the Sierra Nevada between 2 and 3 million years ago and currently reaches a maximum depth of 501 meters (1,645 ft), making it one of the deepest lakes in the world. The basin is located along the western edge of the Great Basin physiographic province near the boundary of the Walker Lane deformation belt (Oldow et al. 2001). Modern geodetic measurements indicate that the highest strain-rates (up to 2-3 mm/yr (0.08 – 0.1 in/yr)) associated with the Basin and Range extension that may be accommodated along the faults in the Lake Tahoe region are located just to the east (Thatcher et al. 1999, Dixon et al. 2000, Bennett et al. 1998).

Prudic et al. (2000) classify the geology into four major material types (Figure 1-2). These are Paleozoic metamorphosed, sedimentary and volcanic rocks, Jurassic and Cretaceous granitic rocks of the Sierra batholith, Tertiary and Quaternary volcanic rocks, and Quaternary sediments of glacial, fluvial and lacustrine origin. Paleozoic metasediments and metavolcanics form the oldest rocks in the basin (Crippen and Pavelka 1972). They crop out at a few locations along the east and west sides of the basin, mostly at high altitude. These represent the remains of the original host rock that has been intruded by Jurassic and Cretaceous igneous rocks.

Granitic rocks form steep, high mountain slopes and peaks throughout the basin except the northwest quarter (Figure 1-2). Along the eastern margin of the lake, granitic rocks decompose to form thick, sandy soils. Mudflows, as well as basalt and andesite flows comprise the Tertiary and Quaternary volcanic rocks in the northwestern part of the basin (Crippen and Pavelka 1972, Prudic et al. 2000). The mudflows are described as being crudely stratified, massive, thick-bedded, and well to loosely consolidated, while the andesite and basalt flows are more thinly layered. Mechanical weathering by freeze-thaw cycling occurs where water enters joints and interstitial spaces in the talus slope.

Glacial deposits are predominantly found in the southern and western portions of the basin where they locally form thick basin fill sequences. Glaciation in the basin began around 1.5 million years ago when all but the highest peaks in the Sierra Nevada were inundated by ice (Purkey and Garside 1995). Subsequently, at least three more glaciations occurred between 100,000 and 120,000 years ago, at 20,000 years ago and at 10,000 years ago (Birkeland 1962, 1964, Purkey and Garside 1995). During these events, ice was largely restricted to the Sierra Nevada, as the Carson Range was situated in a precipitation shadow.

1.5 Quaternary History of the Tahoe Basin

The Quaternary history of the Lake Tahoe Basin has been described by Birkeland (1962, 1964). We acknowledge that more recent work in the Sierra Nevada may provide additional resolution on glacier fluctuations, which can likely be correlated to the global oxygen isotope record; however, Birkeland's work provides the most complete investigation of its type in the Tahoe Basin. According to Birkeland, several highstands in lake level correspond to periods of glaciation where glaciers advancing out of valleys between Bear Creek and Donner Pass dammed the outlet of Lake Tahoe in the Upper Truckee Canyon (Figure 1-3). However, evidence of the highest lakestands are associated with lava flows dated between 2.5 and 1.3 million years ago which also dammed the Truckee River and allowed Lake Tahoe to rise to about 7000 ft above mean sea level (msl) (Burnett 1971).

In his work, Birkeland (1962, 1964) recorded evidence of 4 major glacial periods in the basin. These are, from oldest to youngest, the Hobart, Donner, Tahoe and Tioga. The oldest of these glaciations, Hobart and Donner, were the most extensive and formed large compound valley glaciers that filled significant portions of the upper Truckee Canyon. The lake level during these events is believed to have risen as high as ~6800 ft above msl (Birkeland 1962). The ice dam is believed to have been breached several times, resulting in periodic, catastrophic flooding down valley and periodic lowering of the lake level.

During the Tahoe Glaciation, ice again flowed into the Upper Truckee Canyon but was not as extensive as the previous two glaciations (Birkeland 1962, 1964). Damming of the Lake Tahoe outlet occurred again, but the ice was not as extensive. The resulting lake elevations rose only to between 18 and 27 meters (60 and 90 ft) before the ice dam was broken, again producing catastrophic flooding down valley.

Such damming and flooding likely occurred several times during each glaciation between Hobart and Tahoe. During the interglacial periods, the lake level would have been similar to today's level. Lava flows at the outlet of Lake Tahoe provide a minimum threshold for lake elevation at about 6220 ft above msl. Morgan (unpublished data) suggests that there is additional evidence around the lake of another lake stand around 61 meters (200 ft) above current lake level. This is exemplified by cave elevations at Cave Rock and Eagle Rock, as well as an apparent wave cut platform near the South Lake Tahoe Airport. Given our current lake chronology, the last time the lake level could have been at this elevation was at the end of the Donner glaciation. However, Morgan and others have been revisiting some of Birkeland's field sites, and they feel that the sequence at Eagle Rock represents a shoreline feature of Tahoe age at about 61 meters (200 ft) above present lake level. If this is true, then it places truncation of the Airport Moraine during the Tahoe glaciation.

Recent offshore seismic profiling near the head of the Upper Truckee River indicates that an incision of up to 9 meters (30 ft) may have occurred in the past, but subsequent infilling has resulted in the current threshold to the lakes outlet (Kent 2003). Lake lowstand is recorded by submerged shorelines around the lake that have been tectonically tilted and submerged stumps found at depths less than 6 meters (20 ft) below the lake surface (Lindstrom et al. 2000, Kent 2003)

1.6 Project Staffing

The Environmental Engineering Branch, Sacramento District, U.S. Army Corps of Engineers prepared this report, under the supervision of Richard Meagher, P.E. The project manager is Phillip Brozek of the Civil Works Programs and Project Management Division. The technical team for the groundwater evaluation consists of:

Name	Title
Meegan Nagy, P.E.	Environmental Engineer, Team Leader
Melissa Kieffer, P.E.	Environmental Engineer
Lewis Hunter, PhD, R.G.	Senior Geologist
Timothy Crummett	Geologist
Teresa Rodgers	Geologist
John Baum	Environmental Engineer
Elizabeth Caldwell	Environmental Engineer
Scott Gregory	GIS Specialist
Suzette Ramirez	Engineering Technician
Glenn Cox	Draftsman

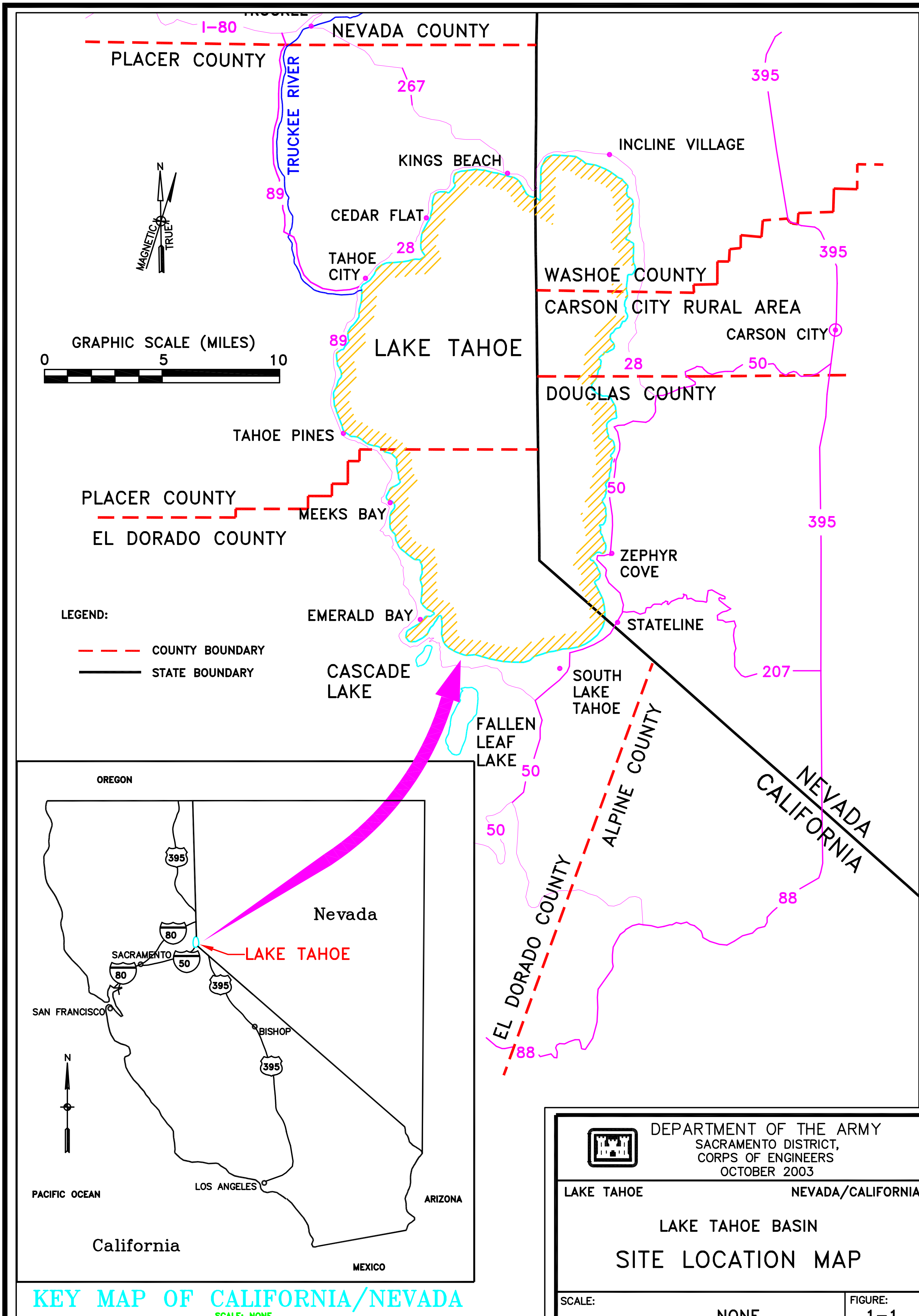
Jon Fenske, P.E., Hydrogeologist, of the U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis California, has conducted all groundwater modeling with the assistance of Makrom Shatila.

1.7 Report Organization

The report is broken down into 13 main sections. The first section is the introduction which includes information on the purpose and background of the evaluation. The second section provides a discussion of the data collection activities as well as a conceptual site model for the groundwater system at Lake Tahoe. Section 3.0 describes the nutrients that are being evaluated, the methodology used to estimate nutrient loading and major basin-wide investigations that have been conducted in the past. Sections 4.0 – 8.0 contain the nutrient loading estimates for five distinct regions in the Tahoe basin, while Section 9.0 evaluates the overall nutrient loading to Lake Tahoe. Section 10.0 discusses the major nutrient sources found in the Lake Tahoe basin and Section 11.0 provides an evaluation of nutrient reduction alternatives. The findings, summary and conclusions are provided in Section 12.0. All references can be found in Section 13.0.

1.8 Acknowledgements

While conducting research and during the composition of this Framework Study, the Corps depended on many other organizations for information and aid. Special thanks goes to the Lahontan Regional Water Quality Control Board for their support and guidance throughout the evaluation. We would also like to thank the Tahoe Regional Planning Agency and Nevada Division of Environmental Protection for their support in developing the report. There are many others who provided information, data, and advice. We appreciate all who took the time to locate data, discuss the groundwater issues at the lake and provide guidance along the way.



DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT,
CORPS OF ENGINEERS
OCTOBER 2003

LAKE TAHOE — NEVADA/CALIFORNIA

LAKE TAHOE BASIN

SITE LOCATION MAP

SCALE: NONE

FIGURE: 1-1

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Figure 1-2. General geology of the Lake Tahoe Basin. From Crippen and Pavelka (1972)

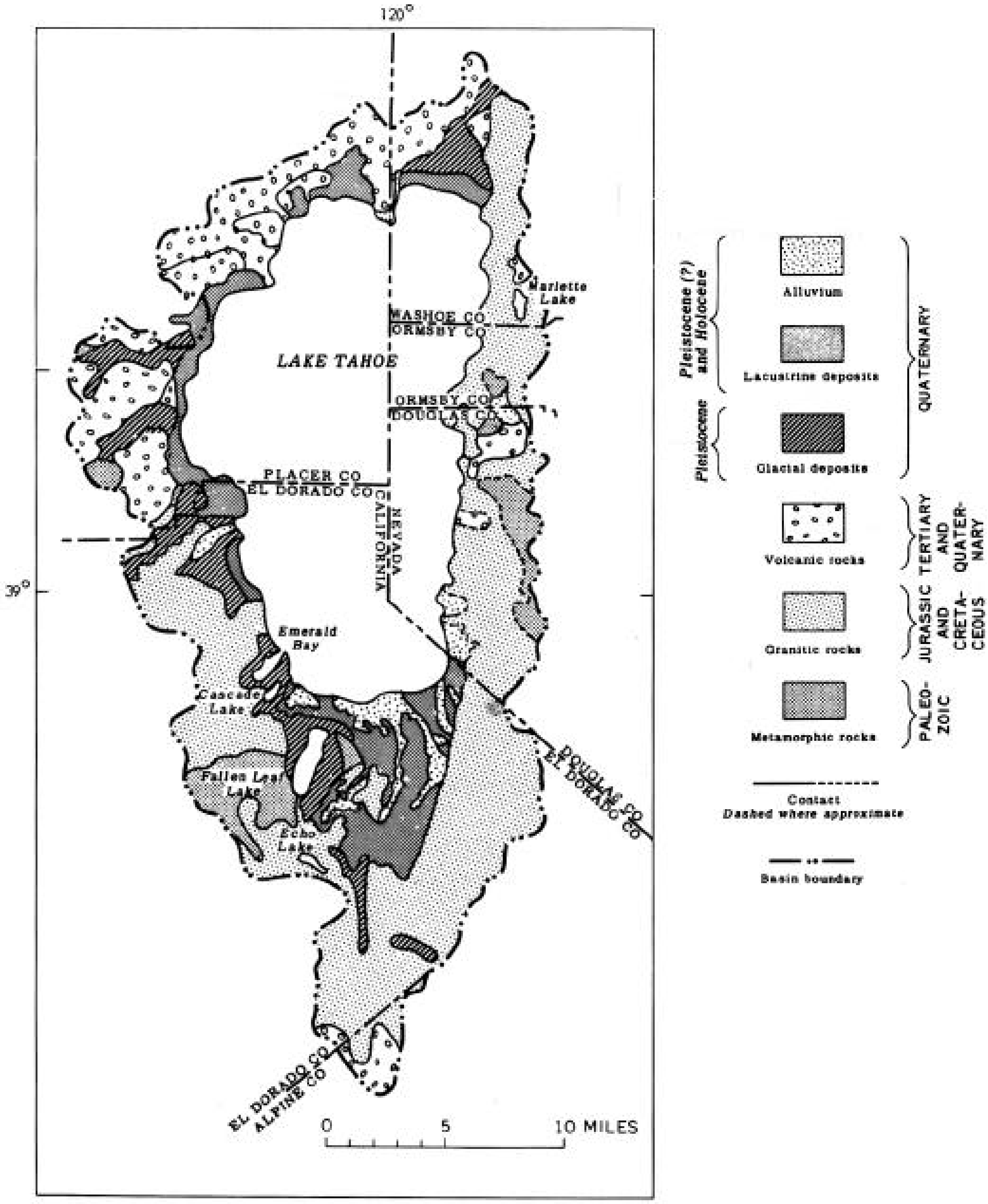

Figure 1-3. Extent of glaciations in the Truckee River Valley. Hobart (dashed), Donner (solid), and Tahoe Glaciations (dot-dash). Modified after Birkeland (1964).