In Cooperation with the United States Department of Agriculture Forest Service, Lake Tahoe Basin Management Unit.

# Ground-Water Resources Inventory of the Lake Tahoe Basin, 2007

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## Conversion Factors and Vertical Datum

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter |
| inch (in.) | 25.4 | millimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| | Area | |
| acre | 4,047 | square meter |
| square mile (mi2) | 2.590 | square kilometers |
| | Volume | |
| acre-foot (acre-ft) | 0.001233 | cubic hectometer |
| acre-foot per year (acre-ft/yr) | 0.001233 | cubic hectometer per year |
| gallons per minute (gpm) | 0.06309 | liter per second |
| | Rate | |
| foot per day (ft/d) | 0.3048 | meter per day |
| foot squared per day (ft2/d) | 0.0929 | meter squared per day |

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F-32)/1.8

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27). Altitude, as used in this report, refers to distance above the vertical datum.

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## Abstract

This report presents a compilation of existing hydrogeologic data and other information needed to determine the extent and characteristics of the aquifers in the Tahoe Basin. Geospatial and other data include geologic maps and soil surveys of the entire basin and for specific watersheds within the basin at the best available scales; land-use maps from several remote-sensing datasets; well information from various local, state, and federal agencies; geophysical surveys; and results of available ground-water studies. The compilation and development of a ground-water inventory geospatial database will assist the United States Forest Service in better assessing the present and future impacts of human activities on ground-water resources within the Lake Tahoe Basin.

## Introduction

### Background

The Lake Tahoe Basin, an area of alpine and subalpine land within the Sierra Nevada Mountains of California and Nevada, is renowned for its beautiful mountain ranges and lakes, especially Lake Tahoe (fig. 1). As part of an ongoing effort over the past 30-40 years, agencies of Federal, State, and local government, research institutions including the Universities of California and Nevada, have collected data regarding the water and land resources of the basin. In addition numerous studies have been undertaken to develop a better understanding of the natural resources of the basin. The ground-water resources of the basin have been the focus of much of the data collection and studies for two reasons. First, ground water enters Lake Tahoe either as discharge to stream channels and subsequent runoff or as subsurface flow directly to the lake. Any changes in ground-water quality have the potential to affect water quality in the lake. The potential for ground water to transport nutrients to the lake is of particular concern. Second, ground water is the principal source of domestic and municipal water supplies. Although most of the ground-water studies done in the basin are readily available, the data are not as available because they are scattered among the different agencies and institutions that did the original data collection.

There is a need to compile ground-water data in the Lake Tahoe Basin from the different sources so the data are readily accessible. To address this need, the U.S. Forest Service (USFS) has requested that the U.S. Geological Survey (USGS) has undertaken an inventory of the ground-water resources of the basin. The overall objective is to develop a geospatial compilation of existing ground-water and related data for the Lake Tahoe Basin within a geographic information system (GIS) database.

**FIGURE 1 MAP SHOWING THE LOCATION OF THE LAKE TAHOE BASIN**

## Purpose and Scope

The purpose of this report is to present the compilation of ground-water and related data in the Lake Tahoe Basin as a GIS database. The compilation includes: (1) a map showing the distribution and extent of hydrogeologic units that influence the movement and storage of ground water, (2) data from selected well drillers' logs including results of pump tests and types of deposits and rocks penetrated, and (3) other basin-wide ancillary data including soils, vegetation, elevation, lake bathymetry, stream network, transportation network, and political boundaries. The report also includes discussions, based on previous studies, of the different hydrologeologic units and, where known, the extent and thickness database.

## Previous Investigations

Numerous hydrologic and geologic studies have been done in the Lake Tahoe Basin. The basin wide hydrologic setting has been summarized previously by Crippen and Pavolka (1970). The hydrogeology and hydrology of the alluvial aquifer in the South Shore area has been studied in more detail than any other aquifer in the basin (Loeb, 1987; Woodling, 1987; Harrill, 1977; Blum, 1979; Marciewicz; 1992; Thodal, 1992, 1995, and 1997; Rowe and Allander, 2000; U.S. Army Corps of Engineers, 2003; Prudic and others, 2004; Allander, 2005; and Green, 2006). The only other aquifers in the basin that have been studied in detail are the Ward Valley aquifer on the west side of the basin (Loeb, 1987 and Niblick, 1988) and those on the east side from the Glenbrook, Zephyr Cove, and Stateline (Thodal, 1995).

Geologic investigation of the South Lake Tahoe ground-water basin was reported by Blum in 1979. Geophysical reconnaissance was part of a ground-water investigation by Loeb (1987) of water quality in three major aquifers within the Upper Truckee River, Trout Creek, and Ward Creek watersheds. Niblack (1988) mapped the boundaries of the Ward Valley aquifer. Geophysical techniques (seismic reflection and electrical resistivity soundings) and evaluation of drillers' logs have been used to estimate alluvial aquifer thickness at several sites in the Incline Village, Kings Beach/Tahoe Vista, and Tahoe City alluvial aquifers (Markiewicz, 1992, and Muehlberg and others, 2003). Thodal (1992) used Bouguer-gravity values to help delineate the bedrock/basin-fill contact in the southeast part of the Lake Tahoe Basin. In 1995, Thodal describes depth to bedrock reported in 51 drillers' logs on file with the Nevada Division of Water Resources (NDWR) from Stateline-Elk Point, Zephyr Cove, and Glenbrook aquifers. An investigation by Schweickert and others (2004) gives evidence indicating the seismically active Truckee and Gardnerville transition zones, north and southeast of the Lake Tahoe basin, are undergoing north-south shortening.

Hydrologic maps have been assembled by Harrill (1977) of the South Lake Tahoe Quadrangle, Nevada and California; by Rowe and Stone (1997) and by Smith and others (1999) of selected hydrologic features of the Lake Tahoe Basin, California and Nevada. A geologic map was assembled by Saucedo (2005) that compiled the most recent and representative geologic mapping and established a seamless geologic database to be used by planning and decision-making agencies in the Lake Tahoe Basin.

A set of spatial databases consisting of natural-resources and planimetric-base layers has been developed and documented for the Lake Tahoe basin by Cartier and others (1994). The databases, in the form of geographic information system coverages, include surface geology, soils, timber type, riparian vegetation, land capability, stream channels, water bodies, roads, political boundaries, the Lake Tahoe basin boundary, slope, aspect, drainage-basin boundaries, and hydrologic-monitoring sites. Another report (Cartier and others, 1995) summarizes spatial and tabular information of the hydrologic basins and the hydrologic-monitoring sites from the Tahoe Environmental Geographic Information System (TEGIS). However, these spatial datasets are outdated and have been replaced by ones presented in this report.

## Sources of Well Data and Site Designations

Well data, including depth to water and construction details for 188 wells (fig. 2), with at least one water-level measurement, in the Lake Tahoe Basin are stored in the USGS National Water Information System (NWIS) database (app. 1). Of these wells, 79 wells were measured in 1995 through 1996 and 49 wells were measured between 2000 through 2004. This database was used as a starting point for the compilation of well data. Other well data such as types of deposits and rocks penetrated and results of pump tests (app. 2 and 3) are available from files of drillers' logs maintained by the Nevada Division of Water Resources (NDWR), and California Department of Water Resources (CDWR). In addition, local government in the basin, including the various public utility districts and counties, maintain files with well information. These state and local agencies were contacted regarding the availability of their data. Drillers' logs for 354 wells on the Nevada side of the basin and 1,243 wells on the California side were obtained from NDWR and CDWR, respectively. Appendixes 2 and 3 list information only for logs that include a drillers' pump test (24 on the Nevada side and 37 on the California side), since compilation of data from all of the logs was beyond the scope of the study. Pump test information are used to determine the productivity of the well. Specific capacity (appendixes 2 and 3) is the yield per unit of drawdown and is determined by dividing the pumping rate ($Q$) at any time during the tests by the drawdown ($s_t$) at the same time, thus specific capacity = $Q/s_t$ (Heath, 1983). Any significant decline in the specific capacity of a well indicates the lowering of the ground-water aquifer or a problematic well screen. Transmissivity (appendixes 2 and 3) is defined as the rate at which water at the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman, 1972). It is the product of aquifer thickness and hydraulic conductivity (K), which is defined as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area at right angles to the direction of flow (Lohman, 1972). Transmissivity ($T$), hydraulic conductivity ($K$), and aquifer thickness (**b**) are related by the equation $T = K \times b$. These aquifer characteristics help evaluate ground-water flow rates and directions.

There is no well log data shown for the South Shore area because of the numerous studies that have been done in that part of the basin. Logs filed with NDWR (app. 2) are considered public information by the State of Nevada and are available on the NDWR website at

<*http://water.nv.gov/Engineering/wlog/wlog.cfm*>. Logs filed with CDWR (app. 3) are considered confidential and ownership, log number, and specific location cannot be shown without an owner’s permission. As a result locations for wells on the California side of the basin show only township, range, and section (fig. 2).

## FIGURE 2 MAP SHOWING THE LOCATION OF SELECTED WELLS IN THE LAKE TAHOE BASIN

Three different designations are used for identifying wells in this report. Two, used by USGS, are the standard site identification number and the Nevada local well name. The site identification number consists of 15 digits and is based on the grid system of latitude and longitude. The first six digits denote degrees, minutes, and seconds of latitude; the next seven digits denote degrees, minutes, and seconds of longitude; and the last two digits (assigned sequentially) identify sites within a 1-second grid. For example, the site identification for the first well listed in appendix 1 is 384920120011101. The number refers to 38$^{0}$49’20” latitude, 120$^{0}$ 01’11” longitude, and it is the first site recorded in that 1-second grid (USGS, 1989). This number is retained as a permanent identifier even if a more precise location is determined later.

The Nevada local well name is based on an index of hydrographic areas for Nevada (Rush, 1968) and on the rectangular subdivision of the public lands referenced to the Mount Diablo base line and meridian. Each number consists of four units separated by spaces. The first unit is the hydrographic area number (app. 1). The second unit is township preceded by an N to indicate location north of the base line. The third unit is range preceded by an E to indicate location east of the meridian. The fourth unit consists of section number and letters designating quarter section, quarter-quarter section, and so on

(A, B, C, and D indicate northeast, northwest, southwest, and southeast quarter respectively), followed by a number indicating the sequence in which the well was recorded. For example, the Nevada local well name for the first well listed in appendix 1 is 90 N11 E18 05CCCC1. This well is in Lake Tahoe Basin (90) and is the first site recorded in the southwest quarter, of the southwest quarter, of the southwest quarter, of the southwest quarter of section 05, Township 11 North, Range 18 East, Mount Diablo baseline and meridian. This naming convention also is used in appendices 2 and 3, although only township, range, and section are shown for wells in California (app. 3) because of restrictions on revealing specific well locations. The third designation for identifying wells used in this report is the well log number assigned by the Nevada Division of Water Resources (NDWR) after the well is completed and the log is filed with that agency. That number is shown in column two of appendix 2.


### Acknowledgments

The authors appreciate the assistance of the California State Department of Water Resources and the Nevada Division of Water Resources for their assistance with well information.


# General Features

## Location and Physiography

The Lake Tahoe Basin is a structural basin bounded by the main range of the Sierra Nevada to the west and the Carson Range to the east. The basin was formed by block faulting during the uplift of the Sierra Nevada 2-5 million years ago, which resulted in dramatic topographic relief (Bateman and Wahrhaftig, 1966 and Hyne and others, 1972). Mountain peaks, snow capped nearly year-round, rise to altitudes above 10,000 ft. About 78 percent of the basin occurs at altitudes greater than 6,500 ft (Boughton and others, 1997).

Approximately two thirds of the Lake Tahoe Basin is in California and one third is in Nevada (fig. 1). The basin encompasses parts of six counties: Alpine, El Dorado, and Placer Counties in California, and Douglas, and Washoe Counties and Carson City in Nevada. The entire basin is about 40 miles long from north to south and 10 to 18 miles wide, and its area is 506 $mi^2$ (square miles) (Crippen and Pavolka, 1970).

Lake Tahoe is an irregular oval shape, about 22 mi long from north to south and 12 mi wide. The surface area of the lake is 192 square miles ($mi^2$), and the surrounding watersheds cover 314 $mi^2$. The maximum depth of the lake is 1,645 feet (ft) and the average depth is 1,027 ft (Thodal, 1992). Lake Tahoe is the second deepest lake in the United States and tenth deepest in the world. It has an average lake-surface altitude of about 6,225 ft (Boughton and others, 1997). The water temperature of Lake Tahoe, near the surface, generally cools to 40 to 50$^{o}$F during February and March and warms to 65 to 70$^{o}$F during August and September. Below a depth of 600 to 700 ft, the water temperature remains a constant 39$^{o}$F. he water clarity of Lake Tahoe has been reduced from about 100 ft deep in the 1960's to 70 feet deep in 2006 (Lake Tahoe facts from web site at <http://tahoe.usgs.gov/facts.html>). Factors contributing to the clarity of Lake Tahoe, even though reduced during the past 40 years, include: (1) 40 percent of the precipitation that falls in the basin lands directly on the lake and (2) the remaining 60 percent drains mostly through granitic soils, which are relatively sterile and create a good filtering system.

## Climate

The climate of the Lake Tahoe basin is strongly influenced by the surrounding mountains. The altitude range, combined with other factors such as prevailing storm systems from the Pacific Ocean, causes an unequal distribution of precipitation throughout the basin. The western side of the basin receives nearly twice the amount of precipitation as the eastern side (Boughton and others, 1997). Average annual total precipitation recorded by the National Weather Service (NWS) for the period of record, January 1, 1914 to December 31, 2006, at Tahoe City, California, is 32 in. and average annual snowfall is 189 in. Summers are cool, compared to the surrounding valleys on either side of the mountains and winters are cold. Mean monthly temperatures recorded by the NWS at Tahoe City range from a minimum of 19 $^{o}$ Fahrenheit (F) for the month of January to 78 $^{o}$ F for the month of July. The mean annual temperature is about 43 $^{o}$ F. On the eastern side of the basin the average annual total precipitation recorded by the NWS for the period of record, July 1, 1948 to December 31, 2006, at Glenbrook, Nevada, is 18 in. and average annual snowfall is 89 in. Mean monthly temperatures range from a minimum of 24 $^{o}$ F for the month of January to 80 $^{o}$ F for the month of July (Data source is Western Region Climate Center web site accessed July 3, 2007, at <*http://www.wrcc.dri.edu/summary/Climsmnca.html*>).

# Geographic Information

The geospatial work was completed using ArcGIS, a commercial GIS software package by Environmental Systems Research Institute (ESRI). Geospatial databases for the ground-water resources inventory of the Lake Tahoe Basin project were compiled from three data types: thematic, digital, and hydrologic. Data were integrated by manual digitizing, electronic scanning, or data conversion from existing information. Geospatial data, in the form of ArcMap GIS coverages, include geologic maps and soil surveys of the entire basin at the best available scales; land-use maps from several remote-sensing datasets; well information from various local, state, and federal agencies; geophysical surveys; and results of available ground-water studies (disc 1). Metadata for the spatial data sets includes sources of the databases, processes of data development, and descriptions of databases. Table 1 lists the geospatial databases and metadata information that were compiled for this ground-water inventory.

## Insert Table 1 here

Table 1. Geospatial databases and metadata information for the ground-water inventory of the Lake Tahoe Basin.

| Database Name | Metadata | Data Type | Source[1] | Source Scale | Description |
|---|---|---|---|---|---|
| gw_cons | gw_cons | Tabular digital data | CDWR, NDWR, USGS | | Basic ground-water well construction data |
| gw_csng | gw_csng | Tabular digital data | CDWR, NDWR, USGS | | Ground-water well casing data |
| gw_disc | gw_disc | Tabular digital data | USGS | | Ground-water discharge records |
| gw_geoh | gw_geoh | Tabular digital data | USGS | | Geohydrologic units |
| gw_hole | gw_hole | Tabular digital data | NDWR, USGS | | Ground-water well hole data |
| gw_hydr | gw_hydr | Tabular digital data | NDWR, USGS | | Hydraulic records |
| gw_lev | gw_lev | Tabular digital data | NDWR, USGS | | Ground-water well water-level record |
| gw_mpnt | gw_mpnt | Tabular digital data | USGS | | Ground-water well measuring point record |
| gw_open | gw_open | Tabular digital data | NDWR, USGS | | Ground-water well openings data |
| gw_otid | gw_otid | Tabular digital data | NDWR, USGS | | Other ground-water well data from well drillers report |
| state_csng | state_csng | Vector digital data | CDWR, NDWR | 1:100,000 | Ground-water well drillers report |
| state_lithology | state_lithology | Vector digital data | CDWR, NDWR | 1:100,000 | Lithology from well drillers report |
| state_pumptest | state_pumptest | Vector digital data | CDWR, NDWR | 1:100,000 | Pump test data from well drillers report |
| state_screenintervals | state_screenintervals | Vector digital data | CDWR, NDWR | 1:100,000 | Well casing screen interval data from well drillers report |

| | | | | | |
|---|---|---|---|---|---|
| state_well | state_well | Vector digital data | CDWR, NDWR | 1:100,000 | Other ground-water well data from well drillers report |
| Aquifers of the Lake Tahoe Basin | Tahoe_Aquifer | Vector digital data | Saucedo, G.J., 2005; USACE, 2003 | 1:100,000 | Aquifer boundaries in the Lake Tahoe Basin |
| Tahoe Geophysical Data | Tahoe_geophysical | Vector digital data | Markiewicz, R.D., 1992; Niblack, R.L., 1988; | 1:100,000 | Geophysical surveys in the Lake Tahoe Basin |
| Hydrogeologic Units of the Lake Tahoe Basin | Tahoe_hydrogeology | Vector digital data | Saucedo, G.J., 2005 | 1:100,000 | Hydrogeology of the Lake Tahoe Basin |
| Generalized Tahoe Area State Well Locations | Tahoe_State_Well_ Generalized | Vector digital data | CDWR, NDWR | 1:100,000 | Ground-water well general location data from well drillers report |
| Lake Tahoe National Water Information Well System | Tahoe_USGS_Well | Vector digital data | USGS | 1:100,000 | Ground-water well location data |

[1]CDWR, California Division of Water Resources; NDWR, Nevada Division of Water Resources; USACE, United States Army Corp of Engineers, USGS, United States Geological Survey.

## Hydrogeologic Framework of the Basin

The Lake Tahoe Basin is a graben formed during the past 2-5 million years by normal faulting along the main part of the Sierra Nevada on the west side of the basin and along the Carson Range on the east side (plate 1, Bateman and Wahrhaftig, 1966 and Hyne and others, 1972). The basin bedrock consists mostly of granitic rocks of Cretaceous and Jurassic age and marine sedimentary and volcanic rocks of Jurassic and Triassic age that were intruded and metamorphosed by the granitic rocks (plate 1). The landscape on the west side of the basin differs markedly from the landscape on the east side. Extensive valley glaciers up to 1,000 ft thick produced the rugged alpine landscape of the main part of the Sierra Nevada on the west side of the basin during four main glacial advances (Burnett, 1971). In contrast, glaciation in the Carson Range was minor to nonexistent because this part of the basin was, and still is, in the rain shadow of the main part of the Sierra Nevada. As a result, the landscape of the Carson Range is more subdued and rolling (Burnett, 1971). Stream erosion combined with the effects of the glacial advances has resulted in the accumulation of deposits of intermixed clay, silt, sand, gravel, and boulders at several locations around the lake. These heterogeneous deposits are interbedded with well sorted clay and sand that accumulated during periods when lake level was at higher stages than at present. These deposits constitute the principal alluvial aquifers in the basin (plate 1).

## Hydrogeologic Units

The Lake Tahoe Basin is composed of a variety of rock types ranging in age from Jurassic to Pleistocene and deposits of glacial, fluvial, and lacustrine origin ranging in age from Pliocene to Holocene (Saucedo, 2005). For purposes of this inventory, geologic units and deposits shown on the Geologic Map of the Lake Tahoe Basin (Saucedo, 2005) are grouped together as ten hydrogeologic units (plate 1). The Geologic Map of the Lake Tahoe Basin (Saucedo, 2005) denotes the most recent and representative geologic mapping and establishes a seamless geologic database providing an important component for performing GIS analysis throughout the basin. The map displays over 120 map units throughout the Lake Tahoe Basin. The grouping of many geologic units into a few hydrogeologic units is based mainly on lithologic and probable hydrologic similarities among the geologic units. Some of the units, such as glacial and alluvial deposits, constitute the principal aquifers of the basin, whereas bedrock units usually impede the movement of ground water. However, any of the bedrock units can yield at least small quantities of water to wells, especially where fractured or deeply weathered.

The ten hydrogeologic units are from oldest to youngest; (1) metamorphic rocks of Jurassic and Triassic age; (2) granitic rocks of Jurassic and Cretaceous age; (3) volcanic tuffs of Oligocene age; (4) volcanic mudflows of Pliocene and Miocene age; (5) shallow volcanic intrusive rocks of Pleistocene to Miocene age; (6) lava flows (lahars) of Pleistocene to Miocene age; (7) older alluvium of Pliocene and Miocene age; (8) glacial outwash deposits of Pleistocene age; (9) glacial till (moraines) of Pleistocene age; and (10) younger alluvium of Holocene and Pleistocene age. The lithologic and hydrologic properties, extent, and thickness where known of each of the hydrogeologic units are discussed below. Lithologic descriptions are from Saucedo (2005).

## Metamorphic Rocks

Metamorphic rocks consist of marine sedimentary and volcanic rocks of Jurassic and Triassic age that were intruded and metamorphosed by the intrusions that formed granitic rocks of the Sierra Nevada. Metamorphic rocks form a small part of the bedrock basement of the Lake Tahoe Basin west of Fallen Leaf Lake and east and southeast of Glenbrook. On the east side of the Carson Range in Eagle Valley, Maurer and Berger (1997) found that basin-fill sediments are underlain by a zone of weathered or fractured metamorphic rocks 200-250 ft thick. Hydraulic conductivity, determined from slug tests of six wells that penetrate the metamorphic rocks, is 0.02-0.4 feet per day (ft/d) in unweathered or unfractured rock, 2-7 ft/d in partly weathered or fractured rock, and 20-22 ft/d in highly weathered or fractured rock (Maurer and Berger, 1997).

## Granitic Rocks

Granitic rocks of Cretaceous and Jurassic age consist of a range of compositions including granodiorite, diorite, quartz monzonite, granite, adamellite, alaskite, gabbro, and aplite dikes. Granitic rocks form most of the bedrock basement of the Lake Tahoe Basin. The permeability of these rocks is low when they are not deeply weathered or fractured, especially on south, west, and north parts of the basin where glaciation has removed weathered rock (Thodal, 1997). Weathered granitic rocks are common in the Carson Range on the east side of the basin because glaciers were not active in this area. According to Nevada Division of Water Resources well-log records, more than 300 wells have been drilled on the Nevada side of the basin and many of these were drilled into granitic rocks. About 20 of the logs show data for a pump test (pumping rate, drawdown, and test duration). These data were used to compute specific capacity of the well and to make estimates of aquifer transmissivity. The logs indicate that the wells are completed either in decomposed granite or in fractured granite. Specific capacity ranges from 0.1 to 3 gallons per minute per foot (gpm/ft) of drawdown and the average value is 0.8 gpm/ft. Transmissivity, estimated from the value of specific capacity, ranges from 20 to 700 feet squared per day ($ft^2/d$). These values of hydraulic conductivity are consistent with values determined as part of a detailed study on the east side of the Carson Range at the mouth of Clear Creek. There Maurer and Berger (1997) found that basin-fill sediments are underlain by a zone of weathered or fractured granite as thick as 150 ft. Hydraulic conductivity, determined from slug tests of three wells that penetrate the granitic rocks, is 0.4 ft/d in unweathered, unfractured rock, 3 ft/d in partly weathered or fractured rock, and 20 ft/d in highly weathered or fractured rock (Maurer and Berger, 1997).

### Tuffs

Rhyolitic tuffs of Oligocene age are both welded and non-welded. The welded tuffs usually are more brittle than non-welded tuffs may have a greater tendency to develop fractures and store and transmit ground water.

### Lahars

Mudflows of Pliocene and Miocene age consisting of tuff breccias and blocky fragments of most of the different types of lava flows in a muddy matrix. These rocks probably do not store or transmit much ground water because the matrix is fine-grained and cemented.

### Intrusive Rocks

Intrusive bodies of Pleistocene, Pliocene, and Miocene age consist of irregular-shaped intrusive masses and shallow dikes composed of basalt, andesite, latite, and rhyolite. These frequently are the sources for other volcanic rocks in the basin. These rocks probably do not readily store or transmit ground water.

## Lava Flows

Lava flows of Pleistocene, Pliocene, and Miocene age include basalt, andesite, latite, and dacite, and are mostly found in northern and northwestern parts of the basin. These rocks have the potential to store and transmit ground water in rubble zones between flows and where fractured or jointed.

## Older Alluvium

Older alluvium of Pliocene and Miocene age consists of fluvial and lacustrine conglomerate, sandstone, and shale. These deposits also include rockslide-avalanche deposits consisting of large volcanic blocks intermixed with mudstone and ash.

## Glacial Outwash Deposits

Glacial outwash deposits of Pleistocene age consist of unconsolidated, poorly sorted boulder and cobble gravel, sand, and silt deposited by streams originating from glaciers. See Aquifers section for hydraulic properties.

## Glacial Till

Glacial till of Pleistocene age ranges from clay, silt, and sand to large weathered granitic boulders and is mostly preserved as moraines. See Aquifers section for hydraulic properties.

## Younger Alluvium

Younger alluvium of Holocene and Pleistocene age consists of moderately sorted sand and gravel of beach and lacustrine terrace deposits; clay, silt, sand, and gravel of flood plains; clay, silt, and sand of lake deposits; sandy-gravelly debris and coarse angular blocks of landslides and talus deposits; sand, gravel, and boulders of alluvial fans. See Aquifers section for hydraulic properties.

## Aquifer Extent and Characteristics

The most extensive and productive aquifers in the Lake Tahoe Basin are composed of younger alluvium, glacial till and outwash deposits, and at depth older alluvium. A US Army Corps of Engineers (USACE) study (2003) delineated five aquifer areas around the lake—South Lake Tahoe/Stateline, Tahoe City/West Shore, Tahoe Vista/Kings Beach, Incline Village, and East Shore. This naming convention is retained for the summaries of aquifer conditions and properties listed below. Aquifer area boundaries (plate 1) are generally based on the contact at land surface between basin fill and bedrock in upland areas. The hydrogeologic framework of each of these aquifers, based on previous studies, is summarized in the US Army Corps of Engineers report (USACE, 2003).

### South Lake Tahoe/Stateline Aquifer

This aquifer area extends from Emerald Bay on the southwest side of the lake to north of Stateline, Nevada on the southeast side (USACE, 2003). The thickness of deposits, including the unsaturated zone, ranges from 200 ft. or less in areas near the granitic bedrock contact to as much as 800 ft in an arcuate south-trending basin west of Tahoe Mountain (Woodling, 1987). . Between Fallen Leaf Lake and Tahoe Mountain, the deposits are up to 1,200 ft thick (Woodling, 1987); however, this thickness includes a morainal ridge of glacial till that rises about 500 ft above the surrounding area. At land surface, aquifer materials consist of glacial outwash and till and younger alluvium. At depth the aquifer materials consist of three sand and gravel beds separated by laterally extensive clay beds between Tahoe Mountain and the Upper Truckee River (USACE, 2003). The gravel beds are 10-60 ft thick and the intervening clay beds less than 10 to 40 ft thick. Between the Upper Truckee River and Trout Creek, aquifer materials consist mostly of sand and gravel up to 100 ft thick separated by discontinuous clay beds up to 20 ft thick (USACE, 2003). Between Trout and Bijou Creeks, aquifer materials consist of discontinuous sand and gravel beds separated by clay beds well over 100 ft thick (USACE, 2003). In the area beneath and about 500 ft east of Bijou Creek sands and gravels are up to 150 ft thick and clay beds are thin and discontinuous (USACE, 2003). From the east part of South Lake Tahoe to Stateline, sand and gravels extend from land surface to depths of 40-50 ft, and they are underlain by a sequence of clay of similar thickness, which in turn is underlain by more sand and gravel 50 ft or more thick (USACE, 2003). Because of the interbedded nature of coarse- and fine-grained deposits, aquifers in the South Lake Tahoe-Stateline area probably include a shallow water-table aquifer and one or more deeper confined aquifers.

## Tahoe City/West Shore Aquifer(s)

This aquifer area extends from Dollar Point on the north to Rubicon Bay on the south, a shoreline distance of about 18 mi (USACE, 2003). In the area around the lake outlet at Tahoe City, aquifer materials consist of lacustrine clay and silt with interbedded sand locally overlying Pliocene volcanic flows, which in turn overlie older sands and gravels (Muehlberg and others, 2003). The estimated depth of the basin is about 590 ft (Muehlberg and others, 2003). A well drilled in section 32, T16N, R17E penetrated sandy clay and sand from 0-52 ft and volcanic rocks from 52-247 ft. A driller's pump test at this well yielded a specific capacity of 0.1 gpm/ft and a transmissivity of 20 $ft^2$/d. Resistivity soundings done in the northern part of section 32 indicate an unsaturated zone 12-34 ft thick, volcanic rocks 36-58 ft thick functioning as a confining layer, and a confined sand and gravel aquifer to depths of at least 160 ft (Markiewicz, 1992).

The west shore of the lake south of Tahoe City is drained by a series of glacially cut watersheds. From south to north, the main watersheds are Lonely Gulch, Meeks Creek, General Creek, McKinney Creek, Homewood Creek, Madden Creek, Blackwood Creek, and Ward Creek. The hydrogeologic setting of the Ward Creek watershed is discussed separately below because it is the only one of the eight watersheds that has been studied in any detail. In general, each of the watersheds is underlain by glacial outwash and fluvial deposits (mostly sands and gravels) along its axis. Glacial till (moraines) form ridges between watersheds from Lonely Gulch to Homewood Creek, and volcanic flows and mudflows capped by moraines form the ridges from Homewood Creek to the Truckee River. Between the lake outlet and Homewood Creek in sections 13, 24, 25, and 36, T15N, R16E and in section 18, T15N, R17E, drillers' logs for nine wells indicate basin-fill and volcanic rocks extend at least to depths ranging from 56 to 450 ft (App. 3). Materials penetrated by the wells include interbedded clay, sand, gravel and boulders and volcanic rocks. Specific capactities determined from drillers' pump tests range from 0.1 to 20 gpm/ft and transmissivities from 16 to 8,000 $ft^2/d$ (app. 3). From Homewood Creek to Rubicon Point in sections 1 and 12, T14N, R16E and in sections 7, 17, 18, 20, and 29, T. 14N, R17E, drillers' logs for 15 wells indicate basin-fill deposits extend at least to depths ranging from 74 to 805 ft (app. 3). None of the wells appears to have penetrated to granitic bedrock. The logs indicate the deposits consist mostly of sand, gravel, boulders, and interbedded clay. Volcanic rocks are absent. Pump tests at the wells indicate specific capacities range from 0.2 to 30 gpm/ft and transmissivity from 40 to 6,000 $ft^2/d$ (app. 3).

The aquifer in Ward Valley is the only one on the west side of the lake that has been studied in detail. It consists of sand and gravel with interbedded volcanic rocks. Estimates of the thickness of upper alluvium, including the unsaturated zone range from 60-70 ft at the west end of Ward Valley to 150 to more than 300 ft at the east end near the lakeshore (Loeb, 1987 and Niblack, 1988). These deposits are underlain by, and abut on the north and south sides of the valley, volcanic mudflows and ash-fall tuff (Niblack, 1988). Depths to granitic basement are not known. The transmissivity of the aquifer, measured from three pump tests, ranges from 2,500 to14,000 $ft^2/d$ (Loeb, 1987).

## Tahoe Vista Aquifer/ Kings Beach

This aquifer area extends from Dollar Point on the west to Stateline Point on the east (USACE, 2003). According to the USACE (2003) report, aquifer materials consist of lake sediments and glacial deposits ranging in grain size from silt to boulders. However, much of the area is underlain by volcanic rocks, and basin-fill deposits occur as a thin strip along the shoreline except where they extend 1-2 miles inland at Carnelian Creek and at Tahoe Vista and Kings Beach (plate 1). The younger alluvium probably overlies volcanic rocks at differing depths and the volcanic rocks in turn overlie older alluvium at greater depths much the same as described in the Tahoe City area by Muehlberg and others (2003). In sections 1, 11, 12, 14, and 15, T16N, R17E and in sections 6 and 19, T16N, R18E, drillers' logs for seven wells indicate basin-fill deposits and volcanic rocks extend to depths ranging from 65 to 890 ft (App. 3). Three of the wells (sections 1, 11, and 12, T16N, R17E) penetrate mostly volcanic rocks to depths of 860-890 ft, and specific capacity and transmissivity range from 0.6 to 10 gpm/ft and 200 to 3,000 $ft^2/d$, respectively (app. 3). The other four wells (sections 14 and 15, T16N, R17W and sections 6 and 19, T16N, R18W) penetrated mostly interbedded clay, sand, and gravel, and specific capacity and transmissivity at these wells ranges from 0.8 to 10 gpm/ft and 200 to 3,000 $ft^2/d$, respectively (app. 3). One well on the east side of the area in section 6, T16N, R 18W penetrated granitic bedrock at a depth of 124 ft (app. 3).

## Incline Village

The Incline Village aquifer is bounded by outcrops of granitic rocks that form Stateline Point on the west and the Carson Range on the east, and by the shoreline of Crystal Bay. Over much of the area aquifer materials consist mostly of sand with lesser amounts of boulders, clay, and silt to depths of 150 ft (USACE, 2003). The maximum thickness of the aquifer probably is at the shoreline where a seismic reflection sounding indicated a depth of about about 1,000 ft to bedrock (Markiewicz, 1992). The hydraulic conductivity of the aquifer is estimated to be 20-26 ft/d (USACE, 2003), although these values are not based on aquifer tests and should be considered rough estimates. On the east side of the area in section 23, T16N, R18E, three wells penetrate mostly sand with lesser amounts of clay to depths of 55 to 153 ft (app.2). Specific capacity determined from drillers' pump tests at these three wells range from 0.6 to 40 gpm/ft and transmissivity from 100 to 10,000 ft2/d (app. 2). A fourth well in section 23 penetrated granitic bedrock from land surface to 163 ft, and the specific capacity and transmissivity were estimated to be 0.5 gpm/ft and 100 $ft^2$/d, respectively (app. 2).

## East Shore

The USACE defines the East Shore aquifer as comprising 15 individual watersheds from the east side of the Incline Village area to the north side of the Stateline area (USACE, 2003). Each watershed is underlain by weathered granitic rocks and in the Glenbrook area by metamorphic rocks. Basin fill is dispersed along the shoreline, but is not continuous and does not function as a continuous aquifer. Areas where basin fill functions as an aquifer of limited extent are at Sand Harbor, Glenbrook, and Zephyr Cove.

### Sand Harbor

The basin-fill aquifer at Sand Harbor is bounded on the east by granitic bedrock. The aquifer consists of decomposed granite and sand along the shoreline. A well drilled for the Sand Harbor State

Park in section 1, T15N, R18W penetrated decomposed granite from land surface to 97 ft and unweathered granite from 97 to 110 ft (app. 2). The specific capacity determined from the driller's pump test was 1 gpm/ft and the transmissivity 200 $ft^2$/d.

### Glenbrook

The basin-fill aquifer at Glenbrook is the largest along the east shore covering an area of nearly one square mile. It is bounded on the north and south by granitic rocks and on the east by metamorphic and volcanic rocks. According to logs for three wells drilled in sections 3 and 10, T14N, R18E, the aquifer consists of boulders, gravel, and clay from land surface to depths of 7-125 ft and decomposed granite to depths of 57-68 ft (app. 2). The three wells penetrated granite, in places fractured, at depths from 57-125 ft (app. 2). Specific capacity determined from drillers' pump tests ranges from 0.2 to 1 gpm/ft and transmissivity from 30 to 200 $ft^2$/d.

### Zephyr Cove

The basin-fill aquifer at Zephyr Cove covers an area of less than one square mile and is bounded by granitic rocks. Four wells drilled in the area penetrated mostly sand, gravel, and some clay from land surface to depths ranging from 10 ft to 80 ft, decomposed granite to depths ranging from 74ft 201 ft, and, at one well, solid granite at 90 ft (app. 2). Specific capacity determined from drillers' pump test range from 0.1 to 0.9 gpm/ft and transmissivity from 20 to 200 $ft^2$/d (app. 2).

## Well Data

Federal, state, and local agencies were contacted regarding the hydrologic data sets for the Lake Tahoe Basin that were used in this report. Agencies that have (past and/or present) hydrologic programs were evaluated for data quality and hydrologic significance at their monitoring sites. Completeness and duration of record were assessed to determine which monitoring sites would be included in the GIS database.

In 1992, Thodal presented data from an inventory of well drillers' reports filed with the Nevada State Engineer for 59 wells drilled in the southeast part of the Lake Tahoe Basin. Included are data on well location and altitude, well-construction information, and water levels reported by the driller at the time of well completion. In 1995, Thodal reported depth to bedrock described in 51 drillers' logs on file with the NDWR ranging from land surface to 191 ft below land surface, with a median of 40 ft below land surface. As part of a 1997 study, Thodal identified more than 600 drillers' logs that were available for the Lake Tahoe Basin from the CDWR and the NDWR. About 80 percent of the well logs (about 480) were for wells constructed in the South Lake Tahoe California area. The advent of community water suppliers has resulted in discontinued use of many of these wells.

Presently the USGS NWIS list 188 wells in the Lake Tahoe Basin (fig. 2) with at least one water-level measurement (app. 1). Of these wells, 79 wells were measured in 1995 through 1996 and 49 wells were measured between 2000 through 2004. A field reconnaissance of existing wells was made by the USGS (Rowe and Allander, 2000) in 1996. Of the 94 wells that were inventoried, 79 were in the Upper Truckee River and Trout Creek Watersheds and water levels were measured at 62 wells in this area. Well locations and associated water-level altitudes were used along with seepage estimates to develop a water-level altitude map, to determine directions of ground-water flow, and to determine hydraulic gradients in the study area. In 2000, 30 monitoring wells were installed prior to construction of a detention basin in the Cold Creek watershed in South Lake Tahoe (Prudic and others, 2004). The locations of the wells were selected specifically to help determine direction of ground-water flow in the area of the detention basin and the exchange of ground water with Cold Creek. Ground-water levels generally were highest in late winter and spring and lowest in late summer and early fall. The observed trends in water levels are consistent with ground-water inflow from the upland areas to the east and south, seepage to and from Cold Creek, and recharge from infiltration of runoff and precipitation (rain and snowmelt) within the detention basin and in the meadow area surrounding the detention basin (Prudic and others, 2004). In 2003, Allander (2005) measured the depths of 18 wells for a ground-water reconnaissance study of the Bijou Creek watershed, South Lake Tahoe.

Several drillers' logs for water wells in the study area are used in this report to define the lithology of basin-fill deposits. Selected well and water-level data for the Lake Tahoe Basin from the NWIS are shown in Appendix 1. The first and most recent dates of water-level measurements are shown for 188 wells in figure 2. According to Nevada Division of Water Resources well-log records, more than 300 wells have been drilled on the Nevada side of the basin and many of these were drilled into granitic rocks. About 28 of the logs show data for an aquifer test (pumping rate, drawdown, and test duration). Aquifer test and other information from each log were compiled on a spreadsheet and used to compute specific capacity and to make estimates of transmissivity. The logs indicate that 10 wells are completed either in decomposed granite or in fractured granite. Specific capacity ranges 0.1 to 3 gallons per minute per foot of drawdown and the average value is 0.5. Transmissivity estimates for these wells range from 20 to 700 $ft^2/d$ (app. 2). The lithology data derived from well drilling logs, 24 wells from the NDWR database and 37 wells from the CDWR, along with supplementary well information, specific capacity and transmissivity, for example, are shown in appendixes 2 and 3, respectively.

## Summary

Geospatial data and other information were either developed or compiled for the Lake Tahoe Basin as part of a ground-water resources inventory project for the U.S. Forest Service (USFS). This ground-water inventory report and database will assist the USFS in better assessing the present and future impacts on ground-water resources within the Lake Tahoe Basin. The data bases provide a geospatial compilation of existing ground-water data for the Lake Tahoe Basin within a GIS to determine extent and characteristics of the aquifers in the basin, as the data allows. Geospatial data sources are divided into two data classes: point data and areal data. The data bases include surface geology, soils, stream channels, water bodies, roads, political boundaries, the Lake Tahoe Basin boundary, slope, aspect, drainage basin boundaries, and hydrologic monitoring sites. Data were compiled from thematic maps, digital data, records, and publications from Federal, State, and local agencies. Documentation and summary data are included on a computer disc for each data base.

A map showing the areal distribution of hydrogeologic units was compiled from existing digital geologic maps. The discussion of the hydrogeologic framework of the study area consists of descriptions of the distribution, both areally and at depth, of rocks and deposits that store and transmit ground water. Well driller's logs were used to evaluate the hydraulic properties of the different hydrogeologic units. Geologic units were reclassified into three general categories, representing hydrogeologic units of differing abilities to transmit ground water. Specifically these are, (1) known aquifers of primarily coarse-grained alluvial material (deposits that transmit ground water readily), (2) potential aquifers representing weathered granite and highly fractured volcanic rock and granitic bedrock (consolidated rocks with low to moderate potential of transmitting ground water), and (3) areas of fine-grained alluvial deposits and unweathered bedrock (likely not capable of transmitting significant amounts of ground water). The grouping of hydrogeologic units generally was based on lithology, and assumptions on how lithology affects the permeability and water-bearing properties of the units. Structural features (major faults) were included in the hydrogeologic map as they have the potential to affect the movement of ground water.

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